

**PROCESS TECHNOLOGY DEVELOPMENT
FOR NAGPUR MANDARIN (*Citrus reticulata*)
POWDER**

THESIS

**Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
in partial fulfilment of the requirements
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**DOCTOR OF PHILOSOPHY
IN
AGRICULTURAL ENGINEERING
(PROCESS AND FOOD ENGINEERING)**

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2020

DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation in the thesis entitled “**PROCESS TECHNOLOGY DEVELOPMENT FOR NAGPUR MANDARIN (*Citrus reticulata*) POWDER**” or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/ publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

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CERTIFICATE

This is to certify that thesis entitled “**PROCESS TECHNOLOGY DEVELOPMENT FOR NAGPUR MANDARIN (*Citrus reticulata*) POWDER**” submitted in partial fulfilment of the requirement for the degree of “**Doctor of Philosophy in Agricultural Engineering (Process and Food Engineering)**” of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Bhagyashree Nivrutti Patil** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.

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List of Abbreviations

%	:	Per cent
<	:	Less than
>	:	Greater than
≥	:	Less than or equal to
≤	:	Greater than or equal to
@	:	At the rate
°C	:	Degree Celsius
AFA	:	Artificial foaming agent
Anon	:	Anonymous
ANOVA	:	Analysis of Variance
AOAC	:	Association of Official Analytical Chemist
Avg	:	Average
a _w	:	Water acitivity
b value	:	Yellow/blue colour
BIS	:	Bureauof Indian Standard
CCD	:	Central Composite Design
CMC	:	Carboxyl Methyl Cellulose
C.V.	:	Coefficient of Variance
CAET	:	College of Agricultural Engineering and Technology
cm	:	Centimeter
db	:	Dry basis
D _{eff}	:	Effective diffusivity
df	:	Degree of Freedom
dia.	:	Diameter
Deptt.	:	Department
DM	:	Dry matter
e.g.	:	For example
Engg.	:	Engineering
<i>et al.</i>	:	And others
etc.	:	Etcetera
EMC	:	Equilibrium moisture content
Eqn	:	Equation

ERH	:	Equilibrium relative humidity
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
FMC	:	Final Moisture Content
FMCD	:	Factorial Multilevel Catecogic Design
g	:	Gram
GMS	:	Glycerol mono state
h	:	Hour
ha	:	Hectare
HP	:	Horse Power
HDPE	:	High Density Poly Ethelene
i.e.	:	That is
IMC	:	Initial moisture content
kg	:	Kilogram
kg/ h	:	Kilogram per hour
kW	:	Kilowatt
Lit/sec	:	Liter per second
m	:	Meter
m ²	:	Meter square
mc	:	Moisture content
mg	:	Milligram
min	:	Minute
mm	:	Millimeter
mi	:	Millileter
MP	:	Metalized Polyester
MR	:	Moisture ratio
MSS	:	Mean sum of square
m/s	:	Meter per Second
MT	:	Metric tone
NFA	:	Natural foaming agent
no.	:	Number
no.	:	Nanometer
NS	:	Not significant

PDKV	:	Panjabrao Deshmukh Krishi Vidyapeeth
PGI	:	Post Graduate Institute
PP	:	Poly Propylene
ppm	:	Parts per millions
R^2	:	Coefficient of Determination
RH	:	Relative Humidity
RSM	:	Response Surface Methodology
Std. Dev.	:	Standard deviation
S.S.	:	Sum of Squares
SEM	:	Standard Error of Mean
viz.	:	Namely
W	:	Watt
w.b.	:	Wet basis
WVTR	:	Water vapour transmission rate

THESIS ABSTRACT

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ABSTRACT

The commercial processing of Nagpur mandarin (*Citrus reticulata*) is negligible, due to the presence of limonin and nomilin in Nagpur mandarin fruit, which causes off-flavor and bitterness in juice. There is wide scope for utilization of fruit powder (Nagpur mandarin) in various food industries such as confectionary, bakery, ice cream, etc. The goal of

this work was to develop the process technology for preparation of Nagpur mandarin powder.

The foam was developed using artificial foaming agents i.e. soy protein isolate (3 to 9%), GMS (2 to 5%), CMC (1 to 3%) and sugar content (5 to 15%) with whipping time (3 to 9 min) and by using natural foaming agent i.e. soy protein isolates (3 to 9%), guar gum (0.3 to 0.9%) and sugar content (5 to 15%) whipped (3 to 9 min) for foam formation. The optimization of concentration of foaming agents was done by CCD in response surface methodology. After optimization the samples were dried in microwave drying at various microwave power (180 to 900 W) with different drying bed thickness (2 to 6 mm) up to bone dry weight. The optimization of microwave power, foaming agent and drying bed thickness was done using optimal custom design.

The optimum operating conditions for foam formation using artificial foaming agent i.e. soy protein isolate 2.10%, sugar content 5.10% GMS concentration 2.75%, CMC 1.75% and whipping time 8 min and by using natural foaming agents i.e. guar gum 0.45%, soya protein isolate 3.30%, sugar content 10% and whipping time 6 min were optimized. The effective moisture diffusivity of foamed juice was found varied from 0.041×10^{-9} to $14.605 \times 10^{-9} \text{m}^2/\text{s}$ at varying microwave power and drying bed thickness. The activation energy was ranged from 17.48 to 19.68 W/g.

The optimum drying condition of Nagpur mandarin foamed juice was found at 540 W microwave power and 3 mm drying bed thickness with soy protein isolate 2.10%, sugar content 5.10% GMS concentration 2.75%, CMC 1.75% and whipping time 8 min (artificial foaming agent).

The total sugar, reducing sugar and non reducing sugar were found 46.16, 36.4. 9.76%, respectively. The protein was increased in developed Nagpur mandarin powder i.e. 14.88% as compared to juice i.e. 8.28%. The values of thiamine, niacin, vitamin B₆ and vitamin C were recorded as 2.90, 5.13, 0.06 and 36.5 mg/100g, respectively in developed powder. The calcium, iron, magnesium, manganese, phosphorus,

potassium and zink were found 178.72 mg/100 g dm, 8.58 mg/100 g dm, 61.48 mg/100 g dm, 5.38ppm, 16.31 mg/100 g dm, 327.54 mg/100 g dm, and 0.565ppm, respectively in Nagpur mandarin powder.

Cookies prepared with developed Nagpur mandarin powder (S₂) having 0.718 (good catogary) in sensory value. The overall acceptability (0.983) has highest quality attributes value followed by texture (0.971), flavour (0.864) and colour (0.829). The foamed Nagpur mandarin powder was stored in metallized polyester (50 microns) package at moderate RH (65%) and ambient temperature of 30 °C for considerably long shelf life (120 days).

From the study, it is concluded that the Nagpur mandarin powder developed by foam mat drying technology using soy protein isolate 2.10%, sugar content 5.50%, GMS concentration 2.75%, CMC 1.75% and 8 min whipping time, dried at 540 W microwave power with 3 mm drying bed thickness gives good quality product in respect with nutritional and sensory parameters with having good shelf life.

CHAPTER I

INTRODUCTION

1.1 Background Information

Mandarin orange (*Citrus reticulata*) is easily peelable and commonly grown citrus fruit in India. Mandarin is a name of cluster for a group of oranges with thin and slack peel. Mandarins include a different group of citrus fruits that are categorized by bright coloured peel and pulp, marvellous flavour, easy-to-peel coating and segments that separate easily. Mandarin is very important fruit crop, second to banana.

The most important commercial citrus species in India are the mandarin (*Citrus reticulata*), sweet orange (*Citrus sinensis*) and acid lime (*Citrus aurantifolia*) sharing 41, 25 and 23%, respectively of all citrus fruits produced in the country. China stands first in citrus production (29.56 million tons) followed by Brazil (18.96 million tons) and India stands third in citrus production (12.74 million tonnes) with an area of 10.55 million hectares (14.9% of total fruit area) with a productivity of 10.4 MT/ha. The total production of oranges in India is 3431.4 thousand MT (3.9% of total fruit production) from an area of 330.0 thousand hectares (4.6% of total fruit area) with a productivity of 10.4 MT/ha.

Citrus is grown in 26 states but only nine states contribute more than 89% of the total production. Maharashtra is the main mandarin producing state in the country having the highest area 0.135 million ha (40.9%), with an estimated production of 7.42 million tonnes (21.61%) and a productivity of 5.5 MT/ha. *Nagpur Santra* (Nagpur mandarin) is a finest variety and very popular in India as well as in world for its good quality fruits. Madhya Pradesh is leading mandarin producing state in the country having the area 0.052 million ha (15.91%) with an estimated production of 8.94 million tonnes (26.06%) and productivity of 17.0 MT/ha (NHB, 2014). In the states like Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu and Tripura, the harvesting of mandarin is undertaken twice a year.

It is generally consumed as raw form and fruit salads as well as juice. The fruit contains three layers. (Jhadeet *al.*, 2018)

1. The external yellow/orange peel is full of oil glands which gives essential oils for producing the distinguishing orange odor.
2. The mesocarp is whitish thread.
3. The endocarp which consisting of 8 to 10 segments filled with juicy sacs (vesicles).

Mandarin fruits are rich source of ascorbic acid and calcium (Morton, 1987). One orange actually has all the vitamin C that one needs for the day. The moisture content in the fruit is nearly 80 to 90% of edible portion. The chemical composition of the Mandarin is as under.

Table.1.1 Nutritional Composition of mandarin (Per 100 g of edible portion)

Composition	Values
Moisture	82.6-90.2 g
Protein	0.61-0.215 g
Fat	0.05-0.32 g
Fibre	0.3-0.7 g
Ash	0.29-0.54 g
Calcium	25.0-46.8 mg
Phosphorus	11.7-23.4 mg
Iron	0.17-0.62 mg
Carotene	0.013-0.175 mg
Thiamine	0.048-0.128 mg
Riboflavin	0.014-0.041 mg
Niacin	0.199-0.38 mg
Ascorbic Acid	13.3-54.4 mg

Source: Morton, J. 1987

Citrus is most commonly used as a good source of vitamin C. However, fruits also contain an impressive list of other essential nutrients, including glycaemic and non-glycaemic carbohydrate (sugars and fibre), potassium, calcium, thiamine, niacin, vitamin B6, phosphorus, magnesium, copper, riboflavin, pantothenic acid and a variety of phyto chemicals. Citrus contains no fat or sodium. The average energy value of fresh citrus is also low, which is important for consumers concerned about putting on excess body weight. A medium orange contains 60 to 80 kcal, a grapefruit 90 kcal and a tablespoon (15 ml) of lemon juice only 4 kcal (Whitney and Rolfes, 1999).

Major citrus producing areas in India are Punjab, Maharashtra, Madhya Pradesh and Andhra Pradesh. At national level the total losses in farm operations like harvesting, sorting and transportation was 7.55% while 2.14% during storage. Overall the total losses of citrus at national level increased significantly from 6.38% to 9.69% (MFPI, 2015).

Drying is the oldest method of preserving food. Drying has been practiced for centuries as a method of preservation of food materials. Dehydrated foods are unique in that they have specific quality attributes which are crucial for the acceptability factor which includes retention of nutritional content, flavour and aroma substances, colour, bulk density and stability during storage. Drying has many advantages. By removing most of the moisture from a food, microorganisms can't grow in it. Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transport weight. But drying of sugar rich foods such as fruit pulp and juices to powder is difficult, mainly due to low molecular weight sugars, such as fructose, glucose, sucrose and acids such as citric acid present in ripe fruits (Jaya and Das, 2003). These low molecular weight materials have low glass transition temperature, T_g (Roos and Karel, 1991; Roos, 1995) and their molecular mobility is high at temperature just above the glass transition temperature. They are very hygroscopic in their amorphous state and loose free flowing nature at high moisture content. The temperature at which amorphous substances exhibit stickiness is about 20 to 50 °C higher than the glass transition temperature

(Roos, 1995). While drying at high temperature, they tend to stick to the walls of the dryer and finally give a paste like product instead of powder (Bhandari *et al.*, 1993).

The foam mat drying is one of the promising new innovations in the field of aqueous foodstuffs. Foam mat drying is a process through which a fluid or semi-liquid is choked and then dehydrated by thermal means into a stable foam. In this drying method, surface area of the product which is to be dried is increased by incorporating air/gases (foaming) and thus drying time is markedly reduced. The developed foam structure offers advantages in drying and removal of dried material; also it improves the texture and rehydration properties. But while maintaining thickness of foamed layer for drying, escaping of air or rupture of bubble is a great problem. Actually foams provide unique texture and the nature of the foam and its physical properties are important for foammat drying (Foegeding *et al.*, 2006). A variety of heat sensitive food products, including fruit juices, have been recorded with foam-mat drying (Hertzendorf and Moshy, 1970). Drying of foam mat that results in an improvement in drying levels and a significant decrease in drying time; increases product texture, nutritional and functional characteristics. The foam mat dried products are very robust against microbial, chemical and biochemical deteriorative reactions. The dryer throughput was higher by 32% when drying foamed apple juice with pulp and by 22% when drying foamed mango pulp as calculated in this study from the experimental data generated by Rajkumar *et al.* (2005). The moisture-staining components of the seed, soluble solids, pulp proportion, amount and concentration of foaming agent, size and concentration of the foam-stabilizer (Hart *et al.*, 1963) influence the development of foam, stiffness and consistency in mold.

When foam mats are drained, the foam layer dries more easily under the same exterior conditions than the same volume of unfoamed air, because vapor is more readily induced by a dry surface of foam than by a thick layer of the same substance. The capillary action along dry interstices and evaporation into bubble spaces and gasses through thin, dry outer walls is the reason for this. The foam structure decreases drying time to

about 1/3 of what it would be for liquids under the same conditions (Sankat and Castaigne, 2004). This procedure provides a broad scope for use in the fruit juice processing industry, as it allows for heat-sensitive foods to be dehydrated or difficult to dry, sticky and viscous under relatively mild conditions, without undue changes in quality. Foam was easily and quickly dried. The foam mat drying makes powder from strawberry, mango, pineapple, citrus fruits, banana and guava juice / pulp etc. Increased use and industrial value of this technology is primarily used in the drying of liquids that include high-quality goods such as milk, meat, tea, soluble coffee, etc. (Kadam *et al.*, 2010a & b).

This process offers numerous advantages which include accelerated drying at lower drying temperature, reducing microbial activity, protection against degradation reactions, low cost, low energy usage and short drying time (Kudra and Ratti, 2006). This method not only preserves food materials but also adds value to the food materials. Higher surface area to volume ratio and foam porosity increases the mass transfer in this process, therefore utilize less time for drying and improves product quality (Dehghannya *et al.*, 2018).

Processing or stabilization of foods is a mechanism by which perishable foods like fruit and vegetables are stabilized to be stored for longer period of time and to reduce their postharvest losses (Kiaya, 2014). Moreover, this helps to maintain nutrient content in fruits. Drying is removal of moisture from fruits which hinders the microbial growth, enhance stability and reduce weight and volume of resultant product that reduces the cost packaging, handling, and transportation (Hardy and Jideani, 2017). Foam mat drying occurs at low temperature, therefore, preserve fruit nutrients. This process offers the wide range of applications in fruit industry because it allows dehydration of fruits, Difficult to dry under mild conditions (viscous and sticky) such as at lower temperature without having any impact on the product quality (Khamjae and Rojanakorn, 2018). Specific fruits such as mango have provided foam-mat drying over the years. (Rajkumar *et al.*, 2007a), banana (Thuwapanichayanan, *et al.*, 2008) (Sankat and Castaigne, 2004), guava (Qadri and Srivastava, 2015), apple

(Valenzuela and Aguilera, 2013), pineapple (Shaari *et al.*, 2017), muskmelon (Sangamithra *et al.*, 2015), cantaloupe (Salahi *et al.*, 2014), and bael fruit pulp (Bag *et al.*, 2011).

Drying using microwave is one of the most rapid way to dry food materials. During this process, electromagnetic waves pass through food material causing oscillation of food molecule henceforth resulting in dielectric heating (Puligundla, 2013). This interaction between food materials and electromagnetic energy eventually results in the production of heat within the food material, increasing the temperature of fluid present within the food material. Microwave heating is considered as the efficient source for the drying process because it provides volumetric heating and reduces processing time (Zhang *et al.*, 2007).

Drying of foams was conducted at comparatively low temperatures, so it is easily used for preserving the nutrient content of fruits. Mandarin may be converted by mould drying into added benefit goods such as sand. The powder is used for preparation of nectar, ice cream flavor and ready to eat fruited cereals, instant soup cubes etc.

1.2 Importance and Need of Study

Nagpur mandarin is seasonal fruit crop. Therefore, bulk of the produce is used for table purpose and is handled at ambient conditions causing considerable post harvest losses. The post harvest handling losses of citrus fruits are 5-10% in most developed countries and 25-30% in developing countries. Due to limonin and nomilin are two bitter compounds present in citrus and are thought to cause off-flavor in Huanglongbing (HLB)-infected fruit/juice therefore commercial processing is negligible (bitterness will be more in juice). Nowadays powder or lather of the fruit are being produced but to a limited extent. Processed food items viz. jam, jelly, squashes and fruit drinks are produced from Nagpur mandarin after blending. It is essential to produce value added products based on Nagpur mandarin, so that farmers can get an assured price for their produce regularly. Creation of essential infrastructure for preservation, cold storage, refrigerated transportation, rapid transit, grading, processing,

packaging and quality control are important aspects which need attention to give a high quality commercial production.

It is always necessary to dehydrate more quickly and produce more quality. The freeze drying method is widely recognised and provides higher quality goods, but this is a very costly procedure. Bleeding has now been a very costly procedure, but because of high metallic containers expense, bleaching of canned fruit is often big, hard and disintegration and decolouration problems are present (Shetty and Ranganna 1986). This procedure is also quite expensive. Also the other drying methods like freeze, drum and foam drying are costly which affects the cost of product. Hence, a method of microwave drying in combination with foam mat drying, in which foam will form by adding foaming agent which influenced the less drying time. The very limited research was carried out regarding foam mat drying of mandarin fruit juice. Therefore, the present study was conducted with following objectives.

1.3 Objective

1. To optimize proportion of artificial foaming agents and its concentration on foaming properties of Nagpur mandarin juice.
2. To optimize proportion of natural foaming agents and its concentration on foaming properties of Nagpur mandarin juice.
3. Optimization of microwave power, foaming agent and drying bed thickness during drying of Nagpur mandarin juice.
4. To study the drying characteristics of foamed juice during microwave drying.
5. To evaluate the quality parameters of developed Nagpur mandarin powder.
6. To study the storage period of developed Nagpur mandarin powder.

1.4 Hypothesis

Fruits are an important source of many nutrients including fiber, vitamin, potassium, and minerals. But, due to a high moisture content in fresh fruits, they are highly perishable. A large quantity of fruits gets wasted due to lack of adequate technique for harvesting and storage of

fruits. Fruits have a short shelf life, it is estimated that about 30-35% of the produce gets wasted in the processing and distribution chain. Foam-mat drying is a procedure whereby a fluid or semiliquid is poured onto solid foam and then thermally dehydrated. A number of heat sensitive food products including fruit juices have received reports of applying foam-mat drying (Hertzendorf and Moshy 1970). Foam Matter Drying, which improves the drying intensity and cuts drying period significantly; increased the product's visual, nutritional and practical characteristics. The goods dried with a foam mat are exceptionally resilient against biological, chemical and biochemical degrading reactions. The foam mat drying variables, i.e. moisture shape, pressures, consistency depend on fruit chemistry, soluble solids and pulp fraction.

1.5 Scope and Limitations

Foam drying experiment was conducted at comparatively low temperatures, so it is easily used for preserving the nutrient content of fruits. Developing a basic fruit drying method involves learning the expansion of the foam, foam density and stability of foamed juice. The foam mat drying plays important role in improving the quality of dehydrated products in terms of sensory and nutritionally rich products. The limitation for large scale production of dried powder by using a foam mat drying is the time required for whipping. Air drying produces physical and biochemical changes in food stuffs. These changes are frequently undesirable for the product quality (browning reaction and vitamin destruction). In order to improve the product quality, it is important to optimize the drying conditions. The quality of the product needs to be evaluated for the consumer acceptance. The functional characteristics of the final products such as water activity, rehydration and textural properties are essential to get a better picture about the product for maintaining its quality. In addition, sensory evaluation has to be undertaken to assess the product characteristics such as taste, flavour and appearance to the level of the consumers' acceptance.

CHAPTER II

REVIEW OF LITERATURE

This chapter examines the research work undertaken by several researchers on the physico-chemical properties of mandarin fruit and pulp, principles of foam mat drying, foaming agents used in foam mat drying and the application of foam mat drying in food processing. The details of various research works reported on thin layer drying in microwave drying method are incorporated in this chapter. In the subheadings, the details accessible related to this work have been referred and checked here.

2.1 Physico-chemical properties of Nagpur mandarin fruit.

2.2 Processing of Nagpur mandarin fruit.

2.3 Theory of foam mat drying.

2.4 Foaming agents used for foam mat drying.

2.5 Foam mat drying of different fruits.

2.6 Thin layer drying in microwave drying.

2.1 Physico-Chemical Properties of Nagpur Mandarin Fruit

Agamiae *et al.* (1982) recorded that for Nareng, Clementine, Satsuma, Cleopatra, Mallawi and Baladi mandarins, the average fruit weight, volume and diameter vary from 95 to 140 g, 100 to 154 cm³ and 4 to 6.5 cm, respectively.

Sharawy (1992) reported the amount of segments per fruit identified in Baladi orange and Baladi mandarin was 10 to 11 and for Ruby Red grapefruit 12 to 13.

Qureshi (1993) carried out a study on twelve Sweet orange (*Citrus sinensis* L) varieties. The weight of the average fruit was 206.67 g. Casa Grande fruits were heavier in weight (226.67 g) while Ruby Red (155.00 g) produced their smallest and least size fruit, Ruby Red and Blood Red claimed to be sweet due to their red flesh.

Kinawy (1995) observed that the average peeling thickness, number of seeds per fruit, mass of 100 seed and percentage juice were 3.2 mm, 11, 12.5 g, and 41.5%; for Baladi mandarin and Ponkan mandarin, respectively.

Mousa (1998) observed that the mean values for Navel, Baladi, Acidless and Valencia orange were in between 69 and 84 mm in diameter; height from approximately 57 to 87 mm; mass size variance between approx. 160 and 208 g; volume ranged from 188 to 241 mm³.

Shirgureet *al.* (2001) studied the quality of Nagpur mandarin during growth. The fruit yield (26.1 kg/tree), fruit weight (135.1 g), total soluble solids in fruits and juice (47.32%) were higher.

Yehia (2001) noticed that the peel width, amount of segments and mass density was found 3.21 through 3.5 mm, 10 to 12 and 440 through 450 kg/m³, respectively. For un-galvanized, galvanized, aluminum and stainless steel, respectively, for baladi white, the maximum traction angle was 12.68, 12.9, 12.73 and 12.84°, respectively.

Awadyet *al.* (2004) studied the physical quality of the oblong shaped Minneola fruit: diameter (62 to 89 mm), height (68 to 104 mm), mass (201 to 345 g), volume (120 to 342 cm³), projected area (54 to 108 cm²), thickness of peel (3 to 5 mm), mass of peel (52 to 73 g), seed/fruit number (9 to 12), volume/fruit juice (8 to 68 cm³), volume/fruit juice mass (0.41 to 0.5 cm³) and seed/fruit volume (2 to 8 cm²). The mechanical properties of Minneola's were determined as the deformation rank increased by loading between 1 to 5 kg from 2.75-3.09 to 8.52-10.02 mm. By rising the period of loading from 15 to 60 s, the deformation range has risen from 2.75 to 8.52 to 3.09 to 10.02.

Khanaliet *al.* (2007) studied tangerin (*citrus reticulates*) fruit mass and volume modelling with other physical characteristics. The results show that weight and volume modelling based on the intermediate diameter in every area projected and the volume measured are the best models. Mass and volume modelling have been identified as the best model based on the

results. For volume modelling based on the projected area, the highest measuring coefficient was achieved in all models under $R^2 = 0.97$.

Khan *et al.* (2008) studied the morphology of kinnow mandarin and feutrell's early. The fruits were spheroid in shape and for Feutrell's Early were obloid. Maximum fruit weight in Feutrell's Early (133.4 g) and Kinnow mandarin (164.3 g) was observed. The highest TSS / acid ratio (20.05) in Feutrell's early TSS/ acid ratio was recorded (25.34) in Kinnow. Feutrell's Early organoleptic values were highest at the end of January and lowest in November. In February and March and at least in early December, Kinnow demonstrated excellent organoleptic values.

Yehia *et al.* (2009) analysed the physical properties of mandarin fruits from Ponka: width (58.61 to 85.50 mm), height (49.45 to 78.8 mm), density (70 to 128 g), tension (60 to 120 cm³), region estimated (41.22 to 81.88 mm²), thickness of peel (2.18 to 3.73 mm), density of peel (24.2 to 36.1 g), segment/fruit (9 to 12), amount/fruit (12 to 4), amount of juice/fruit (23 to 34 cm³), and volume / fruit (0.24 to 0.45 l/kg). The following were examined: The maximum strength at the top and the bottom of the fruit in Ponkan Mandarin was 18.3 N/cm². The distortion size was expanded by growing the load from 2 to 5 kg, from 2.75 – 3.09 to 8.52 – 10.02 mm. By rising the period of loading from 15 to 60 s, the deformation range has risen from 2.75 to 8.52 to 3.09 to 10.02.

Garavand and Nassiri (2010) recorded morphological and physical characteristics of the lemon used in mass models. Based on the ellipsoid volume, $M = 0.903 V_{\text{ellip}} + 15.236$ with $R^2 = 0.886$ was produced for the better, whereas for the sweet citrus form (oblate and actual spheroid) the respective corresponding values were 0.86 and 0.299. Economic and agricultural terms used the intermediary diameter of sweet lemon mass as a non-linear relationship to assess successful rating schemes: $M = 0.002 b^2 + 6.0386b - 239.58$, $R^2 = 0.8566$ and $RSE = 11.898$.

Moharet *al.* (2011) studied the performance of sweet orange and maximum fruit weight (253.67 g) and size (51.25 cm²) was recorded in Salustiana. The maximum juice (56.72%) in Valencia late and minimum

acidity (0.28%) was recorded in musambi. Minimum number of seeds per fruit (1.33) was recorded in Salustiana and maximum number of fruits per plant (450.67) was recorded in Valencia late.

Patilet *et al.* (2011) studied the effect of plant growth regulators and fungicides on quality of Nagpur mandarin. The maximum weight, volume, TSS and number of seeds was found 152.13 g, 161.27 cc, 9.68% and 10.67 seeds/fruit, respectively in the month of November and minimum 109.80 g, 114.94 cc, 8.20% and 9.22 seeds/fruit, respectively in the month of September in dropped fruits. The minimum acidity (0.92%) and ascorbic acid (51.10 mg/100 ml juice) was observed in retained fruits in November. The maximum acidity (1.48%) and ascorbic acid (80.52 mg/100 ml juice) were found in dropped fruits in September.

Verma *et al.* (2012) observed variations in Nagpur mandarin (*Citrus reticulata* Blanco) fruit at different locations for physico-chemical characters. They measured fruit weight, peel thickness, juice content, rag content, total soluble solids, total titrable acidity, TSS: Acid ratio, ascorbic acid content, sugars, reducing sugars and non-reducing sugars. The values of fruit weight (115.25 g), fruit diameter horizontal (5.38 cm) and vertical (5.78 cm), peel thickness (0.31 cm), Segment number per fruit number (9.47), complete number of fruit seeds (7.44) and cumulative seed per plant were recorded.

Abdollah (2013) reported that the highest dimensional features were found on pages, whereas Onsho cultivar showed the lowest value of sphericity (93%) and Clementine cultivar was the higher sphericity (97%). Page cultivar has a specific gravity of 0.97 and this cultivar has the biggest fruit. The calculated volume was 1% more than the expected spheroid shape. A linear relationship was made between the mass and volume of the mandarin mixed cultivar.

Bhatnagar *et al.* (2015) found that the fruit weight, number of fruits/plant, peel thickness and juice percent was ranged from 86.33 to 137.88 g, 616 to 1400, 0.20 to 0.38 cm and 30.27 to 58.70%, respectively. The total titrable acidity, pH, total soluble solids and ascorbic acid varied

from 0.72 to 1.53%, 3.63 to 4.09, 7.66 to 11.83 °B and 34.00 to 41.83 mg/100ml, whereas total sugar and reducing sugar was ranged between 5.75 to 8.87 and 3.73 to 5.76%, respectively.

Mukhimet *et al.* (2015) carried out the study to find the optimal weight for fruits (109.28 to 112.95 g), sizes for sweet lemon fruits (Length $\geq$ 81.05 mm, Breadth $\geq$ 50.13 mm), specific gravity (0.98 to 1.01), juice content (37.68 to 41.23%), TSS ($\geq$ 6.3 °B), titrable acidity (4.18 to 4.35%), ascorbic acid ($\geq$ 32.41 mg/100 g), TSS: Acidity ($\geq$ 1.51%).

Shravan *et al.* (2018) reported the chemical characteristics of sweet orange fruit. Moisture content as 88.5% TSS 11 °B, pH 3.8, acidity 0.51%, total sugars 8.36%, reducing sugars 1.8%, non-reducing sugars 6.56% and ascorbic acid 46.5 mg/ml were observed.

2.2 Processing of Nagpur Mandarin

Byanna and Gowda (2010) developed sweet orange beverages with sugar and sugar substitutes (*Citrus sinensis* O). Specific recipes were made with sweet orange drinks such as, RTS drinks, nectar, squash, kokum, and pomegranate. At the beginning, 90 and 180 days of storage under atmospheric conditions, the goods have undergone chemical analysing and organoleptic assessment.

Pareeket *et al.* (2011) investigated the effect of the Nagpur mandarin (*Citrus Reticulata* B) juice during storage on the quality, of juice extraction methods and temperature-time treatment. The juice extracted and processed at 65 °C at 15 min was better in consistency such as TSS, acidity, ascorbic acid, sugars and non-enzymatic browning during 6 months storage. The minimum naringin and limonin was observed at the extractor and a processing temperature of 65 °C for 15 minutes.

Joshi *et al.* (2012) explored the physico-chemical and sensory evaluation of Himachal Pradesh's specific citrus wines. Fruit varied from aldehyde, colour, ethanol, pH and acidities for various physiological and chemical characteristics. All the wines were similar to TSS, pH and titrable acidity in different physico chemical characteristics. All the wines have

more than 12 for their sensory characteristics, which have proven appropriate.

Manjarreset *al.* (2013) studied the effect on the physical characteristics of impregnated orange peel of drying conditions. Fresh fruit peel about 30-40 g/100g and may be used in the development of value-added products. A drying temperature of 52.3 °C with air flow rates of 2.0 m/s was found optimal. Drying time, durability and humidity levels at 20 h, 78.4 N, and 7.6% were determined at this point.

Kelebek and Serkan (2014) conducted a review of the phenolic and anti-oxidant composition of Robinson, Fremont and Satsuma mandarin juices and wines.

Pareeket *al.* (2015) examined the effect on the degradation and reactivity of the chemical component of mandarin (*Citrus reticulata* Blanco) juice. The juice extracted by the screw-type juice extractor and preserved with potassium meta bisulphite of 1000 ppm, stored at 3 °C, has retained better quality characteristics and minimum biochemical changes observed for 6 months.

Bisht (2017) prepared the sweet orange peel candy using various combinations of treatments, i.e. dipping time and sugar solution concentration. Sweet orange peel was held for 120 days, recording physical-chemical and organoleptic modifications.

Kore *et al.* (2017) standardized the Kagzi lime candy recipe and drying method. The R3D1 (80% sugar solution and sun-dried) treatment combination was recorded in the highest amount of sugars. The storage periods R₂ (70 percent sugar solution) and D₁ (Sun drying) in citrus candy were observing optimum organoleptic properties, such as colour, taste and overall acceptability.

Oyebola *et al.* (2017) investigated selected physical and chemical properties of the primary sweet orange waste. The chemistry showed a high content of protein-rich sweet orange rinds and 12.79% crude fibre as ingredients in processed foods.

Patharkaret *et al.* (2017) studied the physico-chemical parameters of orange such as vitamin C, pH, TSS, acidity, temperature and colour. Fruit juice fermentation was completed with an inoculum amount of 10 percent (v/v) within 7 days at temperature of 27°, pH of 4.5 and total soluble solids of 24 °B. Fruit wine of 8.5% ethanol content was therefore prepared in regulated physico-chemical parameters.

Sajedaet *et al.* (2018) made the mango, pineapple and orange juices for mixed fruit juice. Chemical analysis showed that TSS, acidity and vitamin C were gradually decreased during the storage periods. Samples of 35% mango juice, 40% orange juice and 25%

2.3 Theory of Foam Mat Drying

Foam mat drying is a method of addition of foaming agent and stabilizer by whipping the air incorporated (Franco *et al.*, 2015). Foam mat is converted into foam by means of foaming. Once the aqueous solution has been moistened, air drained at a lower temperature is fed into the food to reduce the moisture content and to form a stable mushroom like a porous sheet which is milled in powder. The method of foam mat drying basically consists of three steps:

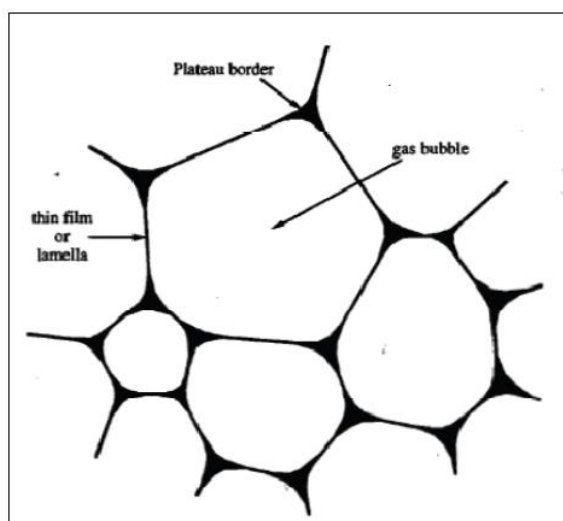
1. Stable structure of foam containing the drying product.
2. Shake the foam to form a slender porous plate or pad.
3. Dried mat compression to provide the ideal food product.

The one of the key steps in foam mat drying is the preparation of stable foam. The first step is to whisk the desired product in a traditional food beater with a whipping agent and an effective stabiliser (Mounir, 2017). Initial mass density of the product and density of foam is checked by means of proper balance between stabilisers, whipping agents and whipping times (Chandrasekar, *et al.*, 2015). Second step is normally carried out by metering the stabilized foam onto a continuous belt which runs through drying ovens maintained at predetermined temperatures. As per literature, maximum temperature for foam mat drying of fruits is 80 °C, with 60 °C being mostly preferred temperature for drying of fruits and vegetables so that quality of resultant product remains intact (Febriantoet

al., 2012). The third step involves removal of the moisture from foam mat and finally desired form of product was formed.

The drying method for foam mat is very quick and cost-effective. However, the lack of consistency during the heating period of the foam was a problem faced previously. If the foam remains stable, the cellular failure will cause serious drying impairment. Addition of foaming agent to a liquid dispersion of a product to be dried by the foam mat during process which makes possible to obtain new and improved results (Gunther *et al.*, 1960)

In food processing operations we encounter different kinds of foams, some of them are desirable (for example egg white foam in bakery products) and in some cases, it may not be desirable (for example foaming during fermentation process). Foams provide unique texture to many of our food products, for example bread, cake and ice creams. Understanding the nature of the foam and its physical properties are important to have good control over them (Foegeding *et al.*, 2006). The structure of foam presented in Fig 2.1.

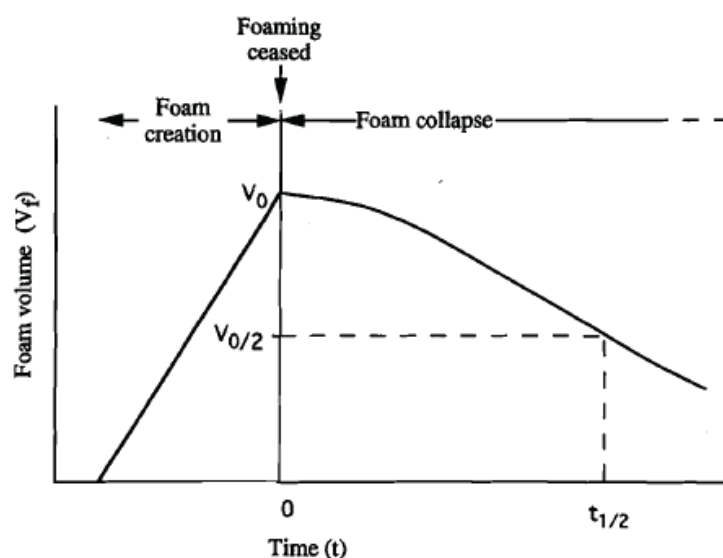


(Wilson *et al.*, 1989; Wilde and Clark, 1996)

Fig. 2. 1 Structure of foam

Foam is a two phase system with a dispersed phase (usually air) and a continuous phase. The phase dispersed is larger than the continuous phase (German and Phillips 1994; Banielet *al.*, 1997). Based on the ratio of phase dispersed to continuous phase, foams was classified

as polyhedral foam and diluted as bulbous foam. In polyhedral foams, the ratio is large; resulting in a large number of bubbles. As the number of bubbles rises, they press each other to form a honeycomb structure. Egg white foam and beer foam is good examples for polyhedral foams. In dilute foams, the ratio is small; therefore, the individual bubbles retain their spherical shape. Choco-mousse may be a good example for dilute bulb foams (Prins, 1988). The texture of foam is also influenced by the proteins and surfactants, as they help in the formation of stable foam (Carter *et al.*, 2001).



(Wilde & Clark 1996)

Fig. 2.2 Typical foam volume profile during and after formation

Proper understanding of mechanism involved in foam formation is important to make foam with required characteristics. Foams have gas bubbles surrounded by plateau border. Lemella is the thin wall of a bubble. The lamella's mechanical strength determines the moisture stability and its air-water interface properties. Using viscous fluids in the manufacture of foams they generate more stable foams because of the greater lamella elasticity. Surfactants (surfactant stabilised foam) or proteins (protein stabilized foams) can restore the stability of the foam. The mechanisms for maintaining or enhancing foam stability (surfactant and protein) for these two are distinct. The surfactants flow through the thin lamella and reinforce

it to give the foam greater stability. The mechanism is known as Marangoni effect (Wilde, 1996).

Formation of foam depends on many parameters such as the properties of the liquid being foamed, method of foaming and foaming conditions. For protein based foams, the adsorption of protein during foam formation must be rapid to have better foam ability. The transportation of protein occurs mainly by diffusion or convection and/or by combination of both these methods. The foam volume profile before and after foam formation presented in Fig 2.2.

The type of protein present in the sample plays a major role in determining the type of foam and its stability. For example in case of egg white presence of albumen gives excellent foaming characteristics (Wilde, 1996; Pugh 2001).

2.4 Foaming Agents used for Foam Mat Drying

Foaming agents are used to concentrates the juice by incorporating air which lead to drying rate decreases. Various proteins are used for the production of very fine foam, including egg albumin and soy protein. The efficiency of foaming agents and the end quality of powder was calculated by their foaming properties. Different factors such as concentration of foaming agents, solid concentrate, whipping times and room temperature during whipping can affect the foaming properties of different foaming agents (Javed *et al.*, 2018)

Food foams are made up of air, liquid and a surface-active agent (Basically protein in most cases) (Kinsella, 1981). A foaming agent is a surface-active agent which facilitates the formation of foam, when present in small quantities. Foaming agent lowers the surface tension between two liquid materials or between a solid and liquid material that results in foam generation. Good foaming agents should have the following properties: able to stabilize the foam properly and rapidly at low concentrations; able to function effectively over the wide range of pH values and ability to perform effectively in the presence the foam inhibitors such as fat, flavouring substances and alcohol (Zayas, 1997).

Foaming agents such as protein immediately adsorb at an interface and lead to the formation of viscoelastic films (Zayas, 1997). This results in a reduction of surface tension and formation of stabilizing film around the bubbles that promote the formation of stable foam (Dickinson, 1998). Therefore, the main function of the protein in foams is to reduce interfacial tension so that the viscous and elastic properties of liquid increases, those results in the formation of stable and strong foam (Yavuz *et al.*, 2014). The most commonly used foaming agents (protein) are egg albumin, whey protein, soy protein and gelatine.

2.4.1 Egg protein

Egg albumin is a natural protein found in eggs, having very good foaming properties (Sangamithra *et al.*, 2015). Therefore, this protein has been used as a foaming agent in various foam-mat drying studies (Raharitsifa *et al.*, 2006; Djaeniet *et al.*, 2013; Falade and Solademi, 2010). On whipping egg albumin rapidly denature at air/liquid interface and interact with the each other to form a stabilizing film (Lomakina and Mikova, 2006). Hence, whipping time required by egg albumin is comparatively less in comparison to other foaming agents. However, there are various disadvantages related with commercial use of egg albumin such as its limited pH range and ionic strength (Hardy and Jideani, 2017).

Thirupathiet *al.* (2008) studied foam-mat drying of whole egg liquids at temperatures of 60, 65 and 70 °C and at thicknesses of 1, 3 and 5 mm. For whole eggs, the portion of foam expansion was $243.5 \pm 12.5\%$. Statistical study of foam mat dried egg powder indicates a greater biochemical and foam content in thickness between 3 and 5 mm compared with samples drained at thickness between 65 and 70 °C, which was drying with a thickness of one mm at 60 °C.

Thuwapanichayanet *al.* (2008) studied the combination of foaming and drying as an alternative method to produce crisp banana chips. Banana puree with egg albumen was foamed to the densities of 0.3, 0.5 and 0.7 g/cm³. The initial foam density of 0.5 g/cm³ was recommended.

Kadam and Balasubramanian (2011) produced tomato powder using foam mat drying and drying temperature and foaming agent (egg albumin) for production. Tomato juice with a foaming agent (0, 5, 10, 15 and 20% w/w) of egg albumin (4 °Brix of total soluble solids). With a period of 5 minutes, it was best to add 10% egg albumin for stable formation of foam. The increase in the amount of the foam agents enhanced the drying process (up to 15% egg albumin) and subsequently followed a decreasing trend

Ibidapo and Erukainure (2012) studied the nectar of ripe papaya fruits (*Carica papaya L.*). The papaya puree frozen in a domestic freezer at -18 °C for 48 h. Papaya nectars (10 and 20 °Brix) were processed from frozen puree and the resultant nectars were made into stabilized product by foam mat drying methods. As a foam stabilizing agent, egg albumin was used at a concentration of 10-20%, whipping at 3 to 15 min, respectively. The findings showed that the concentration of egg albumin influenced the stability of the 20 °brix and 20% egg albumins, creating more stable foam at 3 min.

Kandasamyet al. (2012c) studied egg albumin incorporated 5, 10, 15 and 20% (w/w) in papaya pulp and whipped at room temperature for 5, 10, 15 and 20 min. At 15% egg albumin and whipping time of 15 min, maximum stable formation was 125.62%.

Wilson et al. (2012) tested the use of 0, 3, 5, 7 and 9% egg white as foaming agent in mango foam mat drying (Dussehari variety) at air drying temperatures of 65, 75, and 85 °C. It was decided that foam mat drying with 3% egg white was the best combination at 65 °C drying temperature.

Franco et al. (2015) studied effects of foam mat drying in powdered yacon juice, both physico-chemical and microstructural. The yacon juices foamed with egg albumin with two different concentrations (8°Brix and 24°Brix) as foaming agent.

2.4.2 Whey protein

Whey protein is obtained from the dairy industry as a by-product during cheese production (Tariq et al., 2013). This is one of the main

sources of protein in the food industry because of its favourable properties that include its use as an emulsifier and whitening agent, outstanding nutritional content and its ability to form the gel and stable foam (Broch *et al.*, 2014). Whey protein is also used as an ingredient in various food formulations such as infant formula, supplements, and nutritional bars. As per literature, whey protein also has antioxidant properties (Mann *et al.*, 2015; Dryakova *et al.*, 2010; Liu *et al.*, 2013; Salami *et al.*, 2010). Therefore, whey protein has an ability to slow down oxidation reactions in dried food materials. Moreover, whey protein has a higher capacity to bind flavoured compounds, making it highly favourable for working with vegetables having sensitive and volatile constituents (Zhang *et al.*, 2017). Because of higher solubility of whey protein in water and its surface hydrophobicity, whey protein has an ability to form a high-quality foam (Sangamithra *et al.*, 2015).

2.4.3 Soy protein

Bates (1964) studied the foam-mat drying of tropical fruits using two types of foam inducers, namely modified soybean protein (D-100) and glycerol mono stearate (GMS). It was found that, even for the most systems tested with or without use of foam-stabilizer, only less than 0.25% of D-100 was adequate for the development of density 300 to 400 kg per m of foam. Likewise, 0.5% of GMS could generate density foams of 330-360 kg/m³ in any device (papaya puree), but this purée could not be foamed with usual volume of soy protein on the other side.

Sankat and Castaigne (2004) developed ripe banana foams and the forced air drying characteristics of banana foam mats were studied. After 12 minutes of whipping the added 10 g/100 g soy proteins as a foam inducer, a fresh banana puree with a 0.93 g/ml density was foamed to a density of 0.50 g/ml. At the temperature between 45 and 90 °C, banana foam mats were drizzled into a coarse air dryer into a solid hard, porous and fragile, suitable for grinding in order to generate dehydrated banana powder. The drying time was directly associated with foam mat thickness. The levels of drying did not significantly affect increased air velocity from 0.62 to 1.03 m/s.

Soy protein is obtained by removing oil from soybean at a lower temperature. Soy protein isolate (SPI) is a highly purified form of protein, having a minimum 90% of protein content (Nishinari *et al.*, 2014). Soy Protein Isolate has many functional properties such as solubility, water, fat absorption, water holding capacity, viscosity, foaming or whipping, emulsification and gelling (Liu *et al.*, 2004). This is also used as a food ingredient in food processing industries because it's an excellent source of nutrition, therefore highly advantageous for human health (Morales *et al.*, 2015). Furthermore, this has been used as a foaming agent for foam-mat drying of various fruits (Sangamithra, *et al.*, 2015). According to the US Food and Drug Administration (FDA), soy protein has the ability to lower cholesterol levels (Alp *et al.*, 2016).

2.4.4 Glycerol mono stearate

Berry *et al.* (1965) studied the impact of whipping time on grape-fruit foam with the use of GMS as foaming agent. No substantial differences in bubble size occurred when the whipping period increased from 6.5 to 15 min. Best results will be achieved by adding a lesser quantity of surfactant and obtaining a bulk density of 260 kg/m³ portion for the shortest stirring. The uniformity and absence of fluid drainage in 60 minutes after preparation is a requirement.

Falade *et al.* (2003) studied the foam-mat drying of cowpea using glyceryl monostearate (GMS). GMS were incorporated into cowpea paste (22, 25 and 28% total solids) at 2.5, 5.0, 7.5, 10.0, 12.5 and 15% (w/w), and whipped for 3, 6, 9, 12, 15, 18 and 21 min, maintaining 15, 25 and 35 °C foaming temperatures. Minimum foam densities were obtained in cowpea foams with GMS after 9 min of whipping.

Falade and Okocha (2010) examined the foam-mat dried plantain and the cooking banana. The density of banana foams was generally lower in relation to plantain foam. Low drying and GMS were the result of lower drying temperatures and concentration. The quality characteristics of reconstituted pastes differed with commodities, drying conditions and G

MS concentration. They found that pH (4.41 to 4.80), titrable acidity (0.06 to 0.08) and water absorption capacity differed.

Kandasamy *et al.* (2012b) studied the the process of production of papaya powder using glycerol mono-stearate as foaming agent (1 to 4% w/w) with whipping time (5 to 15 min). During foam expansion, the concentration of the pulp and the 1% of the foaming agent were significantly influenced. At 3% mono stearate glycerol at 9°Brix pulp concentration and a 10 min whipping time the maximum stable foam formation was 90%.

Chakraborty *et al.* (2014) optimized potato foam mat drying conditions based on dried powder functionality. The maximum spread of foam during preparations was 25% with a 10 minute magnetic stirring interactive impact and 2% glycerol mono-stearate (GMS) concentration. At 60 °C for 135 minutes and 2% GMS, the optimum drying condition was obtained. A value of 1.89 ± 0.551 , 0.914 ± 0.025 , 0.013 ± 0.00175 , and $70.00 \pm 1.645\%$ of ultimate moisture content, reconstitution coefficient and gelatin starch was observed at optimum drying condition.

Das *et al.* (2015) determined moisture ratio at different time and also find the best mathematical model for foam mat drying of pumpkin pulp. Pumpkin pulp was foamed using 3% and 4% glycerol mono stearate (GMS) as foaming agent and then dried at drying temperature of 50 °C and 60 °C. Moisture diffusivity was varied from 2.026×10^{-8} to 6.079×10^{-8} m²/s.

Ismail *et al.* (2016) studied the foaming characteristics of sweet potato paste. The foams were produced using different level of stabilizers concentration at level of 5, 7.5, 10, 12.5 and 15%. Glyceryl monostearate stabilized foam was found to be stable after whipping of air into the mixture for 3, 6, 9, 12, 15, 18, 21 minutes at 10, 20 and 30°C, respectively.

2.4.5 Pea protein

Peas are the rich source of proteins, vitamins, minerals, starches and fibres. They are used in various food products such as soups, pasta, snacks, gluten-free confectionery, protein bars and bakery products

(Baracet *et al.*, 2010). Pea Protein Isolate (PPI) is the most commonly used food ingredient, having approximately 80% of protein content. Pea Protein Isolate is produced through aqueous extraction and isoelectric precipitation of pea flour (Owusu and McCurdy, 1991). PPI has many functional properties such as emulsification, foaming, gelling, water holding capacity and fat absorption (Soderberg, 2013).

2.4.6 Gelatine

Gelatine (protein) is derived from collagen; its source could be a mammalian tissue such as skin, bones, tendons and connective tissue (Calvarro *et al.*, 2016). Collagen present in pig and cattle tissue was most commonly used raw materials for large-scale production of gelatine (Febriantoet *et al.*, 2012). Gelatine can also be utilized as foaming agents, as this has the ability to generate stable foams and gels (Li *et al.*, 2016).

2.5 Foam Stabilizers

The foam should have stabilizers or foaming agents in their continuous phase to prolong the durability of the foams. Foam stabilizers increase the interfacial viscoelasticity of foam lamella that enhances the stability of the foam (Klitzing and Muller, 2002). Polysaccharides are the most commonly used stabilizers. Many polysaccharides are hydrophilic in nature; this prevents them from being adsorbed at the interface. Therefore, leads to a strengthening of the bubble wall that improves the foam stability (Zhanget *et al.*, 2017). The most commonly used food stabilizers are carboxyl methyl cellulose (CMC), xanthan gum, arabic gum and propylene glycol alginate (PGA).

2.5.1 Carboxyl methyl cellulose (CMC) or cellulose gum

The cellular derivative carboxyl methyl cellulose consists of glucopyranose monomers and hydroxyl groups of glucopyranose backbones linked to carboxymethyl groups. Carboxyl methyl (CMC) has many functional characteristics such as its use in food products as a thickening agent or viscosity modifier, stabilizer, suspending agent and emulsifier (Tabari, 2017). This is mostly incorporated in the food as a sodium salt. CMC is considered a suitable stabilizer for the generation of mechanically

and thermodynamically stable foam. Therefore, CMC is one of the widely used foam stabilizers in food processing industries (Sangamithra *et al.*, 2015).

Thaisong and Rojanakorn (2011) investigated the effect of concentration of carboxyl methyl cellulose (CMC) (0 to 1.0%) and whipping time (0 to 25 min) on mango foam. It was found that incorporation of 0.5% CMC and whipping time of 25 min produced the foam with the lowest density. The drying of mango foams was dried at 60, 65 and 75 °C during dropping rate experiments. The activation energy of mango foam drying was 22.22 kJ/kmol.

Kandasamy *et al.* (2012a) optimized the process parameters for production of papaya powder using foam mat drying. Papaya pulp was foamed by incorporating methyl cellulose (0.25, 0.5, 0.75 and 1%, w/w), glycerol-mono-stearate (1, 2, 3 and 4%, w/w) and egg white (5, 10, 15 and 20%, w/w) as foaming agents. The maximum stable foam formation was 72, 90 and 125% at 0.75% methyl cellulose, 3% glycerolmono stearate and 15% egg white respectively with 9 °Brix pulp and whipping time of 20 min.

Kaushal *et al.* (2013) studied the fruit leather preparation by altering the foam mat drying technique for marine buckthorn berries. Using the pulp after adding CMC 0 to 3% with 5 °C and drying the resulting dehydrator moisture (55 ± 2 °C) to moisture content of about 12 to 14%, the conversion of the marine buckthorn jus to foam is uniformly harmonized.

Auisakchaiyoung and Rojanakorn (2015) determined the effect of methyl cellulose (MC) concentration and whipping time on the properties of gac fruit aril foam. Gac aril mixed in a mass of 1.0 to 2.0% with methyl cellulose was whipped for a time of 0 to 25 min. The optimum state for foam forming after 25 minutes of whipping was 1.5% methylcellulose.

Khamjae and Rojanakorn (2018) studied foam mat drying of passion fruit aril. The 0.75 to 3.0% passion fruit aril with methylcellulose was whipped for 0 to 25 min. The optimum forming condition for foam was

2.25% methylcellulose after 25 minutes of whipping, because the expansion of the foam (187.25%) was higher and the stability was higher than ever (0.41 g/ml).

2.5.2 Xanthan gum

Xanthan gum is a polysaccharide used as a food additive. This is derived from simple sugars by the process of fermentation. Xanthan is polyelectrolyte, so highly soluble in water. Therefore, even the temperature of the water does not affect the solubility of xanthan gum, making it highly favourable for industrial processes (Becker *et al.*, 1998). It is also an effective stabilizer and gelling agent, so used in the food processing industry to increase the viscosity of the liquid.

Azizpouret *al.* (2013) studied shrimp drying with foam-mat: shrimp puree foams were prepared by adding xanthan gum concentrations (0.1, 0.2, 0.3% w/w), water: shrimp ratios (2:1, 3.5:1, 5:1 w/w) and whipped for five minutes. Incorporation of 0.2% w/w XG with 3.5:1 w/w water: shrimp ratio was selected due to the improved characteristics of the foam produced. Results have shown improved foam stability and density at an elevated amount of xanthan gum. The increase in shrimp water, however, caused stability and foam density to decrease.

Azizpouret *al.* (2014) studied the impact of drying temperature on foam mat drying of shrimp (*Penaeus Indicus*). The research included the concentration of xanthan gum (0.1 to 0.4% w/w), whipping time (2 to 6 min), and the shrimp water ratio (2:1 to 6:1 w/w) to minimize the density of foam (FD) and the amount of drainage (DV). The optimum conditions of foaming have been observed: Xanthan gum concentration 0.19% (w/w), wind, shrimp ratio 4.5:1 (w/w) and whipping time 5.89 min.

2.5.3 Propylene glycol alginate

Propylene glycol alginate (PGA) is an ester of alginic acid. This is high molecular weight 1, 4 Dmannuronic acid and L-guluronic acid. PGA is used in food materials as an emulsifier, stabilizer and thickening agent (Anderson, *et al.*, 1991). This increases the viscosity of a liquid, therefore results in the formation of stable foam by reducing the drainage.

2.5.4 Combination of various foaming agents and stabilizers

Kabirullah and Wills (1988) reported functional properties of sunflower seed protein, however with variations in the pH of the substance the growth of the foam was not affected. The consistency declined with its rise. An increase in protein concentration both increased expansion and increased foam stability. In the same manner, higher stirring times have not considerably affected the growth of mousse, but instead have improved the consistency of the mousse.

Akintoye and Oguntunde (1991) assessed the effect of the foam stabilizer on the physical properties of reconstituted dried foam soymilk. The foam-mat drying process of 65 °C was carried out by soy milk with foam stabilizers, Carboxyl methyl cellulose (CMC) and glycerol distearate (GDS). CMC produced no stable foam at any of the levels used but, for the production of stable foam, a minimum of 10% of GDS was required.

Karim and Wai (1999a) reported the puree Foam mat (*Averrhoacarambula* L.) drying of star fruit. Star fruit puree fumes were prepared by introducing various methocel concentrations. The excess and the density of the foams were compared from different methocel concentrations. A relation between the volumes of juice isolated from foam at 70 °C calculated the relative consistency of the foam. Overflow and durability of moulds with an elevated methocel content improved until a maximum value of 0.4% w/w was achieved.

Faladeet *al.* (2003) prepared cowpea foam-mat drying as foaming agents using glycerol mono stearate (GMS). At 2.5 to 15% (w/w) of GMS and EO were added to cowpea (22 to 28% of total solid) and whipped for 3 to 21 min, keeping the moisture temperature from 15 to 35°C. Cowpea foams have been dried 48 min at the temperature of 60 °C. After 9 and 21 minutes of whipping, minimum foam densities were obtained for cowpea foams with GMS and EA. For drying, EA-stabilizing foam was unstable. No significant difference in quality attributes of okra produced from fresh and reconstituted GMS-stabilized cowpea powders was found in sensory evaluation.

Rajkumaret *al.* (2006) carried out preliminary tests using a batch-type dryer for foam mat drying of alphonso mango-pulp. The test observed that foaming mango pulp, which was dried at 60 °C with a thickness of foam 1 mm, with egg albumen (10%) as a foaming agent with methyl cellulose (0.5%), was best found. Parameters including viscosity (5.7 ± 0.06 Pa s), stickiness (18.9 ± 0.1 g strength) and specific heat (3.66 ± 0.02 kJ/kg°C) values for this foamed pulp have been calculated.

Rajkumaret *al.* (2007a) dried alphonso mango pulp in foam mat drying using various food-foaming agents (0.25 to 1.5%) soy protein with methyl cellulose (0.5%), monostearate glycerol (0.5 to 3%) and albumin eggs (2.5% to 15%) with methyl cellulose (0.5%). The optimal concentrations of 1% soy protein, 2% mono stearate glycerol and 10% of egg albumen, obtained after 25 minutes of whipping time were determined. The 10% egg albumen and 0.5% methyl-cellulose treatment of mango pulp and a drying at 60 °C (1 mm foam thickness) retained the highest nutritional quality properties compared to other treatments.

Rajkumaret *al.* (2007b) conducted the experiment on thin layer dryer has been recorded to dry the mango pulp mist. The mango pulp (Totapuri variety), which has been moulded by egg album attachment, has been stabilized by inserting 0.5 percent methyl cellulose at various concentrations such as 5, 10 and 15 percent.

Zheng *et al.* (2009) investigated a micro-wave-assisted drying method of foam mat for the dehydration of glycerol mono-stearate black-currant pulp (GMS) and food grade insulated proteins (SPIs). A reasonable foaming additive in the form of the black currant pulp was 6% GMS and 3% g SPI for foam inducers and 10 ml carboxyl methyl cellulose (CMC), which had 0.5% stamina and 6 minutes of agitation time.

Bag *et al.* (2011) conducted a study of the bael (*Aegle marmelos* L.) fruit pulp for foam expansion and foam stability. Different concentrations of glycerol mono-stearate (GMS) and methyl-cellulose (MC) have been added to the foams from different pulp levels (PC) over different whipping time (WTs). Optimal conditions for optimum mousse expansion and

stability have been: GMS (3.10 g/100 g pulp), MC (0.32 g/100 g pulp), PC (13.2 °B) and WT (2 min) in the following numerical and graphical optimization. At this optimum point, the desirability was reached by 0.712. The estimated density and volume of the foam drainage were 0.658 g/cm³ and 1.75 ml, respectively.

Kadam *et al.* (2011a) confirmed that foam mat drying is a lucrative method of making powder from mandarin (kinnow). Foaming was done with carboxyl methyl cellulose, milk and egg whites to obtain dried mandarin powder, using them as foaming agents at different concentrations.

Balasubramanian *et al.* (2012) optimized tomato juice foaming conditions. Three processing parameters were optimized, namely egg albumin concentration (EA) as a foaming agent and carboxyl methyl cellulose (CMC) as a foam stabilizer and whipping time (WT). The levels for different input variables have been EA: 5 to 15%, CMC: 0.10 to 0.60%, and WT: 3 to 7 min, respectively. The estimated response levels were: expansion ratio: 91.49%, density of foam: 0.558 g/cc, and volume drying: 10 ml, which is nearer to the experimental value after validation.

Febrianto *et al.* (2012) identified the best combination of treatment among concentration and type of filler to produce milk powder with the best physical and chemical properties made with the method of drying foam mat. There are 3 levels of filler for maltodextrin (10 to 20% w/w fresh milk), whereas for Arabic gum (3 to 9% w/w fresh milk). Fillers contain three levels. The results showed that fillers are 6% Arabic gum and 15% Maltodextrin. The best results from milk powder at filler maltodextrin 15% with a yield value of 19.40%, 71.08% solubility, 3.73% moisture content and 10.2% protein. The best results were obtained from milk powder.

Kadam *et al.* (2012) investigated physical / chemical and microbial consistency of foam-mat dried pineapple powder. Two foaming chemicals, tri-calcium phosphate (TCP) (0 to 1.0%) and egg white (EW) (0 to 2.0%) were used for foaming the pineapple pulp. Applied as a foam stabilizer was the carboxyl methyl cellulose, which was dried at 65, 75 and 75 °C,

and the product was then pulverized into fine powder in a tray dryer. Statistical analyzes using LSD shows that a dried 1% TCP with a total of 4.6% sugars at a temperature of 65 °C, 2.71% reduction of sugar, 4.05 mg of ascorbic acid at 100 g, 0.35% total acid, 0.29 mg/100g iron, 2.24 mg of phosphorous at a rate of 100 g and 6.58 g of calcium at 100 g, with no fungal and bacterial growth.

Khan and Pandey (2012) investigated the dried malta juice concentrate with various levels of carboxyl methyl cellulose (CMC) ranging between 0.08 and 0.016 kg per kg of malta solid. Glycerol mono stearate (GMS), whole milk powder (WMP) and tri-calcium phosphate (TCP) were added at the levels varying between 0.005 to 0.015, 0.02 to 0.06 and 0.0025 to 0.0045 kg/kg of malta solid, respectively. Based on properties of malta powder, optimum level of ingredients obtained by using simultaneous optimization of flow ability time, degree of caking and solubility were: 7.92% carboxyl methyl cellulose, 85 °C temperature, 1.55% whole milk powder, 0.225% tri-calcium phosphate and 0.271% glycerol mono stearate.

Krasaekoopt and Bhatia (2012) prepared yogurt powder by foam-mat drying. Different levels were used for two types of foaming agents such as methyl cellulose and egg albumin at 0.5% to 2.0% for methyl cellulose and 1 to 4% for egg albumin. A high-speed (900 W) mixer (5 to 12 min) blended the yogurt and foaming agent mixture. With 12 minutes of mixing time, 3% egg albumin had better mould characteristics.

Kandasamyet *al.* (2014) optimized the process parameters for the production of papaya powder using foam-mat drying. As foaming agents the pulpe has been foamed in methyl cellulose (0.25 to 1% w / w/), glycerol monostearate (1.2 to 4% w/w), and white egg (5.0% to 20 % w/w). The maximum stable foam composition was 72, 90 and 125% with 0.75% methyl cellulose, 3% glycerol mono stearate and 15% egg white with 9% pulp and 20-minute foaming. The pulp powder of 9 °B, containing 3% glycerol mono stearate, was optimal when flavoured for 20 minutes.

Salahi *et al.* (2014) studied the foam mat drying of cantaloupe using egg white powder as foaming agent (1 to 3% w/w) and xanthan gum (0.050 to 0.2% w/w) as a foam stabilizer (2 to 10 minutes). The main goal of this was to maximize the concentration of the foaming agent, stabilizer and effective whipping time.

Durgeet *al.* (2015) studied the foam mat drying of the sapota pulp with pectin was studied, egg albumin and methyl cellulose at different levels. Foam expansion and stability increased with increasing concentration of pectin and methyl cellulose. The optimum foam expansion of 60.35% and foam stability of 77.13% were obtained with the addition of pectin and methyl cellulose to sapota pulp at optimum concentration of 2.21% and 4.41%, respectively. The foam expansion was very low (25%) with egg albumin.

Sangamithraet *al.* (2015) studied the effect of concentration of soy protein isolate (SPI), carboxymethyl cellulose (CMC) and whipping time on foaming properties of muskmelon pulp. The optimum conditions for foaming process were 8.71% of SPI concentration, 0.54% of CMC concentration and a whipping time of 5.7 min.

Veerapandianet *al.* (2015) observed the foam properties of mixed vegetable juice, phytochemical and antimicrobial properties of powders. The index of foam expansion as well as foam stability and solubility has improved from 79.2 to 104%; 68.7 to 97% and 79 to 92% respectively. The density of foam decreased between 0.2 to 0.17 g/cm³.

Asokapandianet *al.* (2016) investigated the impact of concentration of foaming agents and whipping time on dried muskmelon. Muskmelon pulp is foamed as a foam stabilizer by using SPI as spray agent and CMC. Pulp with 8.71% of foaming agent (SPI) and 0.54% of foam stabilizer (CMC), whipped for 5.7 minutes.

Abbasi and Azizpour(2016) examined the physicochemical properties of dried foam sour powder. The effects on density and drainage volume of sour cherry foam were examined by egg white (1 to 3 g/100g) and methylcellulose (1 to 2 g/100g). With increased concentration of

methylcellulose, drainage rate, foam density, TAC, browning index, and drying time decreased, however, there was a rising trend in solubility and pH of the samples. Perhaps all chemical properties (with the exception of pH) show a reduction in egg white concentration.

Norhazirahet *al.* (2017) made foams of *Nigella sativa* solution by adding different concentrations of egg albumen (2.5 to 15% w/w) and methylcellulose (0 to 1% w/w) to foaming times (2 to 8 min). The best recorded conditions were concentration of egg-albumin (15%), methanecellulose (0.69), and a whipping time (8 min).

Singh *et al.* (2019) examined the drying of foam mat with a foaming agent in totapuri mango pulp. The mango pulp was dried with 5, 7 and 9% GMS, and subsequently egg white as spray agents. Based on the above conditions, the drying of the foam mat with 5% GMS and egg whites was resolved.

2.6 Foam mat drying of fruits

Hart *et al.* (1963) evaluated the type and level of the added foam inducer as influenced by soluble solids. Sample pulp volume and mixing time had an insignificant impact on foam stability. In addition, more concentrations of foaming agent and stabilisers will be applied if the volume of soluble solids in the sample is small. If the sample food was pulp-free, the foam must be whipped to a very low specific gravity to achieve the required rigidity.

Lovriet *al.* (1970) obtained tomato powder with 3% moisture by foam-mat drying tomato paste (29% solids). Samples of powder were stored at various temperatures (-10 +2 +20 and +37 °C), atmospheres (air, nitrogen) and humidity (with and without in-package desiccation), and colour changes were observed for periods of up to 1 year. Storage at +20 °C was more favourable for colour retention than storage at +2 °C, or -10 °C. Storage in an inert atmosphere improved colour retention.

Brygidyret *al.* (1977) investigated the formulation of stable foam paste and the effects on drying rates utilizing hot air and microwave energy of features such as foam thickness, density and bubble size. Air-injected

foams were produced from commercial tomato paste (27% solid) and mono-and diglyceride stabilizers. The foams have been dried at 2450 MHz at different rates of power with hot air (76.7 °C) and with microwave energy. For foams of 0.38 g/cm³ density and corresponding bubble size indices of about 83 µm containing 1% stabilizer, excellent drying properties were obtained.

Karim and Wai (1999) reported the foam-mat of star fruit (*Averrhoa carambola* L.) puree. Dry rates were also compared at two drying temperatures (70 and 90 °C). The dried and reconstituted powder content has been tested with a basic sensory evaluation and a Hunter lab tool. For the foam dried at both levels, drop rate was observed. As the drying temperature rose from 70 to 90 °C, the drying period could be shortened by as much as 30 min. There were, however, clear changes in the colour and flavour, dried at 90 °C, in the product. This research shows that relatively good powder characteristics obtained under laboratory conditions.

Sankat and Castaigne (2004) studied foam mat drying of ripe bananas. Banana foam mats were dried at temperatures from 45 to 90°C in a forced air, cabinet dryer, to a hard, porous and brittle solid which was amenable to grinding so as to produce a dehydrated banana powder.

Kudra and Ratti (2006) examined the drying cycle, a variety of fruit, pulp and juices. The drying process for foamed and non- foamed apple juice dried at 55 °C at 19 mm layer has shown higher drying levels in foaming juice, resulting in a decreased drying period of 500 to 200 minute. Because of the porous nature of the dried foam and the speed of balancing after drying, dry product in contrast to non- foamed juice that dries to viscous syrup on a simultaneous rate has been obtained. For drying the foamed apple juice, energy consumption was 20% for drying non- foamed juice.

Rajkumaret *al.* (2006) studied the foam mat drying of alphonso mango pulp using a batch type cabinet dryer. It took 75 and 35 min to dry the fresh (non-foamed) and foamed mango pulp. On the basis of

preliminary drying results, the mango pulps had been dried with a continuous foam mat (lab model) dryer with a drying capacity of 2.5 kg / day (8 h). Changes were observed in foam-dried flakes relative to non-foamed -dried flakes with continuous foam mat dryer.

Rajkumaret *al.* (2007a) observed the foam mat drying of Alphonso mango pulp. Drying was done in batch thin layer dryers at a thickness of 1, 2, or 3 mm foamed samples at 4 drying temperatures (60, 65 and 70 °C).

Rajkumaret *al.* (2007b) investigated thin layer drying of foamed pulp. The mango pulp (Totapuri) was eaten in different concentrates 5 to 15%, with the adding of egg folder, and the foam was stabilised with the introduction of 0.5% of methyl cellulose. At three dryer temperatures (60 to 70 °C), the foamed pulp had been drained in the thin-film dryer batch form, with three thicknesses of foams (1 to 3 mm), for example. Biochemical tests found that ascorbic acid, gross soluble solids and β carotenes were greatly decreased when dried in the mango flakes at higher temperatures relative to flakes at 60 °C.

Thuwapanichayanet *al.* (2008) reported the combination of foaming and drying as an alternative way of producing chips of crisp banana. Banana foam mats with a thickness of 5 mm were dried to a moisture content of 0.03 kg/kg at 60, 70 and 80 °C temperature with 0.5 m/s shallow air. Experimentally, the extensive porous nature of low-density foams has resulted in higher drying rates, moisture diffusivity and shrinkage. The drying temperature and the concentration of egg albums did not affect the textural properties of the final products but recommended that chips of consistency be produced at 80 °C.

Alakaliet *al.* (2009) evaluated moisture intake kinetics by moisture-dried foam-dried mango pulp, were evaluated at four (10 to 40 °C) temperatures as well as at two relative humidity (55 and 80%), while moisture sorption results were calculated at the same temperature and water activity of 0.032 and 0.925 for shelf-life prediction. At 55, the rate of moisture absorption was higher than at 80% of storage relative humidity.

Raharitsifaet *et al.* (2009) studied freeze-drying at varying concentrations of foamed and non-foamed apple juice and methyl cellulose and egg albumin. Samples of foamed and non-foamed juices of different thicknesses and initial weights were frozen at $-40\text{ }^{\circ}\text{C}$ and then frozen under vacuum at $20\text{ }^{\circ}\text{C}$ for 48 hours. An artificial neural network-based mathematical model has been developed for foam kinetics and temperature curves in freeze-drying. Lower density of foamed materials, however, reduces the dryer load weight.

Kadam *et al.* (2010a) examined the effect on the biochemical properties of foam mat dried tomato juice for different drying temperatures (65, 75 and $85\text{ }^{\circ}\text{C}$) and different foaming agents such as carboxyl methyl cellulose (CMC), milk and egg white. Total sugar, ascorbic acid, lycopene, and total acid were observed to decrease but the pH was slightly higher than the fresh composition of tomato juices and there was no microbial (fungal and bacterial) growth.

Kadam *et al.* (2010b) examined the chemical properties of foam-mated dried mango juice powder for the impact of drying air (65, 75 and $85\text{ }^{\circ}\text{C}$) and milk as a foaming agent at various levels concentrations. Addition of 10% milk was found to yield better results at a temperature of $65\text{ }^{\circ}\text{C}$. In foam-mat dried mango powder microbial load was not detected.

Kadam *et al.* (2011a) stated that the drying of foam mat is a lucrative method for the production of powdered mandarin (kinnow). Air temperature of foamed pulp was 65, 75 and $85\text{ }^{\circ}\text{C}$. The quality of the dried pulp of Mandarin was assessed for 6 months.

Thaisong and Rojanakorn (2011) investigated the effect of concentration of carboxyl methylcellulose (CMC) (0 to 1.0%) and foaming time (0 to 25 min) on the drying of mango foam. During falling rate experimentations, the mango foams were dried at 60, 65 and $75\text{ }^{\circ}\text{C}$. Mango foam drying activation energy was 22.22 kJ / kmol .

Zheng *et al.* (2011) studied the optimization of microwave parameters-assisted foam mat drying of blackcurrant pulp. The dehydration of blackcurrant pulp is a possible method for drying MAFM.

Both the content of vitamin C and anthocyanin content of the pulp are affected by pulp thickness. The optimal parameters 560 W microwave power, 65 g pulp load, 8 min drying time and 4.46 mm pulp thickness.

Kadam and Balasubramanian (2011) determined the effect of drying the temperature of the air on foamed tomato juice. Foamed juice (300 ± 0.5 g) was spread to rectangular trays (2.5 mm thick) and temperature was maintained in a tray at 60-70 °C. The increase in the amount of foaming agents increased the drying cycle (up to 15% egg albumin) and a decreasing trend followed. The drying air temperature of foaming tomato juice was dried with the highest acceptability, respectively, at 510 and 450 min at 60 and 70 °C. Tomato juice's effective moisture diffusivity ranged from 2.026×10^{-8} to 3.039×10^{-8} m²/s.

Widyastuti and Srinta (2011) developed a drink based on foam mat dried papaya. Papaya dry blended with skim milk powder at 6:4 was foam-mat; 5:5; the ratio 4:6 w/w, twice a day, the ingestion of formulated products could provide 9.54% of a daily dietary fibre intake. The foamed papaya slurry was dried at 60 °C for five hours with hot air drying.

Kadam *et al.* (2012) studied the physico-chemical and microbial quality of foam-mat dried pineapple powder. The foamed pineapple pulp was dried at 65 to 85 °C in tray dryers and the dried product was subsequently pulverized into fine powder. The best sample with 4.60% of total sugars, 2% reducing sugars, 4.05% ascorbic acid, 0.35% total acid, 0.29 mg/100g iron, 2.24 mg/100g phosphate and 6.58 g/100g calcium and no bacterial and fungal growth was dried at a temperature of 65 °C.

Kandasamy *et al.* (2012a) conducted foam mat drying of papaya for optimization of process parameters. Methylcellulose, GMS and egg whites were added to the papaya pulp. The foam has been dried at three temperatures (60 to 70 °C), while keeping the foam 2 to 10 mm in thickness. Decrease in the amount of ascorbic acid and sugar in papaya foam dried at higher temperatures. Papaya pulp, with a foaming agent (GMS) of 3%, was found most advantageous for the foam drying.

Kandasamy *et al.* (2012b) investigated the use of GMS to dry foamed papaya puree. In batch dryers, the foam puree was dried at air temperatures between 60 and 70 °C and a foam-thickness of 2 to 8 mm, and at air flow rates of 2.25 m³/min. The papaya powder from the 4 mm thick foam was found optimal and dried at 60 °C.

Kandasamy *et al.* (2012c) studied the drying of foamed papaya pulp using egg albumin. At air temperatures between 60 and 70 °C with foam thicknesses between 2 and 8 mm, the foams were dry at air flow levels of 2.25 m/min. It was found to be optimum for producing a foam-mat, dried papaya powder from a 2 mm thickness and secured to 60 °C.

Krasaekoopt and Bhatia (2012) prepared yogurt powder by foam mat drying. The foam was dried at 50 to 70 °C for 3 h. Dry yogurt was blended and held in an air-tight tub. Yogurt (15%) powder was dissolved and then mixed well in cold water (85 ml). The ingredient has been applied to the ingredient orange taste (0.1 g) and color (0.1 g). Yogurt powder (60 °C) had 0.348 water behaviors and 8.5% moisture. There were no substantially different sensory properties of drinking yogurt

Wilson *et al.* (2012) performed the foam mat drying of the mango pulp. The drying temperature and concentration of foaming agents greatly influence a dried product's nutritional properties. The mango pulp of 3% egg white was found effective at 65 °C drying temperature.

Azizpouret *et al.* (2013) studied the drying and drying of shrimps with foam-mat. The drying time decreased to 55 minutes as the temperature increased from 50 to 70 °C. During the drying process, the falling rate period was observed. It was calculated that the effective diffusivity of dried samples were between $3.24 - 6.49 \times 10^{-9} \text{ m}^2/\text{s}$ for each of the specified temperature ranges. The activation energy was 32.16 kJ/mol. The Midilli – Kucuk model has been found to provide better forecasts for all drying models.

Chaves *et al.* (2013) characterized Brazilian purple cherry (*Eugenia uniflora* L.) pulp foams made with various additives. Drying took place for 2 h at 55 °C. It has been concluded that the characterization of physical

chemistry was satisfying and in line with the Brazilian agro-industrial product standards.

Kandasamy *et al.* (2014) optimized process parameters to produce foam-mat drying papaya powder. The foamed pulp was dried with a 2 to 10 mm foam thickness in a batch cabinet dryer at air temperature of around 60 to 70 °C. The foamed pulp with a thickness of 4 mm at 60 °C was best considered.

Azizpouret *et al.* (2014) investigated the effects of drying temperatures on the foam-mat drying of shrimp (*Penaeus indicus*). The drying air temperature had a significant effect on drying time and drying rate. As the temperature increases from 45 to 90 °C the drying time dropped to 90 min. Curves of drying rates showed that shrimps with foamed were dried mostly over a constant rates period

Salahi *et al.* (2014) studied the foam mat drying of cantaloupe at three different temperatures (40 to 70 °C) in conventional dryers with foam layer thicknesses of 3 and 5 mm. The results of this study indicated that the drying process occurs during the lowering period and that the diffusivity of the moisture increases with an increase in temperature and foam thickness.

Auisakchaiyoung and Rojanakorn (2015) studied Gac fruit aril foam (1, 2 and 3 mm thick) at a rate of 0.5 m/s 60, 70 and 80 °C. The gac fruit aril foam (1 mm thick) drained at 70 °C for 60 min was the most lycopene and β -carotene as well as complete production of phenolic compounds and antioxidants.

Sanghamitra (2015) studied muskmelon foaming under optimum conditions using hot air dryers at 50, 60 and 70 °C. At 70 °C, the drying rate was high. In comparison with the non-foamed muskmelon pulp, the productive moisture diffusiveness was calculated. For muskmelon, the density, colour, water absorption index, solubility index, Hausner ratio and Carr index were also calculated

Franco *et al.* (2015) studied the foam mat drying of yacon juice. The drying was performed under the thickness of the product (0.5 to 1.5 cm)

and at air temperature (50 to 70 °C) for yacon (YJ) and yacon concentrates juice (CYJ). Powder was removed and pulverized from the metal plate after drying. The drying time, the humidity and the water activity (AW) of the product were statistically influenced by the thickness of the layer and air temperature ($p>0.5$). The shortest drying time for optimal Aw (0.1 to 0.3) is 0.5 cm and 70 °C for both YJ and CYJ, respectively, at 59 and 65 minutes.

Norhazirahet *al.* (2017) studied the foams from *Nigella sativa* dried at 50 to 70 °C air temperatures, with a foam thickness of 1 to 3 mm. The optimum conditions for the drying process were 60 °C, with 2 mm of foam thickness.

Shaariet *al.* (2017) showed that the method of foam mat drying is economic and better than drying foam and freezing fruits. They researched the effect of whipping time and the concentration of foaming agents on dried pineapple powder. Results of this study showed that the foaming effects were influenced considerably by the concentration and whipping time needed.

Kartiniet *al.* (2019) investigated the formulation of lime, tomato and carrot into drinks using a foam-mat drying method. Tomato paste or carrot juice is applied along with egg white and methyl cellulose as foaming agents to the lime juice, and then whipped into foam using a blender (10 min). The foam was flattened and dried for 5 h and was put in a tray at 60 °C. Lime juice formulated in functional powder beverages which meet SNI quality requirements in combination with tomatoes (1:1) and Carrot (1:1). Lime-carrot is stronger than lime-tomato mix.

Singh *et al.* (2019) investigated the foam mat drying of totapuri mango pulp. Mango pulp was subjected to foam mat drying at temperatures of 60, 70 and 80 °C along with 5, 7 and 9 per cent GMS and later with egg white as foaming agents and drought.

Table 2.1 Foam mat drying fruits and vegetables

Product	Foaming agents with concentration	Whipping time	Drying method	Findings	Reference
Grape	GMS 1 to 3%	6.5 to 15 minute		A criterion for good foam stability was its uniformity and the lack of fluid drainage in 60 minutes after its preparation.	Berry <i>et al.</i> (1965)
Starfruit	Methocel		70 and 90 °C	Maximum value was obtained at a methocel concentration of 0.4% w/w retained at 70 °C	Karim and Wai (1999)
Cowpea	Glycerol Mono Stearate (GMS) and Egg Albumin (EA) 2.5 to 15% (w/w)	3 to 21 min maintaining 15, 25 and 35 °C	Air drying 60 °C	Minimum foam densities were obtained in cowpea foams with GMS and EA after 9 and 21 min of whipping	Faladeet <i>al.</i> (2003)
Ripe Bananas	10 g/100 g soy protein	12 min	Forced air cabinet dryer 45 °C to 90 °C	Foamed to a density of 0.50 g/ml after 12 min of whipping	Sankat and Castaigne (2004)
Alphonso Mango	Soy Protein (0.25 to 1.5%) with Methyl Cellulose (0.5%), Glycerol Mono Stearate (0.5 to 3.0%), and Egg Albumen (2.5 to 15%) with Methyl Cellulose (0.5%).		Batch type thin layer dryer 60 to 75 °C	Mango pulp with 10% egg albumen and 0.5% methyl cellulose and drying at 60 °C (1 mm foam thickness), retained the highest nutritional quality characteristics.	Rajkumaret <i>al.</i> (2007a)
Mango pulp (Totapuri variety)	Egg Albumen at 5 to 15% and Methyl Cellulose at 0.5%		Thin layer drying 60 to 70 °C	Total soluble solids and β carotene in the mango flakes dried at 60 °C.	Rajkumaret <i>al.</i> (2007b)

Mango pulp (Totapuri variety)	Glycerol Mono Stearate (5 to 9%) and Egg Albumin		60 to 80 °C	Foam mat drying using 5% GMS and egg white dried at 60 °C gives best result.	Singh <i>et al.</i> (2019)
Mango	Carboxyl Methyl Cellulose (CMC) (0 to 1.0%)	0 to 25 min	Air dryer 60 to 70 °C	It was found that incorporation of 0.5% CMC and whipping time of 25 min produced the foam with the lowest density.	Thaisong and Rojanakorn (2011)
Mango pulp	0 to 9% Egg white		65 to 85 °C.	3% egg white at 65 °C air drying temperature was the best combination.	Wilson <i>et al.</i> (2012)
Banana	egg Albumen		60 to 80 °C	The produce quality banana chips, the initial foam density of 0.5 g/cm ³ and drying temperature of 80 °C were recommended.	Thuwapanic hayananet <i>al.</i> (2008)
Egg	whole egg liquids		60 to 70 °C	Foam expansion for whole egg liquid was found 243.5 ± 12.5%. Retained higher biochemical and nutritional content dried at 65 and 70 °C for 3 and 5 mm foam thicknesses respectively.	Thirupathiet <i>al.</i> (2008)
Apple juice	Methyl Cellulose and Egg Albumin		Freeze drying frozen at -40 °C and then freeze-dried at 20 °C for 48 h under vacuum.	Foaming reduced process time for equal sample thickness.	Raharitsifae <i>t al.</i> (2006)

Black Currant	Glycerol Mono Stearate (GMS) and Soy Protein Isolated (SPI)	6 min		Optimum expansion and high stability was at 6% GMS and 3% g SPI as foam inducers and the 10 ml carboxylic methyl cellulose (CMC) with concentration of 0.5%.	Zhengnet <i>et al.</i> (2009)
Banana	Glycerol Mono Stearate (GMS) (0.005 to 0.02%)		Air dried 60 to 80 °C	Lower drying temperatures and concentration of GMS resulted in longer drying time	Falade and Okocha (2010)
Soymilk	Carboxyl Methyl Cellulose (CMC) and Glycerol Distearate (GDS) at 5 to 15%			Physical characteristics and reconstitution properties of 10% GDS foamed soymilk powder and 15% GDS foamed soymilk powder were similar.	Akintoye and Oguntunde, (1991)
Mandarin	Carboxyl Methyl Cellulose (CMC) at 0 to 1.0%, milk at 0 to 9% and egg white at 0 to 2.0%		Tray drying 65 to 85 °C	Minor bacterial growth noticed in all the treatments, which is within the permissible limit, no fungal growth was noticed after 6 months.	Kadam <i>et al.</i> (2010b) and Kadam <i>et al.</i> (2011a)
Bael (<i>Aegle marmelos L.</i>)	Glycerol Mono Stearate (GMS) and Methyl Cellulose (MC)	24 min at 2 min interval		GMS (3.10 g/100 g pulp), MC (0.32 g/100 g pulp), PC (13.2 °Brix), and WT (2 min).	Bag <i>et al.</i> (2011)
Tomato	Myverol 18-100 (Kodak series 2056 - 1%)	4.5 min	Microwave drying 150 to 350W	Drying time required less in microwave drying	Rzepecka <i>et al.</i> (1976)
Tomato	Egg Albumin (0 to 20% w/w)	5 min	Air drying 60 to 70 °C	Foamed tomato juice was dried in 510 and 450 min at 60 and 70 °C drying air temperature, respectively.	Kadam and Balasubramanian (2011)

Tomato	Egg Albumin: 5% to 15%, carboxyl methyl cellulose: 0.10% to 0.60%	3 to 7 min		The responses generated were expansion ratio: 91.49%, foam density: 0.558 g/cc & drainage volume: 10 ml.	Balasubramanian <i>et al.</i> (2012)
Tomato, guava and papaya	Egg Albumin and Soy Protein Isolate		Tray drying 55 to 80°C.		Sharada <i>et al.</i> (2013)
Papaya	Glycerol Mono-Stearate (1 to 4% w/w)	5 to 15 min	Air dryer 60 to 70 °C	Maximum stable foam formation was 90% at 3% glycerol mono stearate with 9 °B pulp concentration and whipping time of 10 min. Powder obtained from the foam thickness of 4 mm and dried at 60 °C was found optimum.	Kandasamy <i>et al.</i> (2012a)
Papaya	Egg Albumin 5 to 20 % (w/w)	5 to 20 min	Air drying 60 to 70 °C	Maximum stable foam formation was 125.62 % at 15 % egg albumin and whipping time of 15 min. Papaya powder obtained from the foam thickness of 2 mm and dried at 60 °C was found optimum to produce the foam mat dried papaya powder.	Kandasamy <i>et al.</i> (2012b)
Papaya	Methyl Cellulose 0.25 to 1.00% on w/w basis.	15 min	Air drying 60 to 70 °C	Papaya powder obtained from the pulp of 9 °B added with 0.75% methyl cellulose, whipped for 15 min and dried with a foam thickness of 4 mm at a temperature of 60 °C was found optimum condition for production of papaya powder.	Kandasamy <i>et al.</i> (2012c)
Blackcurrant	6% GMS, 3% SPI and 10 ml CMC	6 min	Microwave assisted foam mat drying	Optimum parameters for MAFM drying of blackcurrant pulp are as follows: microwave power of 560 W, pulp load of 65 g, drying time of 8 min, and pulp thickness of 4.46 mm. MAFM	Zheng <i>et al.</i> (2011)

				drying is a potential method for dehydrating blackcurrant pulp.	
Milk powder	Maltodextrin (10 to 20% w/w fresh milk), and Arabic Gum (3 to 9% w /w fresh milk).			The best results obtained from the milk powder with the type of filler maltodextrin concentration of 15%.	Febriantoet <i>al.</i> (2012)
Ripe pawpaw fruit	Egg albumin 10 to 20%,	3 to 15 min	Domestic freezer at -18 °C for 48 h	Egg albumin concentration affected the stability of the 20 °Brix nectar and egg albumin at 20% concentration produced more stable foam at 3 min.	Ibidapo and Erukainure (2012)
Pinapple	Tri-Calcium Phosphate (TCP) (0 to 1.0%) and Egg White (EW) (0 to 2.0%). Carboxyl Methyl Cellulose (0.25%)		Tray dryer 65 to 85 °C	1% TCP at 65 °C was the best	Kadam <i>et al.</i> (2012)
Shrimp	Xanthan Gum (0.1–0.4% w/w)	2–6 min	45 to 90°C	Xanthan gum 0.19% (w/w), water: shrimp ratio 4.5:1 (w/w), and whipping time 5.89 min were found optimum foaming conditions.	Azizpouret <i>al.</i> (2014)
Sour Cherry	Egg White (1 to 3 g/100g) and Methyl Cellulose (1 to 2 g/100 g)		50 to 80 °C	As the concentration of methylcellulose increased, drainage volume, foam density, TAC, browning index and drying time were reduced; It was observed that at the drying temperature of 65 °C, sour cherry powder had the maximum solubility, TAC and pH.	Abbasi and Azizpour (2015)
Mixed vegetable (bitter gourd, tomato	Egg Albumin 10 to 30%	90 sec	50 to 70 °C	Foam expansion, foam stability and solubility index were increased from 79.2 to 104%; 68.7 to 97% and 79 to 92%, respectively. Foam density was decreased from 0.2 to 0.17 g/cm ³ .	Chandrasekar <i>et al.</i> (2015)

and
cucumber)

Carrot	Tween 80 0 to 0.3%(v/v)		Tray drying 40 to 70 °C	Maximum drying temperature is 50°C with β -carotene content 10.55 mg/kg and the maximum concentration of foaming agent (tween 80) is 0.2%(v/v)	Fardiyah <i>et al.</i> (2017)
Malta juice	Carboxyl Methyl Cellulose (CMC) 0.08 and 0.016 kg/ kg, Glycerol Mono Stearate (GMS), whole milk powder (WMP) and Tri-Calcium Phosphate (TCP) varying between 0.005 to 0.015, 0.02 to 0.06 and 0.0025 to 0.0045 kg/kg, respectively.		Vacuum drying	7.92% carboxyl methyl cellulose, 85 °C temperature, 1.55% whole milk powder, 0.225% tri-calcium phosphate and 0.271% glycerol mono stearate.	Khan and Pandey (2012)
Yogurt	0.5 to 2.0% for Methyl Cellulose and 1 to 4% for Egg Albumin	5 to 12 min	Air drying 50 to 70 °C	3% egg albumin with the mixing time of 12 min provided better foam characteristics. The highest viscosity product was obtained when 60 °C yogurt powder was used.	Krasaekoopt and Bhatia (2012)
Shrimp	Xanthan Gum 0.1 to 0.3% w/w),	5 min	50 to 70°C	Results showed that stability and density of foam increased with increasing xanthan gum concentration. As the temperature increased from 50 to 70°C, the drying time decreased to 55 minutes.	Azizpouret <i>al.</i> (2013)
Sea buckthorn berries	CMC 0 to 3%		(55 $\pm$ 2 °C)		Kaushal <i>et al.</i> (2013)

Potato	2% Glycerol Mono-Stearate (GMS).				Maximum foam expansion of 25% was found with interactive effect of 10 minutes. The optimum drying condition obtained was at 60 °C for 135 minutes with 2% GMS.	Chakraborti <i>et al.</i> (2014)
Papaya	Methyl Cellulose (0.25 to 1% w/w), Glycerol Mono Stearate (1 to 4 %, w/w) and egg white (5 to 20%, w/w)		Air dryer	60 to 70 °C	Papaya powder obtained from the pulp of 9 °B added with 3% glycerol-mono-stearate, whipped for 20 min and dried with a foam thickness of 4 mm at a temperature of 60 °C.	Kandasamy <i>et al.</i> (2014)
Gac fruit	Methyl Cellulose (MC) 1.0, 1.5 and 2.0%	0 to 25 min		60 to 80 °C	Optimum condition for forming foam was 1.5 % methylcellulose after 25 min whipping. Gac fruit aril foam (1 mm thick) dried at 70 °C for 60 min exhibited	Auisakchaiyong and Rojanakorn (2015)
Pumpkin pulp	3% and 4% glycerol mono stearate (GMS)			50 and 60 °C		Das <i>et al.</i> (2015)
Sapota pulp	Pectin, Egg Albumin and Methyl Cellulose				Optimum foam expansion of 60.35% and foam stability of 77.13% were obtained with the addition of pectin and methyl cellulose to sapota pulp at optimum concentration of 2.21% and 4.41%, respectively.	Durgeet <i>et al.</i> (2015)
Muskmelon	Soy Protein Isolate (8.71 %) Carboxyl Methyl Cellulose (0.54%)	5.7 min		70 °C		Sangamithra, <i>et al.</i> (2015)
Muskmelon pulp	Egg Albumen (EA), Carboxyl Methyl Cellulose (CMC)				Optimum conditions for foaming process were EA (11.59% w/w), CMC (0.59% w/w) and WT (3.97 min).	Sangamithra <i>et al.</i> (2015)
Cantalou	Egg white powder, Xanthan gum			40 to 70 °C)	Weibull distribution model described drying	Salahiet <i>al.</i>

pe				behaviour of foams for all drying processes	(2014)
Sour cherry	Egg White (1 to 3 g/100 g) and Methyl Cellulose (1 to 2 g/100 g)		50 to 80 °C	As the concentration of methyl cellulose increased, drainage volume, foam density, TAC, browning index and drying time were reduced; however solubility and pH of the samples had an increasing trend. Sour cherry powder had the maximum solubility, TAC and pH. Browning index and drying time decreased by increasing the drying temperature.	Elnaz and Mehran (2016)
Nigella sativa	Egg Albumen (2.5 to 15% w/w) and Methyl Cellulose (0 to 1% w/w)	2 to 8 min	50 to 70 °C	With 15% of egg albumen, 0.69% of methyl cellulose and 8 min whipping time. The optimum conditions for the drying process were 60 °C with 2 mm of foam thickness.	Norhazirahe <i>t al.</i> (2017)
Passion fruit aril	Methyl Cellulose at 0.75 to 3.0%	0 to 25 min	60 to 80 °C with air velocity of 0.5 m/s.	Optimized forming foam was 2.25% methylcellulose after 25 min whipping as it provided the highest foam expansion (187.25%) and stability as well as the lowest foam density (0.41 g/ml). Passion fruit aril foam (1-mm thick) dried at 70 °C for 90 min.	Khamjae and *Rojanakorn (2018)

2.7 Thin Layer Drying in Microwave Drying Method

Maskan (2000) dried bananas (4.3 ± 0.177 , 7.4 ± 0.251 and 14 ± 0.492 mm thick) in convection (60°C at 1.45 m/s); microwave (350, 490 and 700 W) and microwave (350 W, 4.3 mm thick sample). Increased drying rate with the higher power level were observed. Drying with microwave shortened drying time by approximately 64.3%.

Alibaset *al.* (2007) dried spinach leaves in microwave oven using eight different microwave power levels ranging between 90 and 1000 W. Energy consumption remained constant within the power range of 350 to 1000 W. The best quality in terms of colour and ascorbic acid values were obtained in the drying period with 750 W power.

Dadaliet *al.* (2007) reported the effects of power level and sample mass on moisture content, moisture ratio, drying rate, and drying time of Turkey okra using microwave drying. Among of the models proposed, Page's model gave a better fit for all drying conditions used. The activation energy for microwave drying of okra was calculated.

Arslan and Ozcan (2010) carried out the experiment to monitor the drying kinetics and quality degradation of the onion product. Page, "Modified Page" and "Midilli and Kucuk" models exhibited high coefficient of determination (R^2) values, ranging between 0.994 and 0.999. The calculated effective diffusivity ($Deff$) values (m^2/s) of onion slices for the sun, oven 50°C and oven 70°C , microwave 210 W and microwave 700 W drying process were 8.339 and 7.468.

Demirhan and Ozbek (2011) investigated the effect on celery leaves' drying properties. By increasing the microwave output power from 180 to 900 W the drying time decreased from 34 to 8 min. To determine the kinetic parameters, the drying data were fitted to various models based on the ratios of the differences between the initial and final moisture contents and equilibrium moisture content versus drying time. Among the models proposed, the semi-empirical Midilliet *al.*, model gave a better fit for all drying conditions applied.

Rayaguru and Routray (2011) investigated the effect of microwave drying technique on drying kinetics of aromatic Pandanus leaves (*Pandanus amaryllifolius*). By increasing the microwave output powers (180 to 900 W), the drying time decreased from 14 to 2 min. The semi-empirical Page model gave the best fit for all drying conditions applied. The effective moisture diffusivity values increased from 5.35 to $1.99 \times 10^{-07} \text{ m}^2/\text{min}$. It is proposed to dry the leaves at 540 W in a microwave dryer to obtain the product with good quality.

Worknehet *al.* (2011) studied microwave assisted hot air ventilation drying of tomato slices. Microwave power densities of 1.13, 2.08 and 3.11 W/g were combined with air ventilation (50 °C) and hot air drying at 40 to 80 °C. The tomato slice dried faster when subjected to microwave heating coupled with hot air ventilation. Microwave drying at 1.13 and 2.08 W/g maintained superior colour quality.

Darvishi and Hazbavi (2012) studied the effect of microwave drying technique on drying kinetics of date palm. Results showed that the change of moisture ratio with drying time in the power density range from 4 to 9.5 W/g is successfully described by Page model. The values of k and D_{eff} increased with the increase of power density. Values of drying rate constant (k) were in the range of 0.052 to 0.142 (per min) and the D_{eff} of date range palm from 2.72×10^{-6} to $4.73 \times 10^{-6} \text{ m}^2/\text{s}$. Activation energy was determined as 3.91 W/g.

Darvishi (2012) studied four microwave power densities from 5 to 20 W/g were recorded on studied drying properties and energy requirements for microwave drying of potato slices. The tests have drained potato slices from 2.294 kgH₂O/kg of dry matter up to a finish moisture level of 0.08 m²/s. The efficient moisture diffusivity of the potato samples has been determined by the second law of Fick and has been observed between 0.025×10^{-8} and $3.05 \times 10^{-8} \text{ m}^2/\text{s}$. The minimum requirements for dry potato slices and the maximum energy requirements were determined as being 4.22 and 10.56 MJ/kg H₂O at 15 and 5 W/g.

Workneh and Oke (2012) studied the influence of the combined microwave power and hot air ventilation on the drying kinetics and colour quality of tomato slices. Microwave power densities (1, 2 and 3 W/g) was combined with hot air ventilation at 50°C and hot air ventilation drying without microwave power at 40 to 80°C to dry tomato slices down to 10% moisture content. The tomato slice sample dried faster when subjected to microwave heating, coupled with hot air ventilation at 50°C. The drying times required for tomato slices to reach 10% moisture content were 3.2, 2.5 and 1.3 h, using 1, 2 and 3 W/g microwave power densities, coupled with 50°C hot air ventilation, respectively. Microwave drying maintained the superior colour of tomato slices after drying period, compared to the other treatments.

Assawarachanet *al.* (2013) investigated the effects of microwave power on drying characteristics and qualities of *Spirogyra* sp. *Spirogyra* sp. can reduce moisture content from 8.54 ± 0.17 to $0.10 \pm 0.02\%$ gwater/g dry matter at 2.5, 2.0, 1.5 and 0.8 W/g microwave power. The best quality in terms of colour and phenolic content, associated with biological activity, were obtained in the drying period with 1.55 W/g microwave power.

Adewaleet *al.* (2014) investigated microwave drying kinetics of banana. Microwave drying kinetics of thin layer drying of banana at power levels 100 to 300 W, drying times was increasing and shorter at a lower and higher oven power. The ED increased with increasing microwave power with values in the range of 5.26×10^{-10} , 1.14×10^{-9} , and 1.97×10^{-9} m²/s at 100, 200 and 300 W, respectively. Five mathematical drying models were fitted and Verma model gave the best results for the description of thick layer drying.

Alibas (2014) studied the mathematical modelling of microwave dried celery leaves and determined the effective moisture diffusivities and activation energy. Celery leaves with 50 ± 0.07 g weight and 91.75% moisture were dried using 8 different microwave power densities ranging between 1.8 to 20 W/g. Weibull distribution model gave the most suitable predictions at all power density. The activation energy was calculated using an exponential expression based on Arrhenius equation and values ranged

from 1.595×10^{-10} to 6.377×10^{-12} m²/s. The linear relationship between the drying rate constant and effective moisture Diffusivity gave the best fit.

Mahdhaouiet *al.* (2014) studied the microwave drying kinetics of olive fruit (*Olea Europaeae* L.). The thin layer drying characteristics of olive fruit (variety Zarrazi) was investigated under three microwave power densities; 1, 1.5 and 2 W/g. The experimental data were fitted appropriately to Page model. The effective moisture diffusivity was calculated in the range from 5.96×10^{-9} to 13.00×10^{-9} m²/s. The values of k and D_{eff} increased with the increase of power density. An Arrhenius relation with an activation energy value of 1.6316 W/g expressed the effect of microwave power density on the diffusivity.

Shukla *et al.* (2014) reported the mathematical modeling of microwave drying of green peas. The drying characteristics of green peas were examined in a microwave dryer for power level of 20, 40 and 60 W. The drying process was continued until sample moisture fell to equilibrium moisture content. The model that best represented green pea drying was Page model.

Chayjan and Kaveh (2016) studied the application of a 270 to 630 W microwave capacity, 40 to 70 °C air temperature and an air velocity of 0.5 to 1.7 m/s. Six mathematical models were used to predict the moisture ratio of eggplant fruit slices in thin layer drying. The results showed that the Midilliet *al.* model had supremacy in prediction of turnip slice drying behaviour.

Karaaslanet *al.* (2016) investigated the microwave drying characteristics on moisture ratio, drying rate of quince slices. Microwave drying results (180 to 900 W) on drying time, drying rate of quince slices have been investigated. The drying data were applied to nine different mathematical models. It was found that the Midilliet *al.* model described the drying curve satisfactorily in all drying methods.

Aral *et al.* (2017) studied the drying characteristics of radix eremut (*Eremuruspectabilis*) using microwave drying method. The drying curves of radix eremut locate in the falling rate regime and time required for drying

reduced by raising microwave powers ranging from 160 to 640 W. The most accurate models for radix eremut were determined to be the Midilli and Page models as the best. Effective moisture diffusion coefficients (D_{eff}) were computed utilizing Fick's second law equation. Revised Arrhenius equation was implemented to identify the activation energy and its value was calculated as 148.82 W/g.

Das and Arora (2017) studied the microwave and convective hot air application for rapid mushroom drying. The optimal thickness was 2.5 mm which met the quality standards of commercial dried mushroom in relatively shorter time (72 min). They compared with conventional hot air drying in terms of drying kinetics, colour, water activity and rehydration ratio.

Karaaslan *et al.* (2017) dried sultana grape fruits was studied using a microwave dryer. The effects of microwave drying (180 to 720 W); combined convective and microwave drying (180 W-100 °C, 360 W-100 °C and 540 W-100 °C), convective drying (100 to 200 °C) on drying time, drying rate of grape samples have been investigated. Four separate mathematical models were implemented with drying data. The drying characteristic curves were estimated against four mathematical models and the Weibull distribution was found best descriptive model for all the drying experiments of thin layer grape fruit samples except for 540 W-100 °C.

Mazandarani *et al.* (2017) reported the mathematical modelling of pomegranate arils. They used microwave power levels (180 to 720 W), oven drying at 45 to 75 °C and solar drying. Increasing the temperature of oven drier and the microwave drier power lead to an increase in the drying rate.

Johare *et al.* (2017) evaluated the microwave drying characteristics of *Ficus deltoidea* leaves by using thin layer drying models. Thin layer drying of *Ficus deltoidea* leaves by microwave dryer was conducted at five different microwave power densities 40 to 15 W/g. The results showed that the drying of the leaves occurred only in the falling rate drying period. The experimental moisture ratios versus drying time were fitted to five thin-layer mathematical models. Thus Midilli *et al.* model was used to describe the

drying process of *Ficusdeltoidea* leaves within the five microwave power density range.

Amarasingheet *al.* (2018) studied the kinetics and mathematical modelling of microwave drying of Sri Lankan black pepper (*Piper nigrum*). Drying experiments were carried out at three different microwave power levels, 180, 360 and 540 W and the moisture content was measured at different time intervals. Statistical indicators showed Midilliet. *al.*, Weibull and Kaletaet. *al.* models give better fit to the experimental values. The Activation energy of black pepper calculated based on the Arrhenius equation is 86.7 W/g. The absence of the constant drying rate period in drying curves show Black pepper drying is absolutely during the dropping rate time where the drying rate is regulated by the diffusion of moisture. Drying rate constants were 0.03, 0.09 and 0.16 per min and the effective moisture diffusivity values were 2.43×10^{-10} , 4.87×10^{-10} and 1.42×10^{-9} m²/s for power levels of 180, 360 and 540 W, respectively.

Hardy and Jideani (2017) reported the comparison of various drying methods viz. sun/solar, microwave, freeze and foam mat drying on food drying was presented in Table 2.2.

Table 2.2 Comparison of food drying methods

Drying Methods	Principle	Food Materials	Simple	Higher product quality	Advantages			Affordable
					Rapid drying	Volumetric heating	Storage reliability	
Solar/sun Drying	Exposure to direct Sunlight	Fruit, vegetables, fish, meat	✓					✓
Microwave Drying	Electromagnetic energy	Foods, vegetables, pasta, cookies, value-added products			✓	✓	✓	
Freeze drying	Removal of frozen water by Sublimation	Fruits, vegetables, coffee		✓		✓	✓	
Foam drying	Liquid atomization into the drying chamber	Liquid foods, suspensions, Dairy products, Coffee		✓	✓	✓	✓	
Foam-mat drying	Vigorous agitation and incorporation of air	Fruits, vegetables, beverages, milk	✓	✓	✓	✓	✓	✓

(Hardy and Jideani, 2017)

CHAPTER III

MATERIAL AND METHODS

The experiments to achieve the required goals were carried out in the Department of Agricultural Process Engineering, Dr PanjabraoDeshmukhKrishiVidyapeeth, Akola. This chapter deals with the study of physico-chemical properties of Nagpur mandarin fruit and segment. The effect of addition of different levels of foaming agent, foam stabilizer, sugar and whipping time on properties of foam were studied. The equipment and process used for determination of various properties of foaming of Nagpur mandarin juice were determined at different levels of foaming agent concentration, stabilizer concentration and whipping time. The drying kinetics and mass diffusivity for foamed juice by using artificial and natural foaming agents of Nagpur mandarin juice was studied. The quality parameters of optimized powder were carried out. The sensory evaluation and shelf life study of the final product are discussed in this chapter. Details of the materials used and test methodology employed are discussed as under:

3.1 Determination of Physical Properties

For characterizing Nagpur mandarin, physical properties viz. dimensions, size, sphericity, fruit volume, fruit weight, moisture content, TSS, bulk density, true density and pH of Nagpur mandarin fruit, segment and juice were determined. The fractions of fruits presented in Plate 3.1. For determination of physical properties, 30 Nagpur mandarin fruits were selected randomly.

3.1.1 Size, sphericity and projected area

The size of Nagpur mandarin fruit was measured with a verniercaliper (Mitutoyo, Japan) having a minimum least count 0.2 mm, for its maximum tri-axial dimensions length (L), width (B) and thickness (T). The equations (3.1) to (3.3) were used to calculate the geometrical mean diameter (D_g), surface area (A_s) and sphericity (Mohsenin, 1986).

$$S \text{ or } D_g = (L \times B \times T)^{1/3} \quad (3.1)$$

$$A_s = \pi (D_g)^2 \quad (3.2)$$

$$\text{Sphericity} = \frac{\text{Geometric mean diameter,mm}}{\text{Length,mm}} \quad (3.3)$$

The projected area was computed using graphical method. The average area projected (known as the criterion area A_c , cm^2) was determined from Eqs (3.4)

$$\text{Average projected area } (A_c) = (PA_1 + PA_2 + PA_3)/3 \quad (3.4)$$



Plate 3.1 Fractions of Nagpur mandarin fruit

3.1.2 Volume

The actual volume of the Nagpur mandarin fruit was determined by displacement method describe under platform scale method. The volume of fruits was also measured with the structure of the body in mind compared to its geometric shape, with the values of length, width and thickness. It has been calculated using (3.5) and (3.6) to measure the geometry as oblate spheroids and elliptical (Mohsenin, 1986).

$$\text{Volume of oblate spheroid, } (V_{osp}) = \frac{2}{3} \pi \left(\frac{L}{2} \right) \left(\frac{B}{2} \right)^2 \quad (3.5)$$

$$\text{Volume of ellipsoid, } (V_{ellip}) = \frac{2}{3} \pi \left(\frac{L}{2} \right) \left(\frac{B}{2} \right) \left(\frac{T}{2} \right) \quad (3.6)$$

Where, V is volume of Nagpur mandarin fruit (cc), L is length of fruit (mm), B is width of fruit (mm) and T is thickness of fruit (mm).

3.1.3 Fruit Weight

The individual fruits was weighed with an electronic precision balance have an accuracy of 0.005 g for weight determination and their average was recorded in grams.

3.1.4 Mass and surface area modeling

The following models were taken into consideration to estimate the volume, mass, area and surface size of Nagpur mandarin fruit:

1. Single or multiple variable regressions of Nagpur mandarin fruit mass, based on dimensional characteristics: length (L), width (W), thickness (T) and geometric mean diameter (Dg).
2. Single regression of Nagpur mandarin fruit mass, based on the surface area and projected area.
3. Single regression of Nagpur mandarin fruit mass, projected area and surface area, based on the volumes of the assumed shape.
4. Single regression of Nagpur mandarin fruit projected area and surface area based on mass (Khanaliet *al.*, 2007 and Soltaniet *al.*, 2011)

From the above, all four classifications were measured for mass modeling whereas the third classification was neglected in volume modeling. In other words, volume modeling based on mass was not done because the results of mass modeling based on volume and volume modeling based on mass are the same. In the case of the first classification, mass/volume modeling was taken with respect to major, intermediate and minor diameters. The model obtained with three variables for predicting fruit mass/volume was:

$$M = k_1a + k_2b + k_3c + k_4 \quad (3.7)$$

$$V = k_1a + k_2b + k_3c + k_4 \quad (3.8)$$

In this classification, the mass/volume was estimated as a function of one, two and three dimensions.

The mass / volume of Nagpur mandarin fruit was estimated in the second classification model based on mutually perpendicular areas as follows (Khanali *et al.*, 2007):

$$M = k_1 PA_p + k_2 \quad (3.9)$$

$$V = k_1 PA_1 + k_2 PA_2 + k_3 PA_3 + k_4 \quad (3.10)$$

where, k_1 , k_2 , k_3 and k_4 were constant of model.

In this classification, the mass/volume was estimated as a function of one, two or three projected area(s).

For the third classification, three volume values were measured or calculated to produce models that can predict the mass of the tangerine by volume. At first, actual volume V_m as stated earlier was measured, then the tangerine shape was assumed as a regular geometric shape viz. oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes,

In this classification (applied only for mass modeling), the mass was estimated as either a function of volume of supposed shape or the measured volume as given in Eqn (3.11 to 3.13) (Khanali *et al.*, 2007 and Soltani *et al.*, 2011).

$$M = k_1 V_{osp} + k_2 \quad (3.11)$$

$$M = k_1 V_{ellip} + k_2 \quad (3.12)$$

$$M = k_1 V_m + k_2 \quad (3.13)$$

In the fourth group, the projected and surface areas were determined according to mass of the Nagpur mandarin as per Eqn (3.14 and 3.15) (Khanali *et al.*, 2007 and Soltani *et al.*, 2011).

$$SP = k_1 M + k_2 \quad (3.14)$$

$$V = k_1 M + k_2 \quad (3.15)$$

In order to analyze the data and regression models between the attributes studied, statistical software has been used. Based on a higher determination coefficient (R^2 , $p < 0.05$) and a lower correlation defect

(RSE), the better suited models have been chosen. The lower regression standard error was determined using equation (3.16).

$$RSE = \frac{(M_a - M_p)^2}{N} \quad (3.16)$$

Where, M_a is actual mass of fruit (g), M_p is predicted mass of fruit (g) and N is number of sample

The lower regression standard error (RSE) value calculated using difference between predicted and actual value. The detailed calculation is as follows:

3.1.5 Pulp, peel and pomace weight

After peeling, the weight of pulp, peel without pomace and pomace weight were determination using electronic precise balance with accuracy 0.005 g.

3.1.6 Peel thickness

A verniercaliper (Mitutoyo, Japan), with minimum least count of 0.2 mm was used to measure peel thickness.

3.1.7 Number of seeds and weight of seeds per fruit

Number of seeds extracted from each fruit was calculated. The mean seed number of seed and weight of seeds were recorded.

3.1.8 Number of segments per fruit

Number of segments per fruit counted and recorded.

3.1.9 Weight of segments per fruit

The segments' weight was measured by using a 0.005 g accuracy electronic precision balance.

3.1.10 Fruit segment size

Using a verniercaliper (Mitutoyo, Japan) of least count 0.2 mm, the overall triaxial measurements length (L), width (B) and thickness (T) were determined.

3.1.11 Fruit juice content

The fruit juice was extracted by using juicer and the juice per cent was measured. The percent juice content calculated by juice weight and total weight of fruit using equation (3.17).

$$\text{Fruit juice content, \%} = \frac{\text{Weight of juice, g}}{\text{Fruit weight, g}} \times 100 \quad (3.17)$$

3.1.12 Fruit juice to pomace ratio

The juice to pomace ratio was calculated as juice weight to pomace weight using equation (3.18).

$$\text{Juice to pomace ratio} = \frac{\text{Weight of juice, g}}{\text{Weight of pomace, g}} \quad (3.18)$$

3.1.13 Specific gravity of fruit and juice

The specific gravity of fruit is the ratio of the mass of a fruit to volume of fruit. The specific gravity of juice is the ratio of the weight of juice to volume of juice. The specific gravity was determined using Eqn(3.19) and (3.20).

$$\text{Specific gavity, g/cc} = \frac{W}{V} \quad (3.19)$$

$$\text{Specific gavity of juice, g/cc} = \frac{W}{V} \quad (3.20)$$

3.1.14 Viscosity of juice

The viscosity of mandarin juice was determined by Brookfield viscometer RVDV II + pro (Brookfield engineering lab, USA) and spindle no. 62 with speed 50 rpm (plate 3.2). The readings were taken thrice until the constant reading was observed.



Plate 3.2 Viscometer

3.1.14 pH and Total soluble solids

The digital pH meter was used for measurement of pH of juice. Total soluble solids of ripen mandarin fruit juice was measured in Brix by using digital refractometer of ranges from 0 to 90 °B (Ranganna, 1986).

3.2 Preparation of Samples

The fresh Nagpur mandarin bought from the local Akola market. Fully ripe Nagpur mandarin fruit was taken then peeled and weighed on the weighing balance (Plate 3.3).



Plate 3.3 Nagpur mandarin fruit



Plate 3.4 Juicer

Peeled fruit was used for juice extraction. The juice was squeezed with a juicer (Bajaj JEX 16 800-Watt Juicer) as shown at Plate 3.4. Fresh juice was blanched at 95 °C for 1 min (Shaari *et al.*, 2017) to inactivate the enzyme and cooled quickly. The juice was used for further processing. The foaming agent's viz. artificial and natural agents were added. In artificial foaming agent the soy protein isolate (90%) and GMS powder, foam stabilizer (CMC powder), preservative (natural sugar) was added in

different concentration then it was whipped at various time period decided on preliminary trials to form foam of Nagpur mandarin juice. Similarly in natural foaming agent the soy protein isolate (90%), guar gum and antibittering/preservative (sugar) was added in different concentration then it was whipped at various time period decided on the basis of preliminary trials to form foam of Nagpur mandarin juice.

3.3 Ingredients

Full mature Nagpur mandarin fruit, soy protein isolate 90%, glycerol mono stearate (GMS), carboxyl methyl cellulose (CMC), guar gum and sugar were used.

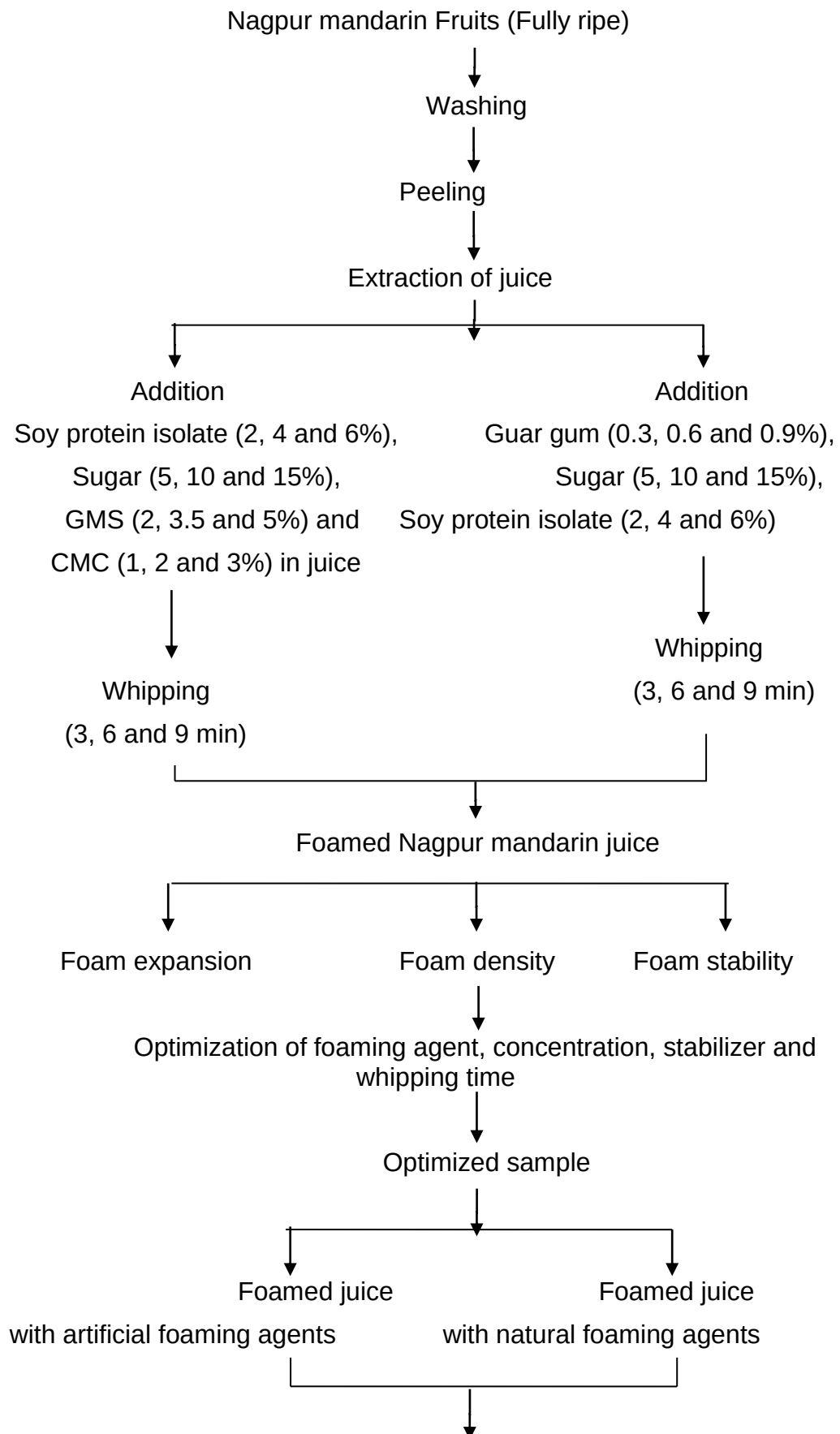
3.4 Equipment and Apparatus

Food processor, juicer, electronic weighing balance, blender, digital vernier calliper, hot air oven, microwave oven, vacuum oven, tray dryer, chroma meter, water activity meter and spectrophotometer were used for the study.

3.5 Process for Preparation of Nagpur Mandarin Juice Powder

Nagpur mandarin juice was taken and weighed. The artificial and natural foaming agents were added into the Nagpur mandarin juice in different concentration such as SPI (3, 6 and 9%), GMS (2, 3.5 and 5%), CMC (1, 2 and 3%) and sugar content (5, 10 and 15%) for different whipping time (3, 6 and 9 min) in artificial foaming. In natural foaming the different concentration of SPI (3, 6 and 9%), guar gum (0.3 0.6 and 0.9%) and sugar content (5, 10 and 15%) with different whipping time (3, 6 and 9 min) were used. Optimization of Nagpur mandarin juice at different levels of artificial and natural foaming agent, sugar and whipping time were carried out. After optimization the samples were dried in microwave drying at various microwave power (180, 360, 540, 720 and 900 W) at different drying bed thickness (2, 4 and 6 mm) up to desired moisture content. The optimization of microwave power and drying bed thickness were conducted using different responses. The grinding of the dried juice was done by food processor to prepare the powder. The powder was packed in polyethylene bag and kept at room temperature for further analysis and

storage study. The process chart for production of Nagpur mandarin fruit powder was presented in Fig.3.1.



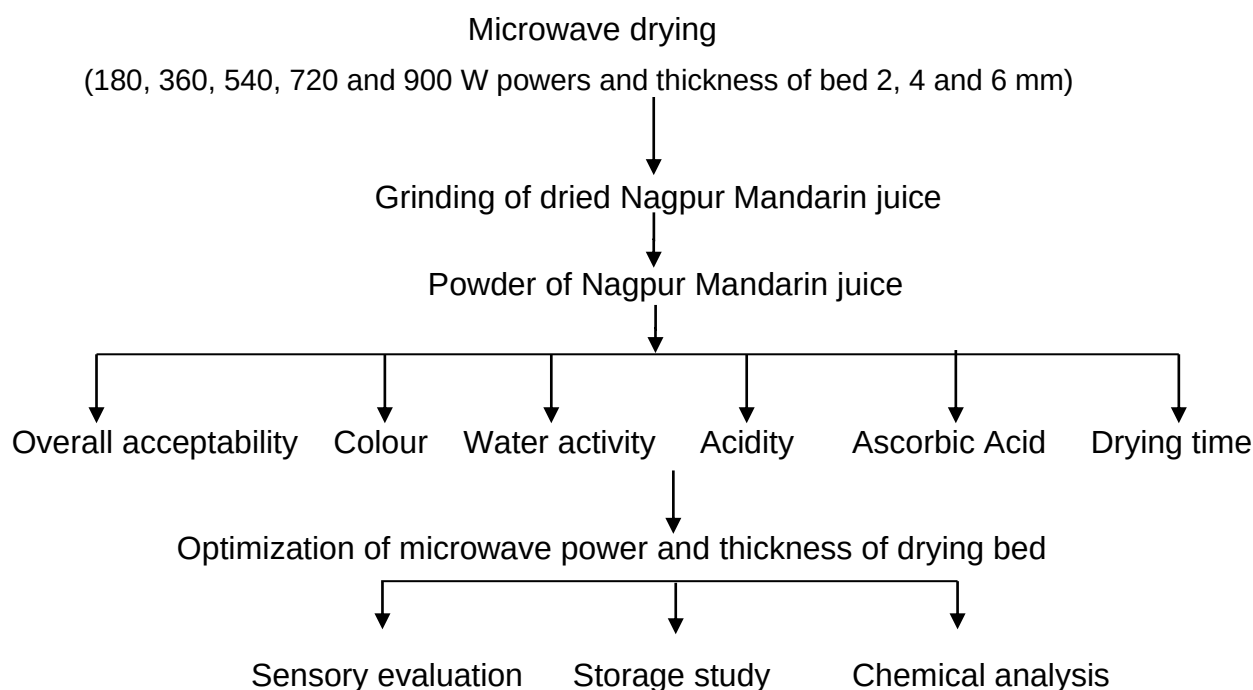


Fig. 3.1 Flow chart for production of Nagpur mandarin juice powder

3.6 Variables under study

Selected parameters were listed for this study as independent and dependent variables. Their proportions were determined on the basis of preliminary trials.

Experiment I: With artificial foaming agent and foam stabilizer

Independent parameters

1. Soy protein Isolate : 2, 4 and 6%
2. Sugar Content : 5, 10 and 15%
3. GMS powder : 2, 3.5 and 5%
4. CMC power : 1, 2 and 3%
5. Whipping time : 3, 6 and 9 min

Experiment II :With natural foaming agent and foam stabilizer

Independent parameters

1. Guar gum powder : 0.3, 0.6 and 0.9%
2. Sugar content : 5, 10 and 15%
3. Soy protein Isolate : 2, 4 and 6%
4. Whipping time : 3, 6 and 9 min

Dependent parameters for experiment I and II

1. Foam expansion ratio, %
2. Density of foamed juice, g/cm³
3. Foam stability, %

3.7 Foaming Treatment

The foaming treatment has been provided by adding different amounts of foaming agents, foam stabilizer at room temperature to prepared Nagpur mandarin juice and whipping it for different time period. The level of foaming agents viz. SPI (2 to 6%), sugar content (5 to 15%), GMS (2 to 5%), CMC (1 to 3%) and whipping time (3 to 9 min) was carried out for study and optimization of concentration was done by Central Composite Design (CCD) under response surface methodology using Design expert software version 11.0.3.0. Similar samples were prepared for the second trial and with natural foaming agents guar gum (0.3 to 0.6%), sugar content (5 to 15%) and soy protein isolate (2 to 6%) and whipping time (3 to 9 min) were also conducted by Central Composite Design (CCD) under response surface methodology using design expert software version 11.0.3.0.

3.8 Foaming Properties

The foam expansion, foam stability and foam density were determined as described by Rajkumaret *al.* (2007b). The foaming parameters were optimized in order to maximize foam expansion (stretching) and longer foam cycles (stability) with minimum foam density. The optimum condition of foaming was considered for production of Nagpur mandarin powder (Bag *et al.*, 2011, Sangamithraet *al.*, 2015; Narender and Pal 2011; Shaari, 2017).

3.8.1 Foaming expansion

During whipping the amount of air incorporated into the juice during whipping which indicated the foam expansion and was calculated by considering the initial volume to the final volume of juice after foaming (Durian 1995). The foam expansion was determined using Eqn(3.21).

$$\text{Foam expansion (\%)} = \frac{V_1 - V_0}{V_1} \times 100 \quad (3.21)$$

3.8.2 Foam density

The density of the foamed Nagpur mandarin juice was measured in g/cm³ (Eqn. 3.22) (Faladeet *et al.*, 2003; Bag *et al.*, 2011). The foamed juice was poured into measuring cylinder of 200 ml without trapping the air voids and also without breaking down the foam structure and density was calculated (Karim and Wai, 1999).

$$\text{Foam density} = \frac{\rho V_0}{V_1} \times 100 \quad (3.22)$$

3.9.3 Foam stability

Many factors such as drainage, film rupture and disproportionate of bubbles were used to determine stability of foams. Generally, measuring the drainage of foam is one of the best methods to determine foam stability. In order to the assessment of foam stability, the drainage test was performed based on the method described by Narender and Pal (2011) and Bag *et al.* (2011). Foam stability of Nagpur mandarin juice was determined by taking 100 ml of the foamed juice in a transparent graduated cylinder and kept at room temperature for 2 hours (Chang and Chen 2000, Marinova, *et al.*, 2009 and Norhazirahet *et al.*, 2017). The volume of liquid, which was separated from foam as a result of foam drainage and reduction in foam volume, were measured. The foam stability was calculated using following equation(3.23).

$$\text{Foam stability, \%} = \frac{V_1}{V_0} \quad (3.23)$$

Where V_0 is initial volume of Nagpur mandarin juice (cm³) and V_1 is final volume of Nagpur mandarin juice (cm³).

3.9 Optimization of Process Parameters

Optimisation of process parameters for Nagpur mandarin juice viz. maximum expansion and stability of foam with minimum foam density were carried out using numerical optimization technique with the help of (CCD) in Design Expert software version 11.0.3.0.

A compilation of mathematical and statistical interpretation and simulation of problems, which impact the different responses by independent variables, is the RSM approach. The RSM is a powerful optimization method where the independent variables have a joint effect on responses Mudaharet *al.* (1989). Several studies have applied to improve food processing by various investigators (Azizpouret *al.*, 2014; Salahi *et al.*, 2014; Norhazirahet *al.*, 2017; Rai *et al.*, 2004; Isa and Olalusi 2019; Varhan *et al.*, 2019).

3.9.1 Optimization of artificial foaming agent, foam stabilizer and sugar content

The CCD was selected for the optimization of process variables i.e. foaming agents, foam stabilizer, sugar and whipping time using response surface methodology.

Table 3.1 Independent process variables of artificial foaming agent and their levels for foamed Nagpur mandarin juice

Sr. No.	Independent variable	Symbol	Levels		
			-1	0	+1
1	Soy protein isolate, %	A	2	4	6
2	Sugar content, %	B	5	10	15
3	GMS powder, %	C	2	3.5	5
4	CMC power, %	D	1	2	3
5	Whipping time, min	E	3	6	9

The optimized condition was taken for five variables and three levels including 28 trails with 5 centre points formed by considering average of three replications. This design was selected as it fulfilled the most of the requirements needed for optimization of the drying condition. The CCD was carried out to establish the spectrum for the foamed Nagpur mandarin juice of independent variables and their stages (Table 3.1).

3.9.2. Analysis of design

Table 3.2 Experimental structure with coded levels of process variables for foamed Nagpur mandarin juice with artificial foaming agent using central composite design

Run	SPI , %		SC, %		GMS,%		CMC, %		WT, Min	
	C	UC	C	UC	C	UC	C	UC	C	UC
1	+1	6.00	+1	15.00	-1	2.00	+1	3.00	-1	3.00
2	+1	6.00	-1	5.00	+1	5.00	+1	3.00	-1	3.00
3	-1	2.00	+1	15.00	+1	5.00	-1	1.00	+1	9.00
4	+1	6.00	+1	15.00	+1	5.00	-1	1.00	-1	3.00
5	+1	6.00	+1	15.00	-1	2.00	-1	1.00	+1	9.00
6	+1	6.00	-1	5.00	-1	2.00	+1	3.00	+1	9.00
7	-1	2.00	-1	5.00	+1	5.00	+1	3.00	+1	9.00
8	-1	2.00	+1	15.00	-1	2.00	+1	3.00	+1	9.00
9	+1	6.00	-1	5.00	+1	5.00	-1	1.00	+1	9.00
10	-1	2.00	+1	15.00	+1	5.00	+1	3.00	-1	3.00
11	-1	2.00	-1	5.00	-1	2.00	-1	1.00	-1	3.00
12	- α	0.36	0	10.00	0	3.50	0	2.00	0	6.00
13	+ α	7.64	0	10.00	0	3.50	0	2.00	0	6.00
14	0	4.00	- α	0.89	0	3.50	0	2.00	0	6.00
15	0	4.00	+ α	19.11	0	3.50	0	2.00	0	6.00
16	0	4.00	0	10.00	- α	0.77	0	2.00	0	6.00
17	0	4.00	0	10.00	+ α	6.23	0	2.00	0	6.00
18	0	4.00	0	10.00	0	3.50	- α	0.18	0	6.00
19	0	4.00	0	10.00	0	3.50	+ α	3.82	0	6.00
20	0	4.00	0	10.00	0	3.50	0	2.00	- α	0.54
21	0	4.00	0	10.00	0	3.50	0	2.00	+ α	11.46
22	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
23	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
24	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
25	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
26	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
27	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00
28	0	4.00	0	10.00	0	3.50	0	2.00	0	6.00

SPI is soy protein isolate, GMS is Glycerol mono Stearate, CMC is Carboxyl methyl cellulose, SC is sugar content, WT is whipping time, C is coded and UC is uncoded.

The study was carried out independently using the statistical software (Design expert version 11.0.3.0 2019) for each response variable with the aid of Response Surface Methodology (RSM). The

coefficients of regression have been calculated using a least square method. A measurement of the variance indicating non adaptation and correlation coefficient checked the appropriateness of the selected model. 28 runs as seen in Table 3.2 were obtained for each response variables

3.10 Optimization of Process Parameters in Natural Foaming Agent

The optimization of process parameters for maximum foam expansion and foam stability with minimum foam density of Nagpur mandarin juice were carried out using numerical optimization technique.

3.10.1 Experimental design for optimization of natural foaming agent and its concentration for foaming of Nagpur Mandarin juice

The CCD was selected for the optimization of process variables i.e. foaming agents, sugar content and whipping time using Response Surface Methodology.

Table 3.3 Independent process variables of natural foaming agent and their levels for foamed Nagpur mandarin juice

Sr. No.	Independent variable	Symbol	Levels		
			-1	0	+1
1	Guar gum, %	A	0.3	0.6	0.9
2	Sugar content, %	B	5	10	15
3	Soy protein isolate, %	C	2	4	6
4	Whipping time, min	D	3	6	9

Four factors and 3 levels of foaming parameters, including 28 trails were used. The experiment conducted thrice. This design was selected as it fulfilled the most of the requirements needed for optimization of the drying condition. The CCD for the foamed Nagpur mandarin juice has been conducted to describe a number of independent variables and their three levels (Table 3.3).

3.10.2. Analysis of design

The analysis was done independently for each response variable with the help of response surface methodology (RSM) by using a statistical package, Design Expert Version 11.0.3.0 2018.

Table 3.4 Experimental structure with coded levels of process variables for foamed Nagpur mandarin juice with natural foaming agent using central composite design

Experiment No./ run	Guar gum, %		Soy protein Isolate, %		Sugar content, %		Whipping time, min	
	C	UC	C	UC	C	UC	C	UC
1	-1	0.30	-1	2.00	-1	5.00	-1	3.00
2	+1	0.90	-1	2.00	-1	5.00	-1	3.00
3	-1	0.30	+1	6.00	-1	5.00	-1	3.00
4	+1	0.90	+1	6.00	-1	5.00	-1	3.00
5	-1	0.30	-1	2.00	+1	15.00	-1	3.00
6	+1	0.90	-1	2.00	+1	15.00	-1	3.00
7	-1	0.30	+1	6.00	+1	15.00	-1	3.00
8	+1	0.90	+1	6.00	+1	15.00	-1	3.00
9	-1	0.30	-1	2.00	-1	5.00	+1	9.00
10	+1	0.90	-1	2.00	-1	5.00	+1	9.00
11	-1	0.30	-1	6.00	-1	5.00	+1	9.00
12	+1	0.90	+1	6.00	-1	5.00	+1	9.00
13	-1	0.30	-1	2.00	+1	15.00	+1	9.00
14	+1	0.90	-1	2.00	+1	15.00	+1	9.00
15	-1	0.30	+1	6.00	+1	15.00	+1	9.00
16	+1	0.90	+1	6.00	+1	15.00	+1	9.00
17	- α	0.18	0	4.00	0	10.00	0	6.00
18	+ α	1.02	0	4.00	0	10.00	0	6.00
19	0	0.60	- α	1.17	0	10.00	0	6.00
20	0	0.60	+ α	6.83	0	10.00	0	6.00
21	0	0.60	0	4.00	- α	2.93	0	6.00
22	0	0.60	0	4.00	+ α	17.07	0	6.00
23	0	0.60	0	4.00	0	10.00	- α	1.16
24	0	0.60	0	4.00	0	10.00	+ α	10.27
25	0	0.60	0	4.00	0	10.00	0	6.00
26	0	0.60	0	4.00	0	10.00	0	6.00
27	0	0.60	0	4.00	0	10.00	0	6.00
28	0	0.60	0	4.00	0	10.00	0	6.00

The regression coefficients were estimated through least square method. The adequacy of the fitted model was tested through the analysis of variance showing lack of fit and coefficient of correlation. For each response variables, observations (28) were obtained as shown in Table 3.4.

The independent variables, the coded variables, uncoded variables and their coded and uncoded levels are shown in Table 3.2 and 3.4. It is assumed that the mathematical function f_k ($k = 1, 2, 3, \dots, n$), exists for each response variable, Y_k in terms of the processing factors, r_i ($i = 1, 2, 3, \dots, m$), such as

$$Y_k = f_k(r_1, r_2, r_3, \dots, r_m) \quad (3.24)$$

Either unclear or highly complex is the exact mathematical description of the function (f). Nevertheless, the next phase was believed to be connected to the second order polynomial Equation, Y_k and the factors, r_i as

$$Y_k = \beta_{k0} + \sum_{i=1}^{i=3} \beta_{ki} x_i + \sum_{i=1}^{i=3} \beta_{kii} x_i^2 + \sum_{i=1}^{i=2} \sum_{j=i+1}^{j=3} \beta_{kij} x_i x_j \quad (3.25)$$

anywhere, Y_k is respond (Foam expansion, foam density and foam stability), β_{k0} , β_{ki} , β_{kii} and β_{kij} are consistent parameters and x_i and x_j are independent variables linearly correlated with soy protein isolate, GMS, foam stabilizer i.e. CMC, sugar content and time of whipping in artificial foaming agent study and soy protein isolate, guar gum, sugar content and time of whipping in natural foaming agent. The rates of the independent variables shift in action between applications. The general designs are thus described in terms of uniform coded variables (x_i), which are connected to r_i by the Eqn (3.25) in each particular application:

$$x_i = \frac{(r_i - \bar{r}_i)}{d_i} \quad (3.26)$$

Where, r_i is actual value in original units, $\bar{r}_i$ is mean of high and low levels of r_i , and d_i is spacing between the low and high levels of r_i .

In the study of artificial foaming agents used for foaming of Nagpur mandarin juice, $n = 3$ and $m = 5$ and hence Eqn. (3.24) is written as

$$Y_k = f_k(A, B, C, D, E) \quad (3.27)$$

Where, A is soy protein isolate 90% (%), B is sugar content (%), C is GMS (%), D is CMC (%), E is whipping time (min) and Y_k is foam expansion or foam stability or foam density using artificial foaming agents in foam mat drying. Hence, Eqn. (3.25) takes the shape below

$$Y_k = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{55} x_5^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \dots \quad (3.28)$$

In the study of natural foaming agents used for foaming of Nagpur mandarin juice, $n = 3$ and $m = 4$ and hence Eqn. (3.24) is written as

$$Y_k = f_k(A, B, C, D) \quad (3.29)$$

Where, A is soy protein isolate 90% (%), B is sugar content (%), C is guar gum, D is whipping time (min) and Y_k is foam expansion or foam stability or foam density in foam mat drying. Hence, Eqn. (3.24) takes the shape below

$$Y_k = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \dots \quad (3.30)$$

The response surface methodology (RSM) used in Design-Expert (version 11.0.4.1, Stat ease Inc, Minneapolis, United States) was applied to the experimental data.

3.11 Optimization of Foaming Agent in Nagpur Mandarin Juice

The response surface methodology was used for the optimized the process variables for the foamed Nagpur mandarin juice. For optimisation, only the responses that had proved to be significant over the quadratic model were chosen for optimisation. The 3D plots and contour plots were drawn according to the model fitted and fixed variable.

3.12 Verification of Optimum Responses

The optimum responses were verified by conducting the experiment under optimum conditions. The responses such as foam expansion, foam density and foam stability at optimum conditions were compared to the values predicted.

3.13 Drying of Nagpur Mandarin Juice in Microwave Oven

3.13.1 Independent parameters

Foaming agents

1. Artificial foaming agent (AFA)
2. Natural foaming agent (NFA)

Drying method : Microwave drying method

Power (W) : 180, 360, 540, 720 and 900

Thickness of bed (mm) : 2, 4 and 6

3.14 Moisture Content

The moisture content of Nagpur mandarin juice with and without adding foaming agents were determined by using hot air oven at 103 ± 2 °C for 6 h as shown in Plate 3.5.



Plate 3.5 Hot air oven

The weight of sample was measured then put the sample in oven and moisture level was determined (Jittanit *et al.*, 2010). The moisture content was expressed as kg moisture/ kg dry mater (dry basis, db). Mean

of three replications was reported throughout the course of study. The moisture content on dry and wet basis was determined using Eqn (3.31) and (3.32).

The MC was determined by using following expression

$$MC (\% \text{ wb}) = \frac{W_1 - W_2}{W_1 - W_3} \times 100 \quad (3.31)$$

Where, W_1 is initial weight of the test sample (g) + weight of sample box (g), W_2 is final weight of the test sample (g) + weight of sample box (g) and W_3 is weight of sample box (g)

Using the following equation, the moisture quality produced in percent wb was converted into percent (db):

$$MC (\% \text{ db}) = \frac{MC (\% \text{ wb})}{100 - MC (\% \text{ wb})} \times 100 \quad (3.32)$$

3.15 Microwave Drying

Microwave oven is one of the most widely used household appliances. The drying of foamed developed by using artificial and natural foaming agent of Nagpur mandarin juice. The microwave oven (LG model MC=9280XC) has been used to dry foamed Nagpur mandarin juice.



Plate 3.6 Microwave oven

The experiments were conducted in microwave oven as shown in Plate 3.6, with inside chamber (450 × 350 × 300 mm). The foam was uniformly spread over a plate lined with teflon and a drying process was performed at 180, 360, 540, 720 and 900 W with bed thickness 2, 4 and 6

mm. All tests have been repeated three times and the average readings have been recorded. The drying data was recorded until the sample attained constant weight.

3.15.1 Calibration of microwave oven

For determination of microwave power output, microwave tool book was used. The measurement was made with water load in glass beaker. The water temperature was initially below ambient temperature (18-20 °C) and was raised to approximately above ambient temperature by heating in the microwave oven.

Procedure:

1. Using the stopwatch, the accuracy of the microwave oven timer was checked. Timer should kept accurate within 2%. If not, determine the necessary settings to ensure accuracy.
2. Fill 2 lit beaker with exactly 1000 ml of distilled water at 18 to 20 °C. Initial temperature of water was recored as T_1 .
3. Remove the thermometer and place the beaker in the centre of the microwave oven. (If the oven has been used recently, allow it to cool until it is at room temperature).
4. Microwave oven kept at full power for 2 min 3 s. The additional 3 s is to allow for the magnetron start up delay.
5. Immediately after the power cycle completion, immerse the thermometer in the water and vigorously stir. Measure the temperature of the water. Record this temperature as T_2 .
6. Repeat the measurements to obtain triplicate measurements of the temperature rise.
7. Calculate the output, O , of the microwave oven in watts using the following formula:

$$O = 34.9 (T_2 - T_1) \quad (3.33)$$

Where, T_1 is Initial temperature of the water (°C) and T_2 is final temperature of the water (°C).

8. Average the three output values and use this mean as the calibrated output wattage of the microwave oven. Once calibrated (Fig 3.2), this oven was used.

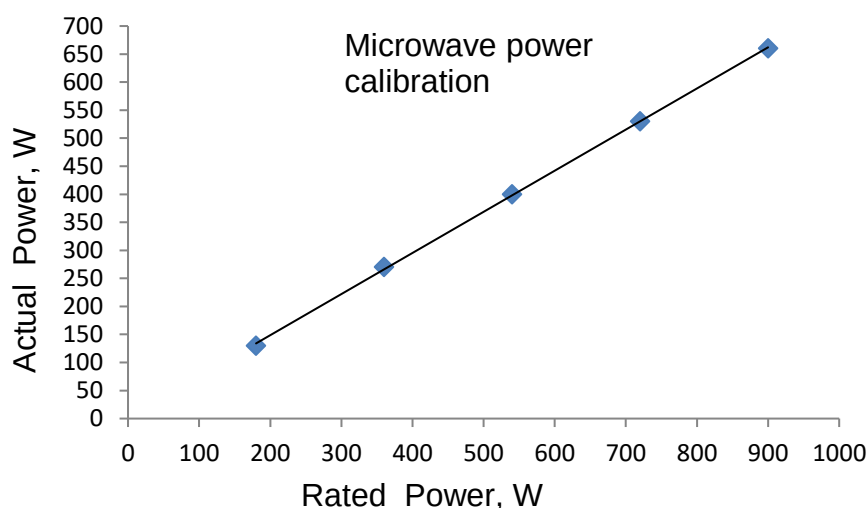


Fig 3.2 Calibration of microwave oven

3.16 Drying Characteristics of Foamed Juice in Microwave Drying

Initial moisture content was calculated by a method of oven drying, as mentioned above for Nagpur mandarin juice. The drying characteristics were determined as

3.16.1 Dry matter

The dry matter and weight of dry matter in sample was determined using Eqn (3.34) to Eqn (3.35) (Mohsenin, 1986).

$$DM (\%) = 100 - IMC (w.b) \quad (3.34)$$

$$\text{Weight of DM} = \text{Initial mass of sample} \times \frac{DM (\%)}{100} \quad (3.35)$$

Where, DM is dry matter of the sample (g) and IMC is initial moisture content (%)

3.16. 2 Equilibrium moisture content (EMC)

The EMC of a hygroscopic material surrounded at least partially by air is the moisture content at which the material neither gaining nor losing

moisture. For determination of EMC the dynamic method was used. The EMC (%) values were determined by drying of juice in the microwave dryer at all power. From 180 to 900 W until the mass loss of the sample ceased. The final moisture content values were calculated from this constant weight and it was used as an EMC value for calculation of the moisture ratio (Mohsenin, 1986).

3.16.3 Drying rate

The moisture content data recorded during experiments were analysed to determine the moisture loss from Nagpur mandarin juice in specific period of time. The sample drying rate was determined according to the following Eqn (Mohsenin, 1986).

$$R = \frac{\text{WML (kg)}}{\text{Time interval (min)} \times \text{DM (kg)}} \quad (3.36)$$

Where, R is drying rate at time θ (kg water/ kg dm min), WML is initial weight of sample – Weight of sample after time θ

3.16.4 Moisture ratio

The moisture ratio (MR) was calculated by using Eqn (3.37) (Mohsenin, 1986).

$$\text{MR} = \frac{M_t - M_e}{M_i - M_e} \quad (3.37)$$

Where M_t , is moisture content at any time of drying at t, M_i and M_e are initial and equilibrium moisture content

3.17 Moisture Diffusivity during Drying

Moist food are typically dry in the falling rate period, during which moisture migrates from inside to the material surface through dissipation. Moisture diffusivity is, thus, a food dehydration-related transport property (internal phenomenon) necessary for the measurement and modelling in the production of various foods (Saravacos, 1986). Fick's second law was introduced to determine the moisture transportation function of the dropping rate regions and is represented mathematically in classical mass equilibrium Equation (Crank, 1975) as.

$$\frac{\partial M}{\partial \theta} = \frac{\partial}{\partial R} \left(D_d \frac{\partial M}{\partial R} \right) \quad (3.38)$$

Where, M is moisture content (kg water per kg dry solids), θ is time (s), R is diffusion path /length (m), D_d is moisture dependent diffusivity (m^2/s).

The only physical means for moving moisture to surface was presumed during drying, clarified with Fick's diffusion Equation (Dadali *et al.*, 2007; Dincer and Dost, 1995; Wang *et al.*, 2007). The diffusiveness (D_d) is substantially different from humidity and it was measured by the drying data review using the slope process. This approach for determining efficient moisture diffusiveness has been utilized by many researchers (McMinn and Magee, 1997; Darvishi and Hazbavi, 2012; Wilson *et al.* 2012 and Azizpouret *et al.*, 2013).

3.17.1 Method of slope

The method of slopes is based on the solution of the Fick's law of unsteady state diffusion Eqn (3.38). The effective moisture diffusivity was measured using a slope method. It involves the comparison between slopes of experimental and theoretical diffusion curves. Straight lines of the liquid drying bed were done for both the microwave power and thickness. Linear regression modelling was used to derive diffusion coefficient values from the slope of the straight lines for different drying conditions.

Due to the minimal evidence on mechanism of moisture movement during drying, and process difficulty (Abe and Afzal, 1997), efficient moisture diffusiveness affecting structure, moisture content, temperature, microwave power and material porosity is used. Goal of successfully diffusing moisture, foamed Nagpur mandarin juice were kept for drying on taflon plate and the thickness of drying bed were assumed to be infinite slabs, being dried from both the sides with the assumptions that (i) Moisture is initially distributed evenly through the sample mass; (ii) resistance to mass transfer at the surface is negligible compared to the internal resistance of sample and (iii) mass transfer is by diffusion only.

Following initial and boundary conditions have, therefore, been fixed for a solution to Eqn. (3.38) as

$$M = M_0 \quad \text{at } \theta = 0 \text{ for all } R$$

$$M = M_s \quad \text{at } \theta > 0, \text{ for } R = (+)\ell \text{ at the surface, and}$$

$$M = M_\infty \quad \text{at } \theta > 0, \text{ for } R = (-)\ell \text{ at the surface}$$

The solution of Eqn (3.38) for constant diffusivity D in terms of infinite series, the moisture content as a function of time in a slab is given as:

$$\frac{M - M_\infty}{M_0 - M_\infty} = \frac{8}{\pi^2} \left(e^{(-)\frac{D\pi^2\theta}{4L^2}} + \frac{1}{9} e^{(-9)\frac{D\pi^2\theta}{4L^2}} + \frac{1}{25} e^{(-25)\frac{D\pi^2\theta}{4L^2}} + \dots \right) \quad (3.39)$$

When the time becomes large, limiting form of the Eqn (3.39) is as.

$$MR = \frac{M - M_\infty}{M_0 - M_\infty} = \frac{8}{\pi^2} \left(e^{(-)\frac{D\pi^2\theta}{4L^2}} \right) \quad (3.40)$$

$$= \frac{8}{\pi^2} \left(e^{(-)\frac{\pi^2}{4} F_o} \right) \quad (3.41)$$

Where, MR is moisture ratio, M_0 is initial moisture content (kg water / kg dry matter), M is moisture content at time θ (kg water per kg dry matter), M_∞ is equilibrium moisture content (kg water per kg dry matter), D is moisture diffusivity (m^2/s), L is thickness of the sample for drying (m), F_o is Fourier number ($D\theta/L^2$) and ℓ is half the thickness of the sample (m).

Eqn (3.41) is evaluated numerically for Fourier number by rearranging and taking logarithm as

$$F_o = (-)\frac{4}{\pi^2} \ln \left(\frac{MR\pi^2}{8} \right) \quad (3.42)$$

$$F_o = (-) \frac{4}{\pi^2} \left(\ln MR + \ln \frac{\pi^2}{8} \right) \quad (3.43)$$

$$F_o = - 0.4052847 \ln MR - 0.0851171 \quad (3.44)$$

The Fourier number from Eqn (3.44) is used in evaluation of “effective moisture diffusivity”, (D_{eff}). This established diffusion parameter (D_{eff}) is interpreted as an overall mass transfer property, wherein all possible contributory moisture transfer mechanism such as liquid diffusion, vapour diffusion, surface diffusion, capillary flow, hydrodynamic flow and the heterogeneity of food materials are recognized. The measurement of the effective diffusivity thus allowed a quantitative study of the drying characteristics in relation to controlled experimental variables.

The effective moisture diffusivity (D_{eff}) varied considerably with the moisture content (M) of Nagpur mandarin foamed juice during drying process, which resulted in nonlinear drying curves. For nonlinear drying curves the method of slope was adopted to estimate D_{eff} at various moisture contents (Perry *et al.*, 1984). The theoretical moisture ratio MR, was evaluated numerically first for a range of Fourier number. The same ratio MR was evaluated using experimental drying data. Both curves of experimental and theoretical MR were plotted against time (t) and F_o , respectively, on a semi-log graph. By comparing the slopes of two curves Eqn (3.45), which could be determined by numerical differentiation at a specific MR, moisture diffusivity D_{eff} was evaluated from the following Eqn. This method was used by many investigators to measure moisture diffusivity of foodstuffs (Karathanos *et al.*, 1990; Marinos and Maroulis, 1995; Zogzas *et al.*, 1996). Therefore, Fick’s second law of diffusion is applicable. Since moisture content (M) corresponded to the specific moisture ratio MR, D_{eff} could be found as a function of moisture content by repeatedly applying Eqn. (3.46).

$$D_{eff} = \frac{\left(\frac{dMR}{dt} \right)_{exp}}{\left(\frac{dMR}{dF_o} \right)_{the}} \times L^2 \quad (3.45)$$

$$D_{eff} = \frac{(F_o)_{th}}{\left(\frac{t}{L^2} \right)} \quad (3.46)$$

3.17.2 Moisture diffusivity

In drying, diffusivity is used to indicate the flow of moisture or moisture out of material. In falling rate period of drying, moisture is transferred mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material. The moisture diffusivity of the samples was estimated by using the simplified mathematical Fick's second diffusion model. The solution of Fick's second law in slab geometry, with the assumption that moisture migration is caused by diffusion, negligible shrinkage, constant diffusion coefficients and temperature is obtained as follows (Crank, 1975):

$$M_R = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n+1)^2} \exp \left[\frac{-(2n+1)^2 \pi^2 D_{eff} t}{4H^2} \right] \quad (3.47)$$

For long drying periods, Eqn (3.47) is further simplified to only the first term of the series as,

$$\ln \left(\frac{M - M_e}{M_0 - M_e} \right) = \ln \frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff} t}{4H^2} \right) \quad (3.48)$$

A general form of Eqn (3.48) could be written in semi-logarithmic form, as follows.

$$\ln(M_R) = A - Bt \quad (3.49)$$

where, A is constant and B is slope.

The $\ln(MR)$ track against the drying period from the Eqn (3.49) shows a straight line with a slope of B as,

$$Slope = \frac{\pi^2 D_{eff}}{4H^2} \quad (3.50)$$

The successful diffusiveness of the pitch B and Half of the H from equation is calculated by substitution meaning (3.50).

3.18 Activation Energy

The effective diffusivity was related with the drying air temperature by Arrhenius model like:

$$D_{eff} = D_0 \exp\left(\frac{-E_a m}{R_g P}\right) \quad (3.51)$$

Where, D_0 is the constant in Arrhenius equation (m^2/s), E_a is the activation energy (W/g), m is mass of sample in g , P is the microwave power (W) and R is the universal gas constant ($kJ / mol K$).

Eqn(3.51) is rearranged in the form of :

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{R_g P} \quad (3.52)$$

The activation energy was calculated by plotting a curve between $\ln(D_{eff})$ v/s $1/P$.

3.19 Modelling of Convective Drying of Nagpur Mandarin Juice

In order to select the appropriate model for the process studied, the experimental value of drying curves were fitted to nineteen thin-layer drying models as shown in Table 3.5.

Table 3.5 Mathematical model used for Nagpur mandarin juice drying

Sr. No.	Name of the model	Model /equation	References
1	Lewis/ Newtons' model	$MR = e^{-kt}$	Lewis (1921); Doymaz and Ismail (2011); Ayensu (1997)
	Henderson and Pabis	$MR = ae^{-kt}$	Henderson and Pabis(1961), Pehlivan and Togrul (2004); Akpinaret <i>al.</i> (2006)

3	Modified Henderson and Pabis	$MR = ae^{kt} + be^{k_0t} + ce^{k_1t}$	Karathanos (1999)
4	Pages' model	$MR = e^{(-kt)^2}$	Zhang and Litchfield (1991); Jangamet <i>al.</i> (2008); Lahsasnet <i>al.</i> (2004); Agrawal and Singh (1977)
5	Logarithmic	$MR = ae^{-kt} + c$	Kingslyet <i>al.</i> (2007); Arslan and Ozcan (2011); Yaldizet <i>al.</i> (2001)
6	Two- term model	$MR = ae^{-kt} + be^{-nt}$	Demirhan and Ozbek (2011); Kouchakzadeh and Shafeei (2010); Lahsasnet <i>al.</i> (2004); Soysalet <i>al.</i> (2006)
7	Two-term exponential	$MR = ae^{-kt} + (1 - a)e^{-kat}$	Alibas (2014); Doymaz (2009); Sharaf-Elden <i>et al.</i> (1980)
9	Diffusion approach	$MR = ae^{-kt} + (1 - a)e^{-kbt}$	Togrul and Pehlivan(2003); Kassem (1998)
10	Simplified Fick's diffusion	$MR = ae^{(-c(t/L^2))}$	Diamante and Munro (1991)
11	Vermaet <i>al.</i> ,	$MR = ae^{-kt} + (1 - a)e^{-gt}$	Vermaet <i>al.</i> (1985); Alibas (2014); Ganesapillaiet <i>al.</i> (2011)
12	Midilliet <i>al.</i> ,	$MR = ae^{(-kt^n)} + bt$	Midilliet <i>al.</i> (2002); Shen <i>et al.</i> (2011)
13	Wang and sing	$MR = 1 + (at) + (b(t^2))$	Ertekin and Yaldiz(2004); (Demirhan and Ozbek 2011); Evin (2012); Miranda <i>et al.</i> (2009); Wang and Singh (1978)
14	Thomose	$t = a \ln(MR) + b(\ln(MR))^2$	Alibas (2014)
15	Welbulli distribution	$MR = a - be^{(-kt^n)}$	Babaliset <i>al.</i> (2006)
16	Aghlashoet <i>al.</i>	$MR = e^{(\frac{-k_1t}{1} + k_2t)}$	Aghlashoet <i>al.</i> (2009)
17	Logistic	$MR = \frac{a_0}{(1 + a e^{(kt)})}$	Alibas (2014)
18	Jena and Das	$MR = a e^{(-kt + b t^{(\frac{1}{2})})} + c$	Jana and Das (2007)
19	Demiret <i>al.</i>	$MR = a e^{(-kt)^n} + c$	Demiret <i>al.</i> (2007)

a, b, c, k, g and n = model coefficients, t = drying time, min and MR = moisture ratio

Nonlinear regression analyzes were performed using Statistica 9.0. The model fitting was assessed by evaluating the coefficient of determination (R^2) and the residual plots were the primary criterion for

choosing the best equation to describe the drying curves. In addition to R^2 , the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE), root mean square error (RMSE), standard error of estimated (SEE) and mean deviation modulus (P) (Togrul and Pehlivan, 2002; Erketinet *al.*, 2004; Demiret *al.*, 2004; Francoet *al.*, 2015).

3.20 Adequacy of Fit of Various Empirical Models

Modeling the drying behavior of different agricultural products often requires the statistical methods of regression and correlation analysis. In particular, for the use of the statistical application (Statistica Software) for the purpose of modifying the mathematical model, linear and non-linear regression modeling is important resources in discovering the relationship between various variables. The determination coefficient (R^2) and plots of residuals were the primary criteria for selecting the best equation to define the drying curves. In addition to R^2 , the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE), root mean square error (RMSE) and mean deviation modulus (P) (Gomez and Gomez, 1983).

Chi square (χ^2) is the mean square of the deviations between the experimental and predicted moisture levels. Lower the value of the reduced χ^2 , the better is the goodness of fit (Eqn 3.53).

$$\chi^2 = \frac{\sum_{i=1}^N (M_{R,exp,i} - M_{R,pre,i})^2}{N - z} \quad (3.53)$$

The root mean square error (RMSE) and mean bias error (MBE) were computed from the following equation which provides information on the short term performance (Eqn 3.54 and Eqn 3.55).

$$E_{RMS} = \left[\frac{1}{N} \sum_{i=1}^N (M_{R,pre,i} - M_{R,exp,i})^2 \right]^{1/2} \quad (3.54)$$

$$MBE = \frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i}) \quad (3.55)$$

The regression coefficient (R^2) was primary criterion for selecting the most suitable equation to describe the microwave drying curves of juice. The correlation was used to test the linear relation between measured and estimated values, which is calculated from the Eqn(3.56).

$$R^2 = \frac{\sum_{i=1}^n (MR_i - MR_{pre,i}) \cdot \sum_{i=1}^n (MR_i - MR_{exp,i})}{\sqrt{[\sum_{i=1}^n (MR_i - MR_{pre,i})]^2 \cdot [\sum_{i=1}^n (MR_i - MR_{exp,i})]^2}} \quad (3.56)$$

Where R^2 is coefficient of correlation, $M_{Rexp,i}$ is experimental moisture ratio found in any measurement, $M_{Rpre,i}$ is predicted moisture ratio found in any measurement and N is total number of observations.

$$P(\%) = \frac{100}{N} \sum_{i=1}^N \left| \frac{\text{Experimentalvalue} - \text{Predictedvalue}}{\text{Experimentalvalue}} \right| \quad (3.57)$$

Standard error of estimated (SEE) provides information on the long term performance of the correlations by allowing a comparison of the actual deviation between predicted and measured values term by term. The ideal value of SEE is “zero”. The SEE is given as (Eqn 3.58):

$$SEE = \sqrt{\frac{\sum_{i=1}^N (M_{Rexp} - M_{Rpre})^2}{N - n_j}} \quad (3.58)$$

Where, M_{Rexp} is experimental moisture ratio found in any measurement, M_{Rpre} is predicted moisture ratio found in any measurement, N is number of observations, z is number of drying constants and n_j is number of constants.

As one with the largest deciding factor, the least mean relative percent variance, the decreased chi-square and the RMSE, the best model was chosen (Sarsavadiaet *al.*, 1999; Saciliket *al.*, 2006). While the statistical metrics typically offer a fair means to comparing simulations, they do not scientifically mean if the predictions of the experiment vary substantially from their calculated equivalents, that is, not statistically significantly (Saravadiaet *al.*, 1999).

3.21 Energy Consumption and Drying Efficiency

The heat energy ratio used for samples to heat provided by the microwave oven for the evaporation was measured as an energy usage and a microwave drying capacity (Soysal, 2004; Yongsawatdigul and Gunasekaran, 1996). The energy demand for evaporation of the unit mass of water has been measured in particular (Mousa and Farid, 2002; Soysal *et al.*, 2006). The energy consumption, dryer efficiency and specific energy consumption were calculated as given in Eqn(3.59) to (3.61).

$$\text{Energy consumption, } Q_t = P \times \frac{t}{60} \quad (3.59)$$

$$\text{Microwave drying efficiency, } \eta = \frac{m_u \lambda_w}{60 \times P \times t} \times 100 \quad (3.60)$$

$$\text{Specific energy consumption, } Q_s = \frac{60 \times 10^{-6} \times P \times t}{m_w} \quad (3.61)$$

Where, Q_t is total energy consumption in each drying (kWh), η is microwave drying efficiency (%), Q_s is specific energy consumption (MJ/g H₂O), P is microwave power (kW), t is drying time (min), m_w is mass of evaporated water (kg) and λ_w is latent heat of vaporization of water (kJ/kg).

The latent heat of water vaporation was measured as 2257 kJ / kg (Hayes 1987) at an evaporation temperature of 100 °C.

3.22 Design of Experiments for Optimization of Drying Parameters

The factorial method is deals with a problem seeking the optimal conditions of the experiment, *i.e.*, most desirable. The standard technique as described by Marcel (2010) was applied. The optimal custom (2FI) design for three variables *i.e.* sample (artificial and natural foamed), microwave power (180, 360, 540, 720 and 900 W) and thickness of bed (2, 4 and 6 mm) including 22 trials formed with 3 replications was used. This design was selected as it fulfilled the most of the requirements needed for optimization of the drying condition.

The experimental design of independent parameters and layout are presented in Tables 3.6 for these three variables in which two levels of sample, five levels for microwave power and three levels of drying bed thickness under the factorial design. All these variables were closely

controlled and accurately measured during experimentation. The dependent variables, also referred as responses, Y_k (*i.e.*, the dependent parameters) were determined experimentally. The independent variables, the coded variables, uncoded variables and their coded and uncoded levels are shown in Table 3.6.

Table 3.6 Levels of independent variables for microwave drying of Nagpur mandarin juice

Independent variables	Symbols		Levels	
	Coded	Un-coded	Coded	Un-coded
Sample	A	S	Level 1 of A	Foamed with AFA
			Level 2 of A	Foamed with NFA
Microwave power	B	P	Level 1 of B	180 W
			Level 2 of B	360 W
			Level 3 of B	540 W
			Level 4 of B	720 W
			Level 5 of B	900 W
Thickness of drying bed	C	T	Level 1 of C	2 mm
			Level 2 of C	4 mm
			Level 3 of C	6 mm

3.22.1 Optimization of microwave power and drying bed thickness

Categorical optimization technique of the Design-Expert software(11.0.3.0 2019 version) was used for simultaneous optimization of the multiple responses like sample, microwave power and drying bed thickness. After optimization of microwave power and thickness of bed, the sample was further compared on quality parameters. The optimization was done for samples, microwave power and drying bed thickness in the optimal custom (2FI) design of three variables including 22 trials. This design was selected as it fulfilled the most of the requirements needed for optimization of the microwave power, drying bed thickness and foaming agents.

The desired goals for factor and response were chosen. The possible goals were: maximize, minimize, target, within range, none (for responses only). All the independent factors (D and T) were kept in range, while the responses viz. water activity, Del E and drying time were minimized and ascorbic acid and overall acceptability were maximized. The colour b value and acidity of all samples were kept within range.

3.22.2 Verification of Optimum Responses

The optimum responses were verified by conducting the drying experiment under optimum conditions. The responses such as water activity, acidity, ascorbic acid, colour b value, Del E, overall acceptability and drying time at optimum drying conditions were compared to the values predicted by the 2FI model.

3.23 Methods for Determination of Dependant Parameters

Drying is most predominant factor which affects the quality; therefore, quality of dried Nagpur mandarin juice was evaluated on the basis of various quality parameters like colour, water activity, acidity, ascorbic acid and overall acceptability. All tests have been repeated three times and the average readings were recorded.

3.23.1 Drying time

Time required for drying the foamed Nagpur mandarin juice in different power and thickness was measured until the constant weight reached.

3.23.2 Colour kinetics for foam mat dried Nagpur mandarin powder

Colour is the basic qualitative characteristic determining attractiveness of dried products as well as the possibility of their further utilization. The assessments of food colour area is critical objective parameter that is used as a quality index for the determination of conformity of food quality to specifications and for analysis of quality changes during food processing, storage and other factors (Giese 2000). Colorimeters / chroma meter were used for colour measurement that

express colours in numerical coordinates as they were widely used in numerous published research articles (Plate 3.7 Chroma meter) (Aktaset *al.*, 2011; Mohamadiet *al.*, 2008).



Plate 3.7 Chroma meter

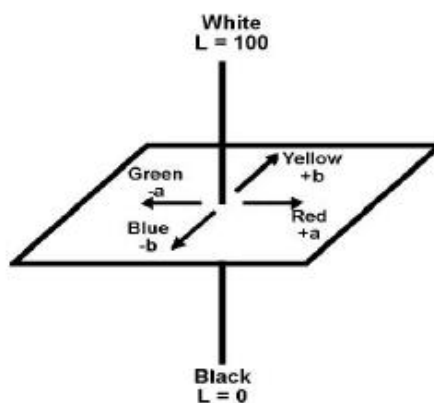


Plate 3.8 Representation of colour solid of L, a and b

Thus, scale L measures lightness (whiteness or darkness) (Fairchild, 1995). The chromatic portion of the solid is defined by +a (red); -a (green); +b (yellow); -b (blue) as shown in Plate 3.8. In terms of three coordinates L, a and b, the data was converted to total colour difference (ΔE) chroma and hue angle as mentioned below (Singh *et al.*, 2012; McGuire 1992; Voss 1992; Schnell *et al.*, 2005; Pedisicet *al.*, 2009).

$$\text{Total colour difference } (\Delta E) = ((L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2)^{1/2} \quad (3.62)$$

$$\text{Chroma} = \sqrt{a^2 + b^2} \quad (3.63)$$

$$\text{Hug angle} = \tan^{-1}(b/a) \quad (3.64)$$

3.23.3 Water activity

The water movement of the food is a confirmation of water quantity as a solvent for food reaction. Water behaviours are the ratio of partial water pressure in food to saturated vapour pressure in water at the same temperature.

$$a_w = P_A / P_{Asat} \quad (3.65)$$

Where, a_w is water activity, P_A is vapour pressure of water exerted in food, P_{Asat} is saturated vapour pressure of water at the same temperature.

If a food is equilibrated in a sealed container and the equilibrium relative humidity of air equals RH, then

$$a_w = RH/100 \quad (3.66)$$



Plate 3.9 Water activity meter

The moisture content of food and temperature are main factors on which water activity depends (Ratti and Mujumdar, 1996). Bound water in molecule was defined the water activity. The powder was filled one third of the volume of the cup provided with the instrument. The instrument took about 1 to 5 min to display the water activity of the sample. A digital water activity meter is shown in Plate 3.9.

3.23.4 Acidity

1-2 g of sample was weighed and dissolved in 20-25 ml of distilled water. From this solution, 1 ml of extract was taken, added to 10ml of 90% ethyl alcohol in a conical flask and mixed well by shaking. Then, titrated it against 0.1 N NaOH using five drops of phenolphthalein as an indicator till pink colour was formed. A blank was also run along with using 10 ml of alcohol in place of extract (AOAC, 2000). The acidity was calculated as percent acidity as citric acid anhydrous using Eqn(3.70).

$$\text{Acidity, \%} = 6.4 \times N \times \frac{A}{V} \times D \quad (3.67)$$

Where, N is normality of NaOH solution, A is volume of standard NaOH solution used in titration in (ml), V is volume of extract taken in (ml) and D is dilution factor.

3.23.5 Ascorbic acid

Ascorbic acid content of powder was estimated by titration method (Ranganna, 1986) using 2, 6- dichlorophenol indophenol dye solution. The method of estimation involves the reduction of 2, 6- dichlorophenol indophenol dye to a colorless form by ascorbic acid in an alkaline solution. The reaction is quantitative and particularly specific for ascorbic acid in solution in the pH range of 1-3.5. In the procedure followed, the dye solution was first standardized against standard ascorbic acid in order to determine the dye factor. The sample was diluted with 3% metaphosphoric acid and then the phosphoric acid extract of the sample was titrated against the dye solution until a pink color was obtained which persists for 15 seconds. Dye factor was determined as(dye factor is equal to 0.5 by titrate volume. the following equation used for determination of ascorbic acid (Eqn 3.68)

$$\text{Ascorbic acid} = \frac{\text{titrable vol. (ml of dye used)} \times \text{dye factor} \times \text{vol. made up} \times 100}{\text{aliquot of sample taken} \times \text{vol. of sample}} \quad (3.68)$$

3.23.6 Sensory evaluation

The Nagpur mandarin powder should have a typical taste, flavour, colour and texture. To test these organoleptic characteristics, sensory evaluation was carried out with the help of a taste panel consisting of 20 panellists. The sensory evaluation was done on the basis of numerical sensory card based on BIS: 6273 (Part II, 1971) as given in Table 3.7. The sensory evaluation was carried out for taste and overall acceptability. The samples of Nagpur mandarin powder were served for the evaluation of above parameters to twenty panellists. The score sheet was provided with the product and the panellists were requested to mark the product score according to their liking. Based on the individual marking the average score was computed.

Table 3.7 Score card for sensory evaluation

Quality grade description	Score
Excellent	8-10
Good	6-7
Fair	4-5
Poor	2-3
Very poor	0-1

3.24 Physico-chemical quality analysis of final product

The physico-chemical quality of optimized foam mat dried Nagpur mandarin powder final moisture content (%), total sugars (%), non-reducing sugar (%), reducing sugar (%), acidity (%), ascorbic acid, calcium, water activity and overall acceptability (%) were estimated. Based on this estimation the best quality product was identified by standard procedures as mentioned below:

3.24.1 Total energy

The value of total energy was estimated on the basis of the physiological fuel value derived from energy giving macronutrients i.e. carbohydrates, fats and proteins. The energy value was calculated by multiplying the amount (g) of each macronutrient with its physiological fuel value (NIN, 2003).

$$\text{Energy (kcal/100g)} = (\text{Protein, g} \times 4) + (\text{Carbohydrates, g} \times 4) + (\text{Fat, g} \times 9) \quad (3.69)$$

3.24.2 Reducing sugar

Reducing sugar was estimated by the spectrophotometer method reported by Sadasium and Manickam (1997) preparation of 3, 5 – Dinitrosalicylic (DNS) acid reagents for estimation of reducing sugars.

$$\text{Reducing sugar (\%)} = R \text{ (}\mu\text{g/ml)} \times \frac{1}{1000000} \times \frac{100}{1} \times \frac{100}{\text{wt of sample (1.07)}} \quad (3.70)$$

$$\text{Reducing sugar (\%)} = R \times 0.00945 \quad (3.71)$$

3.24.3 Total sugar

One gm of powder was diluted by adding 100 ml of distilled water. This sample was centrifuged and filtrated. From the solution, 1 ml of the extract was dissolved in 10 ml of distilled water. Equal amount of 5% phenol was added to 1 ml of filtrate and mixed gently and then 5 ml of conc. H₂SO₄ was added by shaking rapidly and solution is kept for 20 minutes. The spectrophotometer was used for determination of optical density of the sample at 490 nm (Dubois *et al.*, 1956). The concentration of total sugar (as glucose) was calculated from the standard glucose curve (20-100 mg/ml) run simultaneously.

$$\text{Total sugar (\%)} = R \text{ (}\mu\text{g/ml)} \times \frac{1}{100} \times \frac{100 \times 50}{\text{wt of sample (1.07)}} \times 100 \quad (3.72)$$

Where, R is the graph reading

3.24.4 Non reducing sugar

Non reducing sugar was estimated by subtracting the value of reducing sugar from total sugar reported by Sadasium and Manikam (1997).

$$\text{Non reducing sugar (\%)} = \text{Total sugar} - \text{Reducing sugar} \quad (3.73)$$

3.24.5 Protein

Protein content was determined by micro kjeldal method (Latimer, 2016) (Plate 3.10).

Reagents

- 40 % NaOH in distilled water.
- 2 % Boric acid (20 g of reagent grade boric acid dissolved in about 500 mL of hot distilled water) is added in 2 ml of 0.1 % bromocresol green in alcohol (or aqueous solution of the sodium salt) and finally the volume was made up to 1 litre by adding distilled water to prepare 0.01N H₂SO₄ solution (standardized).

Procedure

Protein content of the Nagpur mandarin powder was estimated for which 0.3 g sample was transferred into a 50 ml of long necked micro-Kjeldahl flask and thereafter the sides of the flask was properly washed with the distilled water. After this 2 ml of concentrated sulphuric acid was added and digested in the micro digestion unit. When charring began and white fumes started appearing in the flask, digestion was stopped for a while to allow the flask to cool down before adding a few drops of hydrogen peroxide. The digestion was continued till the solution became clear. Wherever necessary, addition of hydrogen peroxide and digestion were repeated to hasten the process. After this, distilled water was added and was boiled for a few more minutes and then the flask was allowed to cool. After this, 10 ml of the solution of boric acid was taken in a 100 ml conical flask and place it in such a way that the tip of the condenser outlet of the steam distillation apparatus dips below the surface of solution. If colour of the boric acid solution has faded, 2 or 3 drops of bromocresol green indicator was added. Transfer the digested sample completely by means of repeated rinsing to the chamber of the steam distillation apparatus.

The chamber should be previously cleared off against contaminating ammonia by repeated washings. Add about 8 ml of 40 % NaOH and distilled it till about 30 ml distillate is collected into flask. Lower the receiving flask and stop the steam generation. Wash the condenser

outlet tube into the receiving flask with distilled water. The solution in receiving flask coloured blue at this stage. Titrate the contents against 0.1 N H_2SO_4 till the original green colour is obtained. Run the blank preparation through all the steps by taking distilled water in place of the sample.

Calculations - 1 ml of 0.01 N H_2SO_4 = 0.00014 g nitrogen.

$$\text{Nitrogen (\%)} = \frac{0.00014 \times \text{Titra value} - \text{Blank value} \times 100}{\text{Sample wt.} \times 10} \quad (3.74)$$

Conversion factor = 6.25

Protein g/100g = Nitrogen $\times$ 6.25



Plate 3.10 Protein estimation instrument

3.24.6 Fat content

The crude fat was determined using Soxhlet apparatus (Plate 3.11) (Thimmaiah, 2006). The procedure for fat estimation is as follows.



Plate 3.11 Soxhlet apparatus

1. Weigh 2-3 g of dried sample in a thimble (prepared from Whatman No. 1 filter paper) and place it in a Soxhlet apparatus.
2. Connect a dry pre-weighed solvent flask ('a', g) beneath the apparatus and the required volume of solvent (petroleum ether, b.p. 40-60 °C) or ethyl ether or hexane) and connect to condenser.
3. Adjust the heating rate to give a condensation rate of 2-3 drops and extract for 16 h then remove the thimble and retain ether from the apparatus.
4. Evaporate the excess ether from the solvent flask on a hot water bath and dry the flask at 105 °C for 30 min and cool the flask in desiccators and weigh ('b', g).

$$\text{Crude fat or oil content in sample(\%)} = \frac{(b-a)}{\text{Weight of Sample (g)}} \times 100$$

(3.75)

3.24.7 Carbohydrates

The carbohydrate of the sample was computed by the difference between the mass of total sample (100 g) and the sum of the values of moisture, protein, fat and ash (value per 100 g of each) in Nagpur mandarin powder (AOAC, 2000).

$$\text{Carbohydrate in g /100 g} = 100 - (\text{moisture} + \text{protein} + \text{fat} + \text{ash})$$

(3.79)

3.24.8 Fibre content

The fibre was determined using acid- alkali method (AOAC, 2000) (Plate 3.12). The procedure for estimation is as follows.

Reagents: 1.25 % sulphuric acid and 1.25 % sodium hydroxide (NaOH)

Procedure

About 2-5 g of moisture and sample of Nagpur mandarin powder was weighed, and boiled it in 500 ml solution which made up by 0.255 N (1.25%) sulphuric acids. For 30 minutes, this sample was boiled and by the addition of water keeping the volume constant at regular intervals (a glass rod inserted in the beaker to help its smooth boiling). At the end of

this period, the boiled solution was filtered using muslin cloth and remained material was washed with hot water till it get free from acid. The substance was transferred into a beaker and again boiled in 500 ml (0.313 N (1.25%)) NaOH. As before, again boiled the material for 30 minutes and filtered. Then, residue was washed again with hot water till to make free from alkali. Thereafter, it was transferred in a crucible and dried overnight at 80-100°C and weighed. The crucible in a muffle furnace was heated at 600°C for 2 to 3 h and cooled in desiccator then weighed again. The weight differences ($W_2 - W_1$) represented the content of crude fibre.

$$\text{Fibre, \%} = \frac{100 - (\text{moisture} + \text{fat}) \times \text{wt. of fibre}}{\text{wt. of sample}} \times 100 \quad (3.76)$$



Plate 3.12 Apparatus for fibre estimation

3.25 Estimation of Micronutrients

Micronutrients are required in minor amounts for proper growth and development of the body. Micronutrients (vitamins and minerals) were analysed in Nagpur mandarin powder.

3.25.1 Determination of thiamine (B_1)

Reagents

1. Enzyme Solution -Suspend 150 mg of takadiastase and 75 mg of papain in 5 ml of acetate buffer and acetic acid -3 % (v/v).

2. Activated decalso or equivalent - wash decalso (or its equivalent) which passes through 180 to 250 μ IS Sieve (IS: 460-1962) successively once with hot 3 % acetic acid, once with hot potassium chloride solution (g) and again with hot 3 % acetic acid followed by several washes with hot distilled water. Each washing consists of stirring decalso in the liquid for 15 minutes, allowing it to settle and then decanting. The final wash solution should be free of chlorides when tested with 1 % silver nitrate solution. Store the Decalso under water in a stoppered bottle.
3. Bromocresol green Indicator -0.4% in 70% ethyl alcohol;
4. Anhydrous sodium sulphate
5. Potassium ferricyanide solution -1% in water (w/v)
6. Oxidizing reagent - prepared fresh before use. Mix 1 part of potassium ferricyanide solution (l) with 9 parts of potassium hydroxide solution (k).
7. Basic lead acetate solution - dissolve 180 g of lead acetate in about 700 ml of distilled water by heating. To the hot solution add 110 g of finely powdered lead-oxide (litharge) and continue boiling for 45 minutes with constant stirring. Cool the mixture, filter and dilute to 1 liter.
8. Sodium acetate buffer (0.20 M, pH 4.2)- dissolve 34 g of sodium acetate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$) in 250 ml of water. To 30 ml of this solution, add 70 ml in acetic acid and dilute to 500 ml.
9. Stock thiamine solution-Dissolve 25 mg of pure dry crystalline thiamine hydrochloride in 250 ml of 0.01 N hydrochloric acid (1 ml= 100 μg) and acetic acid -0.5 %t (v/v).
10. Potassium chloride solution -25% (w/v) in 0.1N hydrochloric acid.
11. Isobutyl alcohol - redistilled (in an all glass apparatus), fraction distilling at 105-108°C collected and saturated with water.
12. Potassium hydroxide solution -15% in water (w/v).

13. Blank reagent - mix 1 part of water with 9 parts of potassium hydroxide (k) solution.

Extraction

In a mixer with the correct amount of water take homogenized paste. Complete slurry is measured and thiamine extraction is achieved with a weighted aliquot of 10 to 20 g material. Take two aliquots of slurry or powder and apply 5 ml of enzyme suspension and 80 ml of sodium acetate buffer in 250ml flasks labelled 'Check' and 'Recovery.' Apply dilute regular thiamine solution equal to 25 µg of thiamine chloride to the flask labelled 'recovery' (30 µg if the flask is treated with Lead acetate). Connect two or three ml of toluene and incubate overnight (12 to 14 h) at 37 °C. Switch in heating the enzymes, add volume up to 100 ml and centrifuge or movable to extract the trace in a hot water pan.

Procedure

Conversion to Thiochrome-Take two 5ml aliquots (10 ml in the case of extracts obtained with the lead acetate method) from the purified extract marked 'Test' into two separator funnels (50 ml) or glass-stoppered test-tubes labeled 'Test' and 'Blank'. In a third tube labeled 'Recovery' take 5 ml of the purified extract marked 'Recovery' (10 ml in case of extracts obtained with the lead acetate method). To the 'Blank' adds 1 ml of the blank reagent, followed within 1 minute by 15 ml of isobutyl alcohol. To the 'Test' and 'Recovery' tubes (or separatory funnels) add 1 ml of the oxidizing reagent, followed by 15 ml of isobutyl alcohol. Shake both the tubes (separatory funnels) vigorously for 1 minute, allow the layers to separate and transfer the upper butanol layer containing thiochrome to another test-tube (use a 10ml pipet with a rubber bulb to separate the epiphase if separatory funnels are not used). Add a small quantity of anhydrous sodium sulphate to remove the traces of water and read the fluorescence of the clear extracts in a fluorometer using suitable filters for thiamine estimation or A appropriate reagent blank with a regular 2 to 5 mg thiamine hydrochloride should also be

prepared to test fluorescence with a spectrofluorimeter (excitation 365 nm and emission at 435 nm).

Calculation

The next step is to quantify thiamine in mg per 100 g of the food sample.

$$\text{Thiamine, } \frac{\text{mg}}{100\text{g}} = \frac{\text{Test reading} - \text{Blank reading}}{\text{Recovery reading} - \text{Test reading}} \times \frac{\text{Dilution factor}}{\text{Wt. of substance taken}} \quad (3.77)$$

3.25.2 Iron content

The iron content was estimated using following procedure (Ranganna, 1986).

Reagents

1. Concentrate H_2SO_4 (iron-free).
2. Saturated potassium persulphate ($\text{K}_2\text{S}_2\text{O}_8$) solution: Shake 7 to 8 g of reagent grade iron-free potassium persulphate with 100 ml of water in a glass stoppered bottle. The undissolved excess settles to the bottom and compensates for loss by decomposition. Shake briefly before using. Keep the reagent in refrigerator.
3. 3 N potassium thiocyanate solutions: Dissolve 146 g of reagent grade potassium thiocyanate in water and dilute to 500 ml. Filter if turbid. Add 20 ml of pure acetone to improve the keeping quality.
4. Standard iron solution: Dissolve 0.702 g of reagent grade crystalline ferrous ammonium sulphate [$\text{FeSO}_4 \cdot (\text{NH}_4)_2 \text{SO}_4 \cdot 6\text{H}_2\text{O}$] in 100 ml of water. Add 5 ml of concentrated H_2SO_4 , warm slightly, and add conc. potassium permanganate solution drop until one drop produces a permanent colour. Transfer to 1 lit volumetric flask, rinse with water and make up to volume. This solution contains 0.1 mg of ferric iron per ml and is stable indefinitely.

Procedure

A 5 g sample was digested in long necked Kjeldahl flask with 10 ml concentrated H_2SO_4 and 5 ml concentrated HNO_3 till the content become colourless. Volume was made 100 ml with distilled water. A 20 ml sample was taken in volumetric flask. A 5 ml potassium thiocyanate was added

followed by 1 ml HCL. Volume was made 100 ml and the content of the flask were mixed well. The red colour was read after 10 min. at 480 nm in colorimeter. Construction of standard curve: 2.6 g ferric ammonium sulphate was dissolved in 1 lit of distilled water. Few drops of concentrated H₂SO₄ were added to the solution to make it colourless/transparent. Concentration of iron in this solution was 0.3 mg per ml. To make the working standard, 10 ml of stock solution was taken and diluted to 100 ml. 0, 2, 4, 6, 8 and 10 ml of working standard was taken in volumetric flasks. 5 ml potassium thiocyanate and 1 ml HCL were added. Volume was made 100 ml content of the flasks were mixed well. The red colour was read at 480 nm in colorimeter. A graph was plotted of concentration on X-axis versus optical density on Y-axis(Ranganna, 1986).

$$\text{Iron } \frac{\text{mg}}{100} \text{ g} = \frac{\text{OD of sample} \times 0.1 \times \text{Total volume of ash solution} \times 100}{\text{OD of standard} \times 5 \times \text{Wt. of sample taken for ashing}} \quad (3.78)$$

3.25.3 Calcium content

Calcium content was determined as per titrimetric method (NIN, 2003).

Reagents: • 4% ammonium oxalate solution, dilute ammonia solution (2 ml of liquor ammonia + 98 ml), 1N H₂SO₄ and 0.01N potassium permanganate solution

Procedure

Calcium content was analysed in Nagpur mandarin powder as 2 ml of sample was taken into a 15 ml centrifuge tube with 2 ml of distilled water and 1ml of 4 % ammonium oxalate solution and mixed them thoroughly and left the mixture as such overnight. The contents were mixed again and centrifuged for 5 min at 1500 rpm. The supernatant liquid was poured off and the centrifuge tube was drained by inverting the tube for 5 min on a rack (care should be taken not to disturb the precipitate). The mouth of the centrifuge tube was wiped with a piece of filter paper. The precipitate was stirred and the sides of the tubes were washed with 3 ml of dilute ammonia. It was centrifuge again and drained as before. The precipitate was washed once more with dilute ammonia to ensure the

complete removal of ammonium oxalate. The precipitate was then dissolved in 2 ml of 1 N H₂SO₄. The tube was heated in water bath for 1 min and titrated against 0.01N KMnO₄ solution to a definite pink colour persisting for at least 1 min.

$$\text{Calcium, } \frac{\text{mg}}{100\text{g}} = (X - b) \times 0.2004 \times 100 \quad (3.79)$$

Where, X is number of ml of 0.01N KMnO₄ required for titration, b is number of ml of 0.01N KMnO₄ required to titrate 2 ml of H₂SO₄ (blank) if the normality of KMnO₄ is N, the value obtained in the above formula to be multiplied by the factor, N/ 0.01.

1 ml of 0.01N KMnO₄ is equivalent to 0.2004 mg of calcium.

3.25.4 Magnesium content

Magnesium was determined using titrimetric method (NIN, 2003).

Reagents: 10 % ammonium phosphate solution, 10 % sodium citrate solution, 0.1 % methyl red indicator and 1:4 and 1:10, ammonia: water solution.

Procedure

Nagpur mandarin powder was used for analysis of magnesium content in triplicate. To the calcium free filtrate (obtained from the filtrate after precipitation of calcium as oxalate) the 30 ml of concentrated HNO₃ was added and the solution was evaporated completely on a boiling water bath. A 5 ml of concentrated HCL and 100 ml of water were added in solution and stirred well with a glass rod. It was followed by the addition of 10 ml of 10 % ammonium phosphate solution and 5 ml of 10% sodium citrate solution and the mixture was stirred well. After adding 2- 3 drops of methyl red indicator to the mixture and the solution was neutralized with the addition of 1:4 diluted ammonia. Strong ammonia (25 ml) was then added and stirred vigorously and the mixture was left to stand overnight and then filtered through Whatman No. 40 or 44 filter paper followed by washing to make free from chlorides using 1:10 dilute ammonia (tested with HNO₃+ silvernitrate solution). The funnel with the precipitate on the filter paper was dried in an oven. The filter paper was then transferred to a

weighed crucible (the crucible was previously heated, cooled and weighed) and ashed slowly over a burner. It was then kept in a muffle furnace at 900 °C for 2 h. The crucible and the contents were re-cooled in desiccators and weighed to get magnesium as its pyrophosphate.

$$\text{Manganese, } \frac{\text{mg}}{100\text{g}} = \text{wt. of ash} \times \frac{48.64}{222.6} \times \frac{100}{\text{ash solution taken}} \times \frac{100}{\text{wt. of sample}} \times 100$$

(3.80)

3.25.5 Phosphorous content

Phosphorous content of powder was determined by photometric method (AOAC Official Method 965.17). The spectrometer is shown in Plate 3.12.

Procedure:

- Ash 2 g sample in 150 ml beaker about 4h at 600 °C then cool the sample.
- Add 40 ml HCL (1+3) and several drops HNO₃. Bring it to boiling point and kept to cool it. Then transfer to 200 ml volumetric flask and dilute to volume with H₂O.
- Filter and place aliquot containing 0.5-1.5 mg P in 100 ml volumetric flask.
- Add 20 ml molybdovanadate reagent, dilute to volume with H₂O and mix well.
- Let stand for 10 min; then read percent T at 400 nm against 0.5 mg standard set at 100 % T (Use 15 mm diameter cells). Determine mg P from standard curve.



Plate 3.13 Spectrophotometer

$$P (\%) = \text{mg P in aliquot} / (\text{g sample in aliquot} \times 10) \quad (3.81)$$

3.25.6 Potassium

The potassium was determined using flame photometric method described by Rangana(2009).

Reagents:

1. Potassium chloride (KCL) stock solution: 1.909 g of AR potassium chloride was dissolved in distilled water and make up it up to 1 liter (1.0 mg K per ml or 1000 ppm).
2. Standard solution: Measure 150 ml stock standard solution (containing 150 ppm of potassium) and 5 ml HCL into a flask and make solution upto 1 liter. In order to compensate for minute interference produced by other ions in the flame photometric determination of potassium, it is recommended that the standard solution be augmented with approximately equivalent concentrations of those ions that occur in highest proportions in the sample being analyzed. Dilute aliquots of the standard solution from 0 to 150 ml made each aliquot to a volume of 150 ml with 0.5% HCL.

Procedure

Nagpur mandarin powder and juice were used for estimation of potassium content by taking readings in triplicate. Dilute an aliquot of ash solution containing less than 150 ppm potassium. Add sufficient amount of HCL so that the concentration of acid was same as that in the standard solution. Atomized the diluted extract in a calibrated flame photometer with the wavelength dial set at 768 nm and the transmittance set at 100% for the top standard solution of potassium. Check the instrument periodically with the top standard solution. From the standard curve note the concentration.

$$\text{potassium, } \frac{\text{mg}}{100\text{g}} = \frac{\text{ppm found from std.curve} \times \text{volume made up} \times \text{dilution} \times 100}{\text{wt.of sample} \times 1000} \quad (3.82)$$

3.26 Sensory Evaluation of Developed Nagpur Mandarin Powder

In the food industry, sensory testing is an important method. The different sensory qualities measured by the panel of Judges of Nagpur mandarin powder and RTS items derived from powder. The data were evaluated using the fuzzy logic in order to evaluate the sensory and consistency characteristics of the produced cookies obtained from panel (Das, 2005).

3.26.1 Sensory evaluation

The cookies were prepared from composite sample of 90% wheat flour and 10% Nagpur mandarin powder. The process parameters were taken as beating time 13 min, baking temperature 180 °C and time 20 min. The cookies using Nagpur mandarin powder (S₂) served along with similar commercial cookies manufactured by britannia marie gold orange (S₁) and locally manufactured orange cookies (S₃) shown in Table 3.8.

Twenty-two judges from the faculty and research scholars of the Department of Agricultural Process Engineering, Dr. PDKV, Akola (10 males and 12 females in age range of 25 to 45) were chosen for the sensory appraisal of the final product (Table 3.8), focused on good fitness, combined awareness and sensory preferences, capacity to focus and understand, and experience with bakery foods. In keeping with the chosen colour, taste, texture and overall acceptability (OAA) attributes for each sample panel members were questioned. Prior to sensory assessment, the judges became acquainted with the concepts of bakery commodity consistency attributes. Before research, two or three samples were demanded to be taken and the flavour settings were provided in the score sheet first. Also, in checking the successive tests, they were instructed to clean their mouth with tender water. (Das, 2005; Sinija and Mishra 2011). This method has been successfully applied for mango drinks (Jaya and Das, 2003), soy fortified paneer (Uprit and Mishra, 2002), dahi powder (Routray and Mishra, 2011), instant green tea powder (Sinija and Mishra, 2011), millet-based bread (Singh *et al.*, 2012) and

Kharodi (Solankeet *al.*, 2018). Appendix – G includes a report sheet that is required for the test.

Table 3.8 Coding of the product considered for sensory evaluation

Product Code	Name of product
S ₁	Britannia marie gold orange
S ₂	Cookies with powder
S ₃	Local manufactured cookies

There were unsatisfactory, fair, medium, good and excellent sensory size indicators and numerical values applied to each of the consistency parameters. Judges were asked to offer a tick mark and also numerical score for of sample element, and to offer their rank of preferences for quality attributes of cookies in general. The scale factors used for quality attributes were 'not significant,' 'slightly important,' 'important,' 'highly important' and 'very significant' in general.

The minimum amount of tick marks and consistency ratings for all bakery items have been obtained in general. The data available from the subjective assessment of the prepared cookies using mandarin powder and the other two were evaluated using fuzzy reasoning to assess sample rating, rankings of the different sample quality characteristics assessed, and their relative value in general.

3.26.1.1 Modelling of sensory scores using fuzzy theory

Judges' sensory orientation and ratings are unknown and may be mathematically controlled using fluorescent environment hypotheses (Zadeh, 1965). A detailed analysis method may be extended to the classification of food and new items (Zhang and Litchfield 1991). Fuzzy participation on a five-point sensory scale was given food samples and consistency qualities (Das, 2005).

Sensory dimensions are represented by a group of three numbers called 'triplets' in the triangular fluctuating membership array. In order to approximate the similarity values needed for a sample classification, the

sensory values of the cookies and their qualitative characteristics are translated into triples. Fuzzy sensors' simulation includes the following essential steps : (1) calculating the total sensory score of cookies in triplet form (2) calculating the membership feature at the regular fuzzy scale (3) calculating overall membership function on standard fuzzy scale for cookies (4) estimating resemblance values and sample rating (5) quality attribute ranking of food samples in general and (6) ranking of quality attributes of individual food samples (Jaya and Das, 2003; Sinija and Mishra, 2011, Shinde and Pardeshi,(2014).

3.26.1.2 Triplets associated with five point sensory scale

The sensory scores are translated into a five-point 'triplet' range of three numbers. The 5-point sensory distribution pattern is poor / not at all, fair / lightly relevant, medium/important, good/highly important and excellent/ extremely important as shown in Fig 3.3. As triangle 'abc' for the low/not all big categorical membership function, triangle 'ade' reflects fair/slightly significant distribution function, etc. The five-point sensory scale triplets are seen in Table 3.9. The first number of the triplet corresponds to the abscissa coordinate at which the membership function is of one type. Second and third number of a triplet indicates the difference from the left and right of the first number of members (Shinde and Pardeshi, 2014).The first number of Membership is zero.

Table 3.9 Triplets associated with five point sensory scale

Poor/Not at all important			Fair/Slightly important			Good/ Important			Very good/Highly important			Excellent/ extremely important		
0	0	25	25	25	25	50	25	25	75	25	25	100	25	0

3.26.1.3 Triplets for sensory scores of bakery product and overall quality

The triplet for a particular quality attributes (Shinde and Pardeshi, 2014) gives the amount of the sensory tests, triplets linked to the five point sensory scale and the number of judges of the survey was collected. For eg, for a total of 22, one judge of 22, gave 'Fair' score, three judges provided the score as 'Medium,' 15 judges gave 'Good,' and 3 judges gave 'Excellent': the sensory ratings was measured using equation three

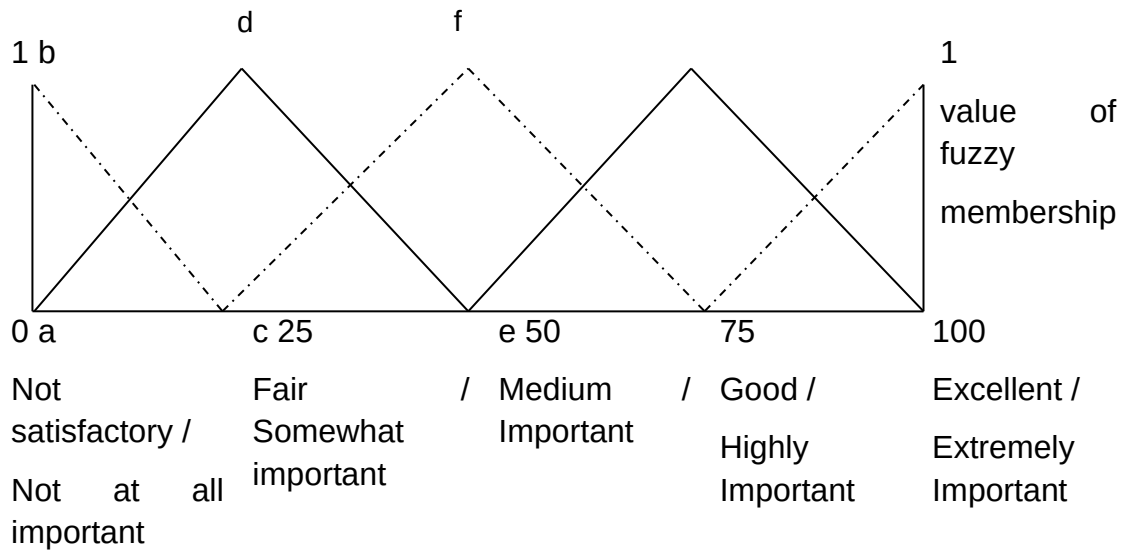


Fig 3.3 Triplets associated with five point sensory scale

times. Colour qualities are the same as examples, for example (3.83).

$$Cs_1 = \frac{0(0 \ 0 \ 25) + 1(25 \ 25 \ 25) + 3(50 \ 25 \ 25) + 14(75 \ 25 \ 25) + 2(100 \ 25 \ 0)}{20} \quad (3.83)$$

All the samples and quality attributes in general of cookies were collected according to the Eqn (3.83) for-quality element. Likewise, triplets for relative weighing of qualitative features (QRel) have been determined by the general weighting provided by judges by the quality features of samples in general. Triplets were calculated with Eqn (3.84) for total sensory scores of cookies, in which triplets of sensory value and were compounded by triplets for any consistency attribute, and the total of

the corresponding triplets for all attributes was taken for relative weighing for this specific attribute.

$$S01 = CS_1 \times QC_{rel} + FS_1 \times QF_{rel} + TS_1 \times QT_{rel} + OS_1 \times QO_{rel} \quad (3.84)$$

Where, CS_1 , FS_1 , TS_1 and OS_1 represents the triplets corresponding to the colour, flavor, texture and overall acceptability of sample one and QC_{rel} , QF_{rel} , QT_{rel} and QO_{rel} Denotes triplets corresponding in general to the relative weighting of cookies quality attributes. The overall values for all samples have been calculated using similar equations. The triplet (a b c) was multiplied by threefold (d e f) by applying a rule as defined in Eq. (3.85)

$$(a \ b \ c) \times (d \ e \ f) = (a \times d \ a \times e + d \times b \ a \times f + d \times c) \quad (3.85)$$

3.26.1.4 Membership function for standard fuzzy scale

The five-point triplets are transformed into a six-point tactile system defined as a regular fuzzy system. In Fig 3.4, the triangular pattern of sensory propagation is shown by the symbols F1 , F2 , F3, F4, F5 and F6. Each of the sensory scales is assigned to a triangular pattern of distribution, where the maximum member function value is one. The fuzzy membership ratings vary from 0 to 10. The values from F1 to F6 are therefore represented by a set of 10 numbers as stated in Eqn (3.86).

$$\begin{aligned} F1 &= (1, \ 0.5, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0) \\ F2 &= (0.5, \ 1, \ 1, \ 0.5, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0) \\ F3 &= (0, \ 0, \ 0.5, \ 1, \ 1, \ 0.5, \ 0, \ 0, \ 0, \ 0) \\ F4 &= (0, \ 0, \ 0, \ 0, \ 0.5, \ 1, \ 1, \ 0.5, \ 0, \ 0) \\ F5 &= (0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0.5, \ 1, \ 1, \ 0.5) \\ F6 &= (0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0, \ 0.5, \ 1) \end{aligned} \quad (3.86)$$

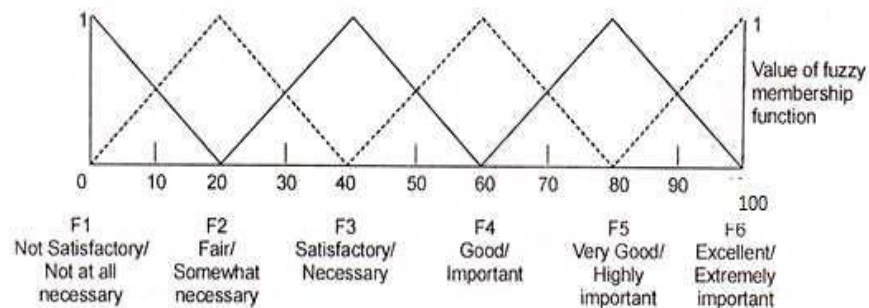


Fig. 3.4 Standard fuzzy scale

3.26.1.5 Overall membership function of sensory scores on standard fuzzy scale

Figure 3.5 shows the graphical representation of a triplet (a, b and c) membership. The figure shows that the values of an abscissal for a triplet (a, b, c) are 1; and if they are less than a-b or more than a+c, the value is 0. The membership value of the B_x function may be represented as Eqn (3.87) for a defined value of x on abscissa.

$$B_x = \frac{x-(a-b)}{b} \text{ for } (a-b) < x < a$$

$$B_x = \frac{(a+c)-x}{c} \text{ for } a < x < (a+c) \quad (3.87)$$

$$B_x = 0 \text{ for } x < (a-b) \text{ and } x > (a+c)$$

For each of the samples and its triplets, value of membership function B_x at x = 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100. This membership function value of samples on standard fuzzy scale will be given a set of 10 numbers which are (maximum value of B_x at 0 < x < 10), (maximum value of B_x at 10 < x < 20), (maximum value of B_x at 20 < x < 30), (maximum value of B_x at 30 < x < 40), (maximum value of B_x at 40 < x < 50), (maximum value of B_x at 50 < x < 60), (maximum value of B_x at 60 < x < 70), (maximum value of B_x at 70 < x < 80), (maximum value of B_x at 80 < x < 90), (maximum value of B_x at 90 < x < 100)'.

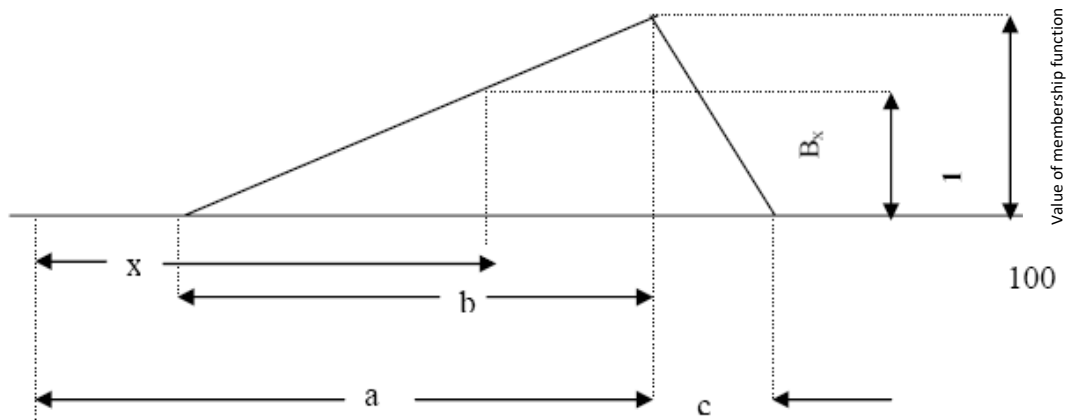


Fig 3.5 Graphical representation of triplet (a, b, c) and its membership function

3.26.1.6 Values and ranking of cookies

After the B values for each sample obtained as 10 values for the normal fuzzy scale, the similarity values for the sample were obtained using Eqn (3.88) (Siniya and Mishra, 2011).

$$S_m(F, B) = \frac{F \times B'}{\text{Max}(F \times F' \text{ and } B \times B')} \quad (3.88)$$

Where, S_m is the similitude attribute of a reference, $F \times B'$ is the matrix F element by transposition of matrix B , $F \times F'$ is the product of matrix by transposing F and $B \times B'$ is the product of matrix B with its transpose. One similarity attribute is seen for example $S_m(F_1, B_1)$, $S_m(F_2, B_1)$, $S_m(F_3, B_1)$, $S_m(F_4, B_1)$, $S_m(F_5, B_1)$ and $S_m(F_6, B_1)$. The values were calculated using the rules of matrix multiplication (Shinde and Pardeshi, 2014).

The maximum similarity value was associated with similarity levels in six groups of sensory scales. It was deemed important for its consistency that the division corresponded to the highest similarity rating. Use of above technique also specified the overall output of each study. The ranking of three samples is achieved by combining the given total qualities of the samples as determined by the above procedure.

The consistency characteristics of cookies were typically calculated using the process mentioned above. The total sensory values were calculated for every quality attribute using triplets of the four quality attractions and the standard fuzzy scales. By comparing the similarity values for each criterion, the highest similitude value has been identified for cookies in general as the best quality criteria.

The sensory scores were collected from judges using the ten-point scale, in order to assess the sample classifications and quality attributes of cookies resulting from fuzzy analysis. Average scores were calculated for accuracy and overall sample acceptability, and analysis of variance is performed to determine statistical meaning for quality attributes.

3.27 Storage study of Nagpur mandarin powder

Storage studies were conducted on the final product prepared by optimization of process parameter using different packaging materials. Metalized polyester (MP), high density polyethylene (HDPE) and polypropylene (PP) used for storage studies, as these materials are known to be fairly good moisture and oxygen resistant and are being used commercially for packaging (Dhumal, 2010). This also provides an outstanding light filter and decreases oxygen permeability. Keeping quality of dehydrated food powders is influenced by water activity (Shibyet *al.*, 2017). The water vapour transmission rate (WVTR) was determined for all packaging material. A broad variety of environmental factors such as light, temperature, humidity and oxygen, which may contribute to several reaction pathways that ultimately kill the food through storage and delivery, are subjected to fruit powders (Puaet *al.*, 2008).

3.27.1 Sorption isotherm of the Nagpur mandarin powder

Sorption isotherm behaviour of the powder at accelerated condition was studied to show the variation in moisture content with water activity (a_w). Sorption isotherm, a plot of the equilibrium moisture content of a food against water activity at a constant temperature i.e. 30 °C, was prepared. Powdered food products are usually very hygroscopic. Food powder is capable of removing moisture from the air with a strong relative humidity (Jaya and Das, 2004).

Table 3.10 Level of water activity for food products

Water activity	Level
≤ 0.2	Any deterioration reaction for colour browning is checked.
≤ 0.3	Enough to check enzyme reaction other than any reaction.
≤ 0.5	Enough to check any lipid oxidation (rancidity).
≤ 0.7	Check mould action.
≤ 0.77	Check yeast activity.
≤ 0.8	Check bacterial activity.

The adsorption isotherm are useful for determining the highest moisture content attainable during storage, and for estimating the water activity of a food from its moisture content and critical water activity, up to which was stored safely (Ahmad, 1997). The level of water activity and its effect on quality of food products (Dhamsaniya, 2008) was shown in Table 3.10.

3.27.2 Sorption apparatus

Desiccator was used for providing required air tight environment. Lower compartments of the desiccators separated by perforated base plates, held the chemical salt solutions prepared with distilled water. The chemical salt used was of extra-pure laboratory or certified grade. Saturated salt solutions with excess salt gave the required ERH environments inside the desiccators. Excess salt in solution was required to compensate for the possible solution dilution by the liberated moisture from samples (Igathinathaneet *al.*, 2005).

3.27.3 Selection of salt for maintaining humidity

The reagent grade salt slurries, namely potassium nitrate was chosen. The salts used were of extra-pure laboratory or certified grade. The salts were dissolved in distilled water at 100 °C and then cooled to the test temperatures (30 °C) for crystallization to form saturated slurries. Relative humidity of this salt fluctuates from 90 to 95% at given temperature. The ERH value of the saturated salt solutions at 30 °C temperature was obtained directly from reported data (Greenspan, 1977).

3.27.4 Sorption procedure

Weighed quantity of prepared sample ($5 \text{ g} \pm 0.5 \text{ g}$) was taken into tin plate and then placed inside the desiccator with saturated solution of potassium nitrate and kept in atmospheric condition (30 °C). Experiments were conducted in triplicates for best results. Equilibrium moisture content (EMC) in terms of kg of water/kg of dry matter was obtained for all samples. The product's water level was calculated by the meter of water activity (Plate 3.14) (Model CT-100, Aqualab).



Plate 3.14 Setup for sorption isotherm of final product

The sample was filled one third of the volume of the cup provided with the instrument in powder form of the product. The EMC were plotted against relative humidity to establish moisture sorption isotherm.

3.26.5 Determination of water vapour transmission rate (WVTR) of packaging material

The packets of 70 mm wide and 100 mm length of each packaging materials were prepared from the MP, PP and HDPE material by heat sealing. Water vapour pressure inside the packet was zero ($P_{in} = 0$ Pa). The desired relative humidity of 85% was created in desiccators by saturated solution of potassium nitrate and 40°C temperature was maintain by keeping in incubator. The weight of packet was measured periodically of 7 days interval. The desiccators were placed under dark conditions in incubators maintained thermostatically at 38 ± 2 °C. This arrangement was done for accelerated storage of powder (Jaya and Das, 2004 and Puaet *al.*, 2008). Weight gained by desiccant (W) with respect to time (θ). Plot of weight gain (W) vs time (θ) gave straight line, slope ($\Delta W / \Delta \theta$) of which i.e WVTR was determined by regression. At given thickness the value of permeability of the packaging materials was determined by using Eqn (3.89) (Siracusa, 2012). The physiological and microbiological characteristics improvements were assessed at periods of 0, 1, 2, 3, 4, 5, 6 and 7 weeks.

The permeability of packaging material was calculated using following Eqn:

$$K_A = \frac{\Delta W / \Delta \theta}{P_{out} A'} \quad (3.89)$$

Where, W_s is weight gain by desiccant (g), θ is time (days), K_A is permeability ($\text{kg} / \text{m}^2 \text{ day Pa}$) for given thickness (x) of the packaging material, A' is area of the package (m^2), x is thickness of packaging material (mm) and P_{out} is water vapor pressure at 40°C (Pa)

3.27.6 Procedure for shelf life calculation

The MP, PP and HDPE packets of 70 x 100 mm size of each packaging material were prepared by heat sealing. The developed powder was filled in each packet and sealed with heat sealing taking care of minimum air space remained in the packet. The sealing was carefully inspected to avoid any possibilities of leakage. These packets were placed in desiccators. The relative humidity of 90% was maintained inside desiccators by introducing salt solution of potassium nitrate (Pardeshiet *al.*, 2009). The desiccator was placed at 40°C for 49 days. Total 21 packet of all packaging material of Nagpur mandarin powder was kept in desiccator and one packet of each packaging material was taken out after certain interval of time and quality parameter was measured.

3.27.7 Shelf life calculation:

Shelf life of the powder ' θ ' (days) i.e. period required for the moisture content of the Nagpur mandarin powder to increases from an initial value of M_i (kg water per kg dm) to its critical value M_c where it lost its flowability and hygroscopy increases degree of caking was estimated numerically (Das, 2005).

$$\theta = \frac{W_s}{P^* K_A A'} \int_{M_i}^{M_c} \frac{M}{RH - a_w} \quad (3.90)$$

Where, θ is shelf life (days), W_s is dry matter in the product (kg), W_{gain} is weight gain due to moisture uptake = $W_s (M_c - M_i)$ and P^* is saturation vapour pressure of water at $T^\circ\text{C}$ (Pa)

$$= \exp\left(23.0603 - \frac{3723.67}{222.857 + T}\right) \quad (\text{Geankoplis, 1983})$$

KA is permeability of the packaging material (kg / m² day Pa), A' is area of the package (m²), RH is relative humidity in which package is placed (fraction), a_w is water activity (fraction) of the product at T °C = f (M) and Wc is critical water activity and is less than or equal to RH

3.27.9 Degree of caking

Weighed the 5 g sample and put in a sieve. The degree of cake was calculated as the difference in weight. The degree of caking was determined according to Ramachandran *et al.* (2014). The following limits are given for degree of caking (Rakhiet *et al.*, 2008).

Value	< 30°	indicates excellent flow
Value	> 56°	indicates very poor flow

Indicator scale

good (θ between 31–35°)

fair (θ between 36–40°)

Possible (θ between 41–45°) which hang up the flow

Poor (θ between 46–55°) agitated the powder

3.26.10 Flowability

The powder flowability was calculated with the method explained by Chauhan and Patil (2013). A funnel with a narrow stem was mounted 20 mm above a piece of paper. Nagpur mandarin powder was poured into the funnel and permitted into a fine stream to shape a conical hole before the end of the funnel was reached at the top of the powder heap. A pencil was fixed to the base of the powder heap and the powder was extracted. The remainder angle (θ) was determined according to the Eqn (3.84).

$$\tan \theta = \frac{\text{height of stem base (mm)}}{\text{radius of base of powder heap (mm)} - \text{radius of funnel stem (mm)}} \quad (3.91)$$

CHAPTER IV

RESULTS AND DISCUSSION

The findings of the investigations are mentioned in this chapter on process technology for development of Nagpur mandarin foamed juice, powder and quality analysis of dried product. The statistical analysis of experimental data are also presented and discussed in the following sections:

4.1 Physico-Chemical Characteristics of Nagpur Mandarin

4.1.1 Physical parameters of Nagpur mandarin fruit

The physical properties of 30 Nagpur mandarin fruit and segment were determined and are presented in Appendix A. The detail results are given in following sections.

4.1.1.1 Fruit size

Data on fruit length, width and thickness are summarised in Table 4.1 and were found to vary in the ranges from 64.58 to 75.69, 61.24 to 72.54 and 60.25 to 72.57 mm, respectively. The data for geometric mean diameter and sphericity were found in the range of 60.31 to 70.36 mm and 0.85 to 0.95. The range of surface area and projected area were found in the range of 124.09 to 169.40 cm² and 89.35 to 99.38 cm².

Table 4.1 Physical parameters of Nagpur mandarin fruit.

SN.	Particular	Average	Range	SD	CV
1	Length, mm	70.56	64.58 to 75.69	2.84	4.02
2	Width, mm	68.05	61.24 to 72.54	2.98	4.38
3	Thickness, mm	67.11	60.25 to 72.57	3.15	4.70
4	Geometric mean diameter, mm	65.72	60.31 to 70.36	2.70	4.11
5	Sphericity	0.932	0.85 to 0.95	0.018	1.88
6	Surface area, cm ²	147.35	124.09 to 169.40	10.64	7.22
7	Average projected area, cm ²	94.83	89.35 to 99.38	2.785	2.94
8	Shape		Oblate Spheroid Ellipsoid		

The mean values of length, width and thickness of the fruit were 70.56, 68.05 and 67.11 mm, respectively. The average geometric mean diameter and sphericity of fruit were 65.72 mm and 0.932. The average surface area and projected area were 147.35 cm² and 94.83 cm².

The classification of shape according to Mohsenin (1980) was oblate spheroid and elliptical. Similar results were found by Biswas and Teotia (2012) for small garden fruit of length 68.00 mm; Varaneet *et al.* (2015) for average length 71.70 mm, 70.30 mm and 71.70 mm with breadth 68.00, 66.00 mm and 66.70 mm for Kondonaran, Mudkhed and Nagpur Mandarin cultivar of mandarin, respectively. Garavand and Nassiri (2010) for sweet lemon with average length 68.89 mm, width 66.83 mm, thickness 63.41 mm, geometric mean diameter 66.32 mm, sphericity 0.924, surface area 138.81 cm² was reported.

4.1.1.2 Fruit weight

The maximum and minimum weights of the Nagpur mandarin fruit were found 174.45 g and 143.54 g with standard deviation of 7.57. The average weight of the Nagpur mandarin was 162.24 g (Table 4.2). Similar results were found by Varaneet *et al.* (2015) reported the average weight of 173.57 g for coorg mandarin cultivar, Garavand and Nassiri (2010) with average weight 154.96 g for sweet lemon. Bhatnagar *et al.* (2015) reported the fruit weight ranged from 86.33 to 137.88 g and Patilet *et al.* (2011) reported the average weight of 152.13 g for Nagpur mandarin.

4.1.1.3 Volume

The actual volume, elliptical volume and oblate spheroid volume of the Nagpur mandarin was determined using mathematical expression as described in section 3.1.2 and the result obtained is presented in Table 4.2. The actual volume, elliptical volume and oblate spheroid volume were found to vary from 144.36 to 167.96, 130.01 to 207.37 and 131.89 to 206.14 cm³, respectively. The average actual volume, elliptical volume and oblate spheroid volume of fruit were 155.70, 168.55 and 171.36 cm³, respectively. A similar result was reported by Garavand and Nassiri (2010)

with 171.84, 154.81 and 163.43 cm³ for actual volume, ellipsoid volume and oblate spheroid volume for sweet lemon. Patilet *et al.* (2011) reported 161.26 cm³ volume of Nagpur mandarin.

4.1.1.4 Specific gravity of fruit and juice

The specific gravity of fruit and of juice was found to vary from 0.99 to 1.067 kg/cm³ and 0.94 to 0.96 kg/cm³. The average specific gravity of fruit and juice were found 1.04 and 0.95 kg/cm³ (Table 4.2).

4.1.1.5 Viscosity of juice

The viscosity of Nagpur mandarin fruit juice was determined and the results obtained and are presented in Table 4.2. The viscosity of juice was found to vary from 493.65 to 499.35 mPa.s with the average viscosity of 496.64 mPa.s. Viscosity measurements of food and beverage often build an important basis for the evaluation of their quality. The viscosity of juice was useful during reconstitution of dried product.

Table 4.2 Variation in volume, density and viscosity of Nagpur mandarin fruit and juice

SN	Particular	Average	Range	SD	CV
1	Fruit weight, g	162.24	143.54 to 174.35	7.57	4.66
2	Actual Volume, cm ³	155.70	144.36 to 167.98	6.59	4.23
3	Elliptical Volume, cm ³	168.55	130.01 to 207.37	18.19	10.79
4	Oblate Spheroid Volume, cm ³	171.36	131.89 to 206.14	18.10	10.57
5	Specific gravity of fruit, kg/cm ³	1.04	0.99 to 1.067	0.015	1.411
6	Specific gravity of juice, kg/cm ³	0.95	0.94 to 0.96	0.006	0.634
7	Viscosity, mPa.s	496.64	493.65 to 499.35	0.006	2.86

4.1.2 Mass and surface area modeling classifications

4.1.2.1 First classification models

In the first mass grouping (numbers 1-8 displayed in Table 4.3) models were included. The model 1, 4, 5 and 7 was considered to have the highest value of R^2 (0.978) but the lowest RSE value was found in model 7 (0.200) as compared to model 1 (0.239), model 4 (0.226) and 5 (0.239). However, for model 7, all three diameters have to be calculated in which this process was more complicated and time consuming, therefore model 1 which is having higher R^2 (0.969) and lower RSE (0.239) of the single-dimensional mass model was selected. The predicted mass model for Nagpur mandarin is shown in Fig. 4.1.

Table 4. 3 Regression mass models for Nagpur mandarin fruits

SN	Models	Parameter		Equation
		R^2	RSE	
1	$M = k_1a + k_2$	0.969	0.239	$M = 2.999a - 48.687$
2	$M = k_1b + k_2$	0.896	0.439	$M = 2.88b - 34.206$
3	$M = k_1c + k_2$	0.785	0.630	$M = 2.548c - 8.406$
4	$M = k_1a + k_2b + k_3$	0.972	0.226	$M = 2.507a + 0.522b - 49.679$
5	$M = k_1a + k_2c + k_3$	0.969	0.239	$M = 2.959a + 0.041c - 48.691$
6	$M = k_1b + k_2c + k_3$	0.912	0.403	$M = 4.426b - 1.500c - 38.731$
7	$M = k_1a + k_2b + k_3c + k_4$	0.978	0.200	$M = 2.373a + 1.593b - 0.919c - 51.622$
8	$M = k_1D_g + k_2$	0.917	0.392	$M = 2.921d_g - 37.727$
9	$M = k_1A_p + k_2$	0.835	0.552	$M = 2.484A_p - 73.29$
10	$M = k_1A_s + k_2$	0.911	0.405	$M = 0.679A_s + 62.155$
11	$M = k_1V + k_2$	0.920	0.384	$M = 1.101V - 9.224$
12	$M = k_1V_{osp} + k_2$	0.934	0.350	$M = 0.404V_{osp} + 93.024$
13	$M = k_1V_{ellip} + k_2$	0.905	0.419	$M = 0.396V_{ellip} + 95.533$

From Table 4.3, it shows that the model 3 had the lowest mass prediction power. Similar results were reported by Tabatabaefar and Rajabipour (2005) for apples, Khoshnamet *al.* (2007) for pomegranate and Soltaniet *al.* (2011) for bananas.

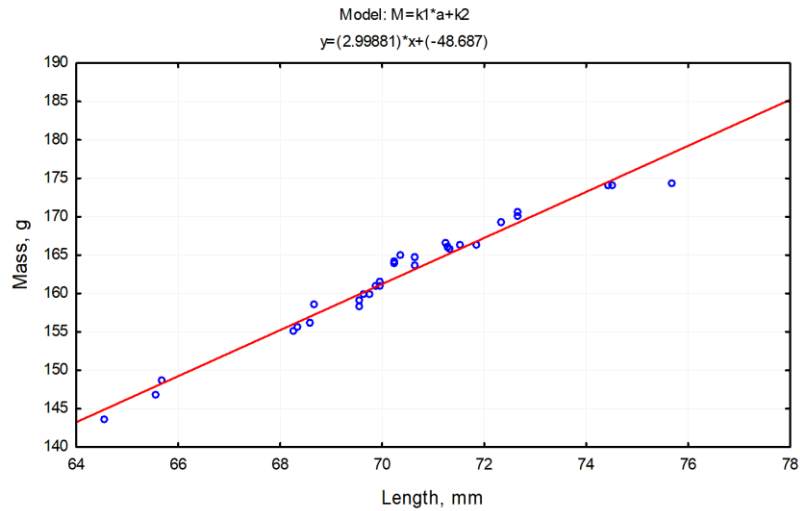


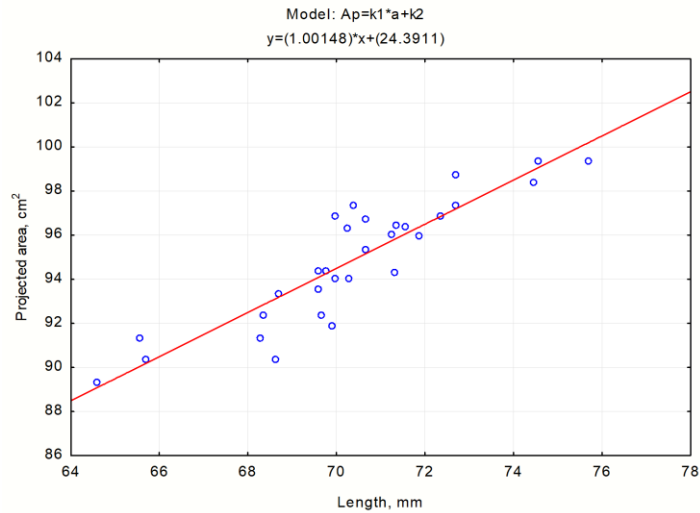
Fig. 4.1 Mass model based on length of Nagpur mandarin fruit

4.1.2.2 Second classification models

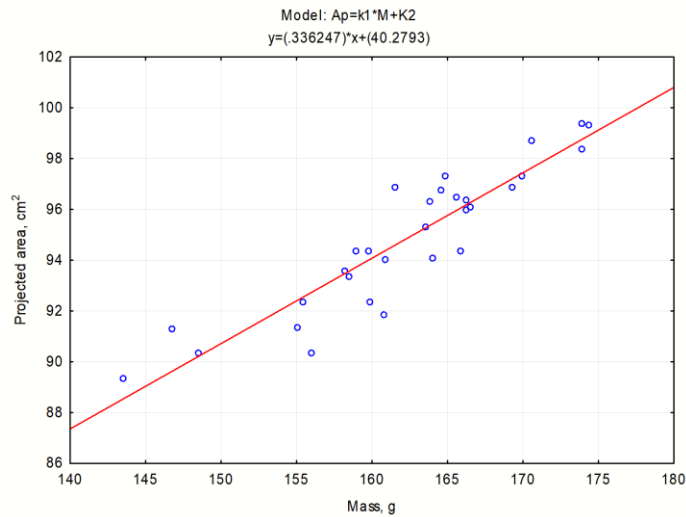
As seen in Table 4.3, the Nagpur mandarin fruit mass model based on surface area ($R^2=0.911$) and projected area ($R^2 = 0.835$) was found less acceptable. In the second group, the Nagpur mandarin fruit mass model based on surface area also had higher $R^2(0.911)$ and lower RSE (0.405) value than the model based on the projected area, but the fruit must be peeled for calculation of surface area, which destruct the fruit. Therefore this model is an impractical method. The better suited line for mass model based on the projected area had a linear pattern, while Khoshnamet *al.* (2007) considered a power modeling feature for pomegranate based on its projected area.

4.1.2.3 Third classification models

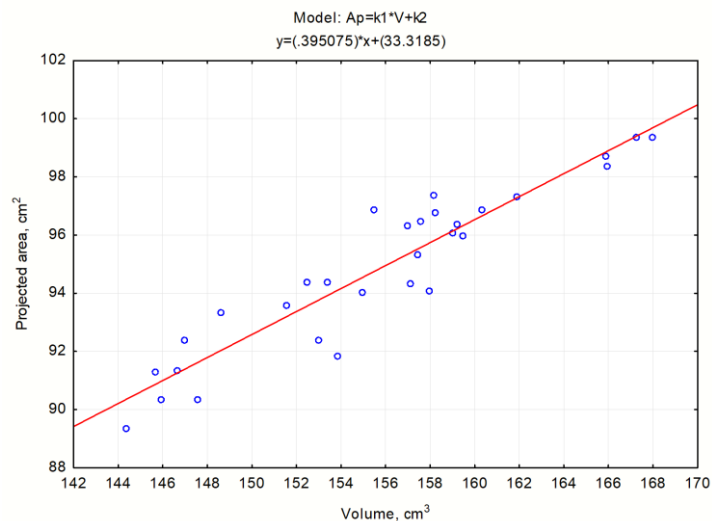
From Table 4.4, a strong association between the mass and the expected oblate spheroid volume of Nagpur mandarin fruit was assumed ($R^2 = 0.82$). The R^2 value for projected area and surface area were 0.85 and 0.875.



a) Projected area verses length



b) Projected area verses mass

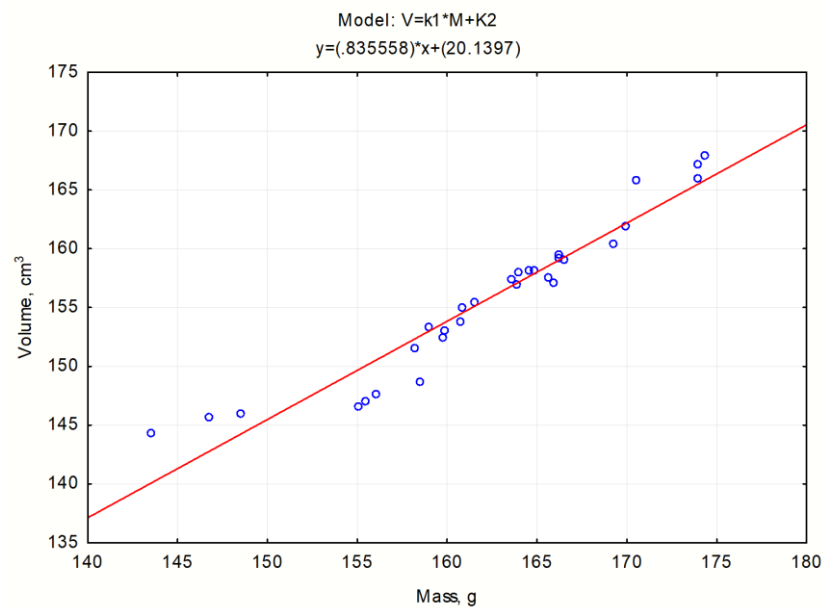


c) Projected area verses volume

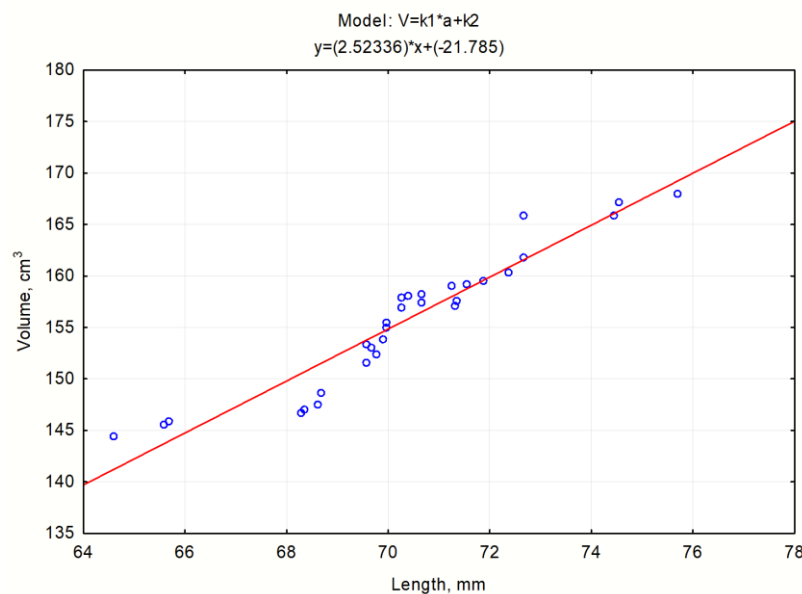
Fig. 4.2 Surface area model based on length, weight and volume of Nagpur mandarin fruit

4.1.2.4 Fourth classification models

Calculating the surface area and projected area in mandarin fruit is a troublesome method. The mass was calculated easily and reliably with only a digital balance. Therefore, these parameters were determined roughly by having a relationship between the surface / projected area of fruit to mass. There was a clear relation between the surface area and fruit mass (Fig. 4.2) with highest R^2 (0.911).



a) Volume verses weight



b) Volume verses length

Fig. 4.3 Volume model based on length and weight of Nagpur mandarin fruit

The linear model was the best fit for the results. There was little gap between linear and polynomial pattern with respect to R^2 . As shown in Fig. 4.3, the fruit mass was not ideally predicted the projected area, however the outcome was found satisfactory. The volume model also predicted highest R^2 (0.920) with correlation to mass with lower RSE value (0.334) shown in Table 4.4 and Fig. 4.3.a. Similarly the relation between volume and length is also described in Fig. 4.3.b. with higher R^2 values (0.904). This implies that the volume of the supposed ellipsoid may well predict the surface and area. The configuration of the saffron crocus corm mass dependent on the approximate volume of the present and presumed spheres, Oblate spheroid and ellipsoid types has also been proposed by Hassan-Beygi *et al.* (2010).

Table 4. 4 Regression volume models for Nagpur mandarin fruits

SN.	Models	Parameter		Equation
		R^2	RSE	
1	$V = k_1a + k_2$	0.904	0.366	$V = 2.523a - 21.785$
2	$V = k_1b + k_2$	0.825	0.495	$V = 2.411b - 8.501$
3	$V = k_1c + k_2$	0.721	0.625	$V = 2.127c + 13.240$
4	$V = k_1a + k_2b + k_3$	0.906	0.363	$V = 2.244a + 0.297b - 22.349$
5	$V = k_1a + k_2c + k_3$	0.904	0.366	$V = 2.573a - 0.052c - 21.78$
6	$V = k_1b + k_2c + k_3$	0.841	0.472	$V = 3.745b - 1.298c - 12.415$
7	$V = k_1a + k_2b + k_3c + k_4$	0.911	0.353	$V = 2.130a + 1.201b - 0.776c - 23.98$
8	$V = k_1D_g + k_2$	0.847	0.462	$V = 2.446D_g - 11.742$
9	$V = k_1A_p + k_2$	0.850	0.458	$V = 0.572A_p + 71.491$
10	$V = k_1A_s + k_2$	0.875	0.419	$V = 2.214A_s - 54.272$
11	$V = k_1M + k_2$	0.920	0.334	$V = 0.836M + 20.140$

4.1.3 Fractional classification of Nagpur mandarin fruit

4.1.3.1 Pulp weight

After removal of peel, the weight of the fruit pulp was assessed using a top pan balance and the data obtained are reported in Appendix A. The pulp weight of fruit was found to vary in the range from 104.25 to

149.25 g with an average weight of 128.54 g and a standard deviation of 7.77 (Table 4.5). It was observed that the Nagpur mandarin fruit having higher weight had a better pulp recovery.

4.1.3.2 Peel thickness and weight

The peel thickness and weight of fruit was found to vary in the range of 2.31 to 4.24 mm and 22.98 to 38.57 g with an average peel thickness and weight of peel was 3.02 mm and 31.04 g with a standard deviation of 0.52 and 3.74 (Table 4.5). Similar result reported by Bhatnagar *et al.* (2015) for Nagpur mandarin.

4.1.3.3 Seed weight and number of seeds

The seed weight and number of seeds in fruit were found to vary in the range of 0.61 to 3.26 g and 3 to 9. The average seed weight and number of seeds were found 1.34 g and 5.87 $\approx$ 6 with standard deviation of 0.62 and 1.59 (Table 4.5).

Table 4.5 Variation in fruit fractions and pulp recovery of Nagpur mandarin fruit

SN	Particular	Average	Range	SD	CV
1	Pulp weight, g	128.54	104.25 to 149.25	10.00	7.77
2	Peel thickness, mm	3.02	2.31 to 4.24	0.52	17.03
3	Peel weight, g	31.04	22.98 to 38.57	3.74	12.40
4	Number of seeds	5.87	3 to 9	1.59	27.13
5	Seed weight, g	1.34	0.61 to 3.26	0.62	46.66
6	Pomace weight, g	50.19	41.51 to 57.64	3.83	7.63
7	Juice content, g	49.35	41.81 to 57.64	4.90	7.63
8	Juice content, %	29.73	24.42 to 37.04	3.23	10.87
9	Juice to pomace ratio	0.60	0.43 to 0.85	0.08	13.42
10	Peel to pomace ratio	0.62	0.48 to 0.83	0.10	14.77

4.1.3.4 Pomace weight

The pomace weight was found to in the range of 41.51 to 57.64 g with an average weight of 50.19 g and a standard deviation of 3.83 (Table 4.5).

4.1.3.5 Juice content and recovery

The juice content of fruit was found to vary in the range of 41.81 g to 57.64 g with the average juice content of 49.35 g and standard deviation of 4.90 (Table 4.5). Similar result reported by Bhatnagar *et al.* (2015) for Nagpur mandarin.

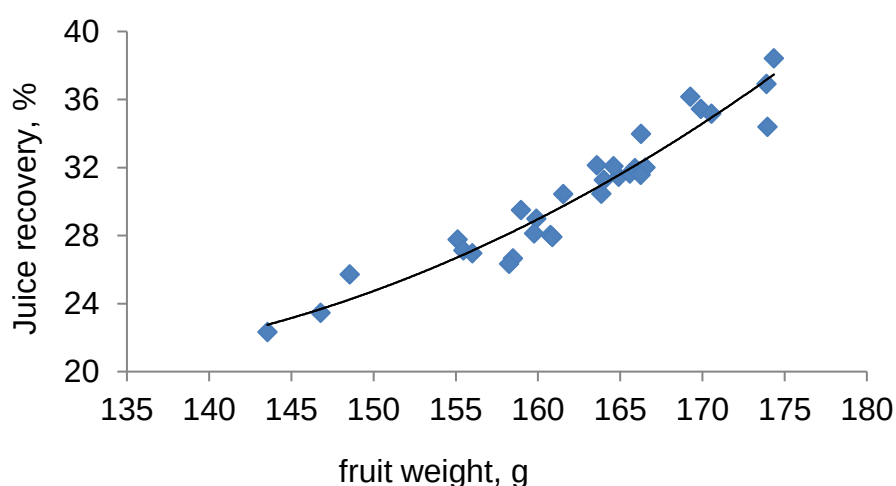


Fig 4.4 Relationship between weight and juice recovery of Nagpur mandarin fruit

$$y = 0.007x^2 - 1.743x + 129.0 \quad R^2 = 0.921 \quad (4.1)$$

Where, y is juice recovery (%) and x is fruit weight (g).

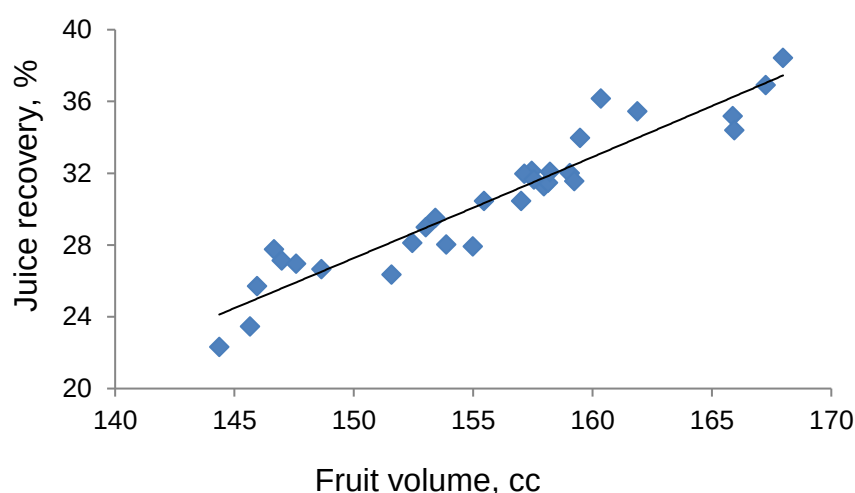


Fig 4.5 Relationship between voloume and juice recovery of Nagpur mandarin fruit

$$y = 0.0004x^2 + 0.451x - 48.55 \quad R^2 = 0.895 \quad (4.2)$$

Where, y is juice recovery (%) and x is fruit volume (cc).

In the case of the Nagpur mandarin fruit, the maximum juice recovery was 37.04%, while minimum was 24.42% and the standard deviation was 3.23 (Table 4.5). The average juice recovery was 29.73%. The fruit with higher weight was observed to higher pulp weight with higher recovery of the juice.

It was also found during the experiment that the weight of fruit and its juice recovery had a certain relation. The relation between the weight or volume of the fruit and the recovery of juice is indicated in Fig. 4.4 and 4.5. After a second degree polynomial regression the recovery of juice was related with fruit weight and volume ($R^2 > 0.895$).

4.1.3.6 Juice to pomace ratio and peel to pomace ratio

The juice to pomace ratio and peel to pomace ratio of fruit were found to vary in the range of 0.43 to 0.85 and 0.48 to 0.83 with an average juice to pomace ratio and peel to pomace ratio were 0.60 and 0.62 with standard deviation of 0.08 and 0.10 (Table 4.5).

4.1.4 Physical parameters of Nagpur mandarin fruit segment

The size of segment of fruit was determined on the basis of estimation of length, width and thickness. Data were given on the fruits length, width and thickness in appendix A and summarised in Table 4.6 and found to vary in the ranges from 42.08 to 50.14, 15.24 to 25.05 and 9.00 to 16.19 mm, respectively.

The data for geometric mean diameter and sphericity was found in the range of 18.10 to 26.48 and 0.42 to 0.54. The mean values of the size of segment in terms of thickness, width and length were found 45.05, 19.37 and 11.44 mm, respectively. The average geometric mean diameter and sphericity of fruit was found 21.48 mm and 0.476. The number of segments, weight of each segment and projected area of segment were found in the range from 7 to 14, 9.24 to 14.25 g and 18.16 to 26.29 mm², respectively. The mean values were 10.87, 11.53 g and 21.43 mm² for

number of segment, weight of segment and projected area of segment, respectively.

Table 4.6 Variation in physical properties of Nagpur mandarin fruit segments

SN.	Particular	Average	Range	SD	CV
1	Length of segment, mm	45.05	42.08 to 50.14	2.21	50.14
2	Width of segment, mm	19.37	15.24 to 25.05	2.32	11.96
3	Thickness of segment, mm	11.44	9.00 to 16.19	1.90	16.63
4	geometric mean of segment, mm	21.48	18.10 to 26.48	2.09	9.75
5	Sphericity of segment	0.476	0.42 to 0.54	0.031	6.43
6	No. of segments	10.87	7 to 14	2.00	18.36
7	Weight of segments, g	11.53	9.24 to 14.25	1.42	12.36
8	Projected area of segment	21.43	18.16 to 26.29	2.18	10.17

4.1.5 Chemical parameters of Nagpur mandarin juice

The chemical parameters i.e. pH, TSS, acidity, ascorbic acid, total sugar, reducing and non reducing sugar of Nagpur mandarin fruit juice were determined and summarized in Table 4.7. Also TSS to acid ratio and sugar to acid ratio was calculated. The data obtained on Ph, TSS, acidity and ascorbic acid of fruit juice were found to vary from 2.21 to 2.70, 10.59 to 11.25 °B, 0.54 to 0.69% and 41.45 to 43.92 mg/100g, respectively. The data for total, reducing and non-reducing sugar were in the range of 7.21 to 7.72%, 2.29 to 3.44% and 4.21 to 4.92%, respectively. The range of sugar to acid ratio and TSS to acid ratio were found 10.45 to 14.30 and 16.30 to 19.61.

The mean values of the chemical properties size i.e. pH, TSS, acidity, ascorbic acid, total sugar, reducing and non-reducing sugar of Nagpur mandarin fruit juice were found 2.52, 10.82 °B, 0.62%, 42.59 mg/100g, 7.53%, 3.03%, 4.50%, 12.30 and 17.60, respectively. Similar results for ascorbic acid (41.83 mg/100g), total sugar (5.75 to 8.87%) and reducing sugar (3.73 to 5.76%) were reported by Bhatnagar *et al.* (2015)

for Nagpur mandarin. Patil *et al.* (2011) reported 9.68 °B TSS for Nagpur mandarin. Shravan *et al.* (2018) reported 11 °B TSS and 46.5 mg/100g for sweet orange fruit.

Table 4.7 Variation in chemical parameters of juice

SN	Particular	Average	Range	SD	CV
1	Ph	2.52	2.21 to 2.70	0.27	0.11
2	TSS, °B	10.82	10.59 to 11.25	0.37	0.03
3	Acidity, %	0.62	0.54 to 0.69	0.08	0.12
4	Ascorbic acid, mg/100g	42.59	41.45 to 43.92	1.25	0.03
5	Total sugar, %	7.53	7.21 to 7.72	0.28	0.04
6	Reducing sugar, %	3.03	2.29 to 3.44	0.64	0.21
7	Non reducing sugar, %	4.50	4.21 to 4.92	0.37	0.08
8	Sugar to acid ratio	12.30	10.45 to 14.30	1.93	0.16
9	TSS to acid ratio	17.60	16.30 to 19.61	1.77	0.10

Part I Foaming properties of Nagpur mandarin juice

Based on the results of preliminary investigations on foam expansion and overall acceptability, the range of input variables were fixed for further experimentation of optimization as soy protein isolate 90% (3 to 9%), GMS (1 to 5%), sugar (5 to 15%), CMC (1 to 3%) in artificial foaming and soy protein isolate 3 to 9%), guar gum (0.3 to 0.9%), sugar (5 to 15%) and whipping time (3 to 9 min). Similar levels were selected according to previous investigation done by various researchers (Kandasamyet *al.*, 2012a; Krasaekoopt and Bhatia, 2012; Kaushal *et al.*, 2013; Faladeet *al.*, 2003; Thaisong and Rojanakorn, 2011; Bag *et al.*, 2011; Zhengnet *al.*, 2009; Kandasamyet *al.*, 2012b; Zheng *et al.*, 2011; Azizpouret *al.*, 2014).

4.2 Effect of Artificial Foaming Agents, Stabilizer and Sugar Content on the Foaming Properties of Nagpur Mandarin Juice

The experiments were conducted for foaming treatment to the prepared Nagpur mandarin juice by adding soy protein isolate (3 to 9%), GMS (1 to 5%), sugar (5 to 15%), CMC (1 to 3%) with whipping time (3 to 9 min). The sample was analysed for their foaming properties i.e. foam expansion, foam stability and foam density. The analysis was done using CCD design under response surface methodology which is explained in section 3.10. The variation of foam properties due to process parameters were discussed in following sections.

4.2.1 Effect of artificial foaming agent on foam expansion of juice

The variation in foam expansion by changing concentration of foaming agents, foam stabilizer, sugar and time of whipping are presented in Table 4.18.

From Table 4.8, the foam expansion of Nagpur mandarin juice was found to ranges from 36.25 to 15.25%. The maximum foam expansion was obtained as 36.25% for 4% soy protein isolate, 10% sugar, 3.5 % GMS, 2% CMC and 11.46 min whipping time. Similarly, the minimum foam expansion was obtained as 15.25% for 4% soy protein isolate, 10% sugar, 3.5 % GMS, 2% CMC and 0.54 min whipping time.

The foam expansion increases with increase in concentration of foaming agent viz. SPI and GMS. This was due to protein present in the foaming agents. During whipping the protein become denatured at the interphase and interaction with one other. Similar observations were recorded for banana (Sanket and Castaigne, 2004), for beal (Bag *et al.*, 2011).

The eqn. 4.3 gives the predicted per cent foam expansion, as a function of foaming agent soy protein isolate (A), GMS power (B), sugar content (C), foam stabilizer i.e. CMC power (D) and whipping time (E) expressed in coded form. This equation was obtained using reduced

quadratic model where factors with F-values less than one were rejected as described by Snedecor and Cochran (1967).

Table 4.8 Foam expansion of juice with using artificial foaming agent with process parameters

Sr. No.	Soy protein isolate (90%) (%)	Sugar content (%)	GMS (%)	CMC (%)	Whipping time (min)	Foam Expansion (%)
1	6.00	15.00	2.00	3.00	3.00	25.37
2	6.00	5.00	5.00	3.00	3.00	27.54
3	2.00	15.00	5.00	1.00	9.00	28.37
4	6.00	15.00	5.00	1.00	3.00	27.54
5	6.00	15.00	2.00	1.00	9.00	30.26
6	6.00	5.00	2.00	3.00	9.00	28.57
7	2.00	5.00	5.00	3.00	9.00	35.48
8	2.00	15.00	2.00	3.00	9.00	33.26
9	6.00	5.00	5.00	1.00	9.00	31.51
10	2.00	15.00	5.00	3.00	3.00	34.21
11	2.00	5.00	2.00	1.00	3.00	22.48
12	0.36	10.00	3.50	2.00	6.00	32.43
13	7.64	10.00	3.50	2.00	6.00	35.90
14	4.00	0.89	3.50	2.00	6.00	27.54
15	4.00	19.11	3.50	2.00	6.00	31.04
16	4.00	10.00	0.77	2.00	6.00	25.37
17	4.00	10.00	6.23	2.00	6.00	34.31
18	4.00	10.00	3.50	0.18	6.00	28.35
19	4.00	10.00	3.50	3.82	6.00	32.25
20	4.00	10.00	3.50	2.00	0.54	15.25
21	4.00	10.00	3.50	2.00	11.46	36.25
22	4.00	10.00	3.50	2.00	6.00	31.51
23	4.00	10.00	3.50	2.00	6.00	32.43
24	4.00	10.00	3.50	2.00	6.00	30.56
25	4.00	10.00	3.50	2.00	6.00	31.51
26	4.00	10.00	3.50	2.00	6.00	31.04
27	4.00	10.00	3.50	2.00	6.00	30.56
28	4.00	10.00	3.50	2.00	6.00	31.55

The result for foam expansion was analysed by stepwise regression analysis method and shown in Table 4.9. The quadratic model better matched to the experimental results and for linear, quadratic and interaction conditions the model was significant for determination of foam expansion. The R^2 value was determined by the least square

methodology and was 0.991 that indicated the model was well fitted to the results. In this case linear terms (A, B, C, D and E), interaction terms (AB, AE, BC, BD, BE, CD and DE) and quadratic terms (A^2 , B^2 , C^2 , D^2 and E^2) are significant model terms ($P < 0.01$). The effect of the interactive terms (AC and AD) was found non significant.

Table 4.9 ANOVA for effect on foam expansion of Nagpur mandarin juice using artificial foaming agent

Source	Sum of Squares	Df	Mean Square	F-value
Model	517.37	17	30.43	65.21***
A-Soy protein isolate, %	13.44	1	13.44	28.79***
B-Sugar content, %	7.16	1	7.16	15.34**
C-GMS powder, %	54.51	1	54.51	116.79***
D-CMC powder, %	11.10	1	11.10	23.79**
E-Whipping time, min	280.48	1	280.48	600.99***
AB	4.34	1	4.34	9.30*
AE	13.21	1	13.21	28.30**
BC	13.62	1	13.62	29.18**
BD	59.18	1	59.18	126.80***
BE	4.68	1	4.68	10.02*
CD	29.51	1	29.51	63.22***
CE	19.78	1	19.78	42.39***
A^2	14.59	1	14.59	31.25**
B^2	9.30	1	9.30	19.93**
C^2	5.15	1	5.15	11.04*
D^2	2.63	1	2.63	5.64*
E^2	64.33	1	64.33	137.84***
Residual	4.67	10	0.47	
Lack of Fit	2.06	4	0.51	1.18 ^{NS}
Pure Error	2.61	6	0.43	
Cor Total	522.04	27		
Std. Dev.	0.68			
C.V. %	2.27			
R²	0.991			
Adjusted R²	0.976			
Predicted R²	0.863			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS - Non significant

The lack of fit F value of 1.18 implies that it is not significant relative to the pure error. In comparison, the expected R^2 was 0.863 with modified R^2 of 0.976 is a fair agreement. This is less than 0.2 disparity

which shows not to be included in the design with the non-significant terms. Each factor's comparative influence was observed in the F values of the ANOVA (Tables 4.9) and also in the magnitude of coefficient of the coded variables.

The results of the coefficient of variance in Eqn 4.3 suggested that the foaming agent, foam stabilizer, sugar and whipping time during foaming of Nagpur mandarin juice were highly significant at 1% level. F values showed that the most important element was soy protein isolate, GMS and whipping time. The regression equation which describes the impact of process variables on foam expansion in terms of variable coded and actual values is shown in the following equation

$$\begin{aligned} \text{Foam expansion (\%)} = & 31.350 + 1.210A + 0.754B + 2.430C + 1.100D + \\ & 5.510E + 0.975AB - 1.970AE + 1.600 BC + \\ & 3.600BD - 0.940BE + 2.940CD - 1.820CE + \\ & 0.818A^2 - 0.653B^2 - 0.347D^2 - 1.720E^2 \end{aligned}$$

($R^2 = 0.863$) (4.3)

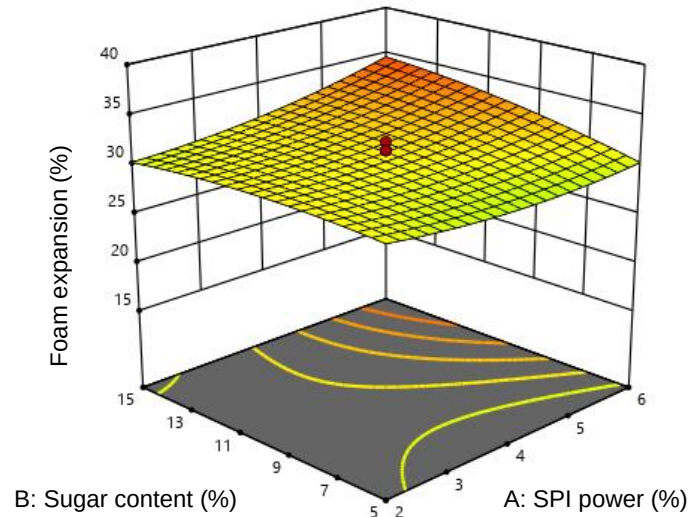
Replacing A, B, C, D, and E with (Sp-4)/2, (Su-10)/5, (Gm - 3.5)/1.5, (Cm -2)/1 and (Wt -6)/3, respectively [Eqn. 3.27] in Eqn. (4.3), the foam expansion in real terms of soy protein isolate, sugar, GMS, CMC and whipping time is given in the following Eqn.

$$\begin{aligned} \text{Foam expansion (\%)} = & 17.682 - 0.038\text{Sp} - 1.529\text{Su} - 0.502\text{Gm} \\ & - 1.584\text{Cm} + 7.485\text{Wt} + 0.097\text{SpSu} - \\ & 0.328\text{SpWt} + 0.214\text{SuGm} + 0.720\text{SuCm} - \\ & 0.063\text{SuWt} + 1.963\text{GmCm} - 0.405\text{GmWt} + \\ & 0.205\text{Sp}^2 - 0.026\text{Su}^2 - 0.216\text{Gm}^2 - \\ & 0.347\text{Cm}^2 - 0.191\text{Wt}^2 \end{aligned}$$

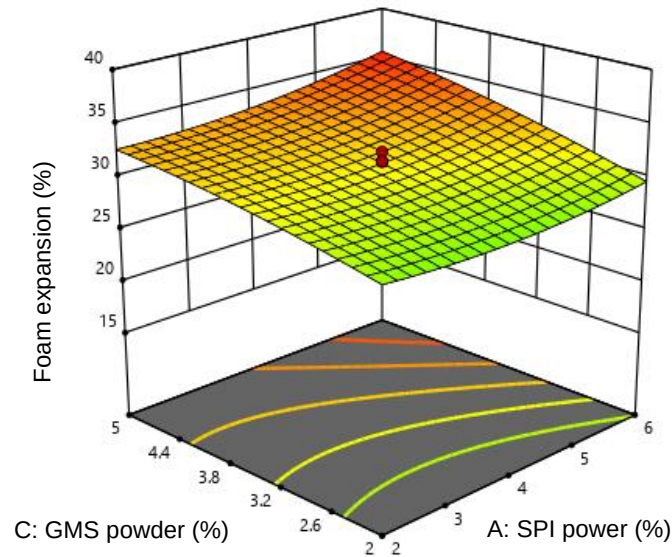
($R^2 = 0.991$) (4.4)

In coded equation the positive linear terms whipping time, GMS, soy protein isolate, CMC and sugar content indicated that the increase in foam expansion with increase in linear terms. The most prominent factor which affects foam expansion was found whipping time followed by GMS, soy protein isolate, CMC and sugar content. The quadratic terms soy

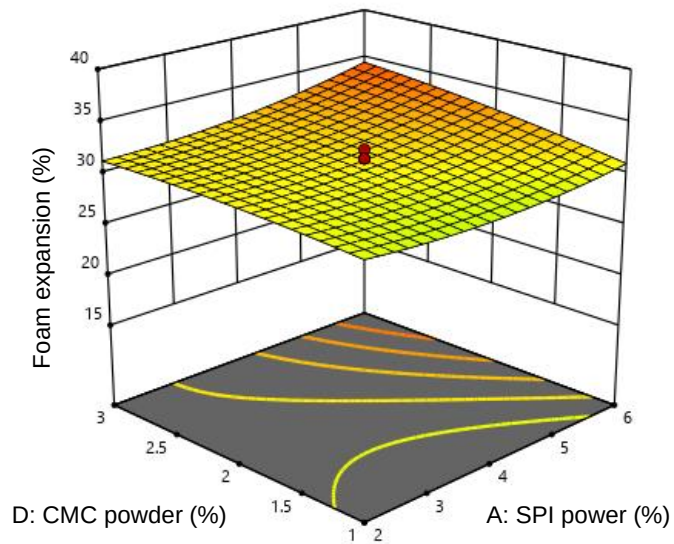
protein isolate, sugar, CMC and whipping time were also significant, indicating nonlinear variation in foam expansion due to change in protein isolate and whipping time. The interaction terms were significant which indicates the influence of combined effect on foam expansion.



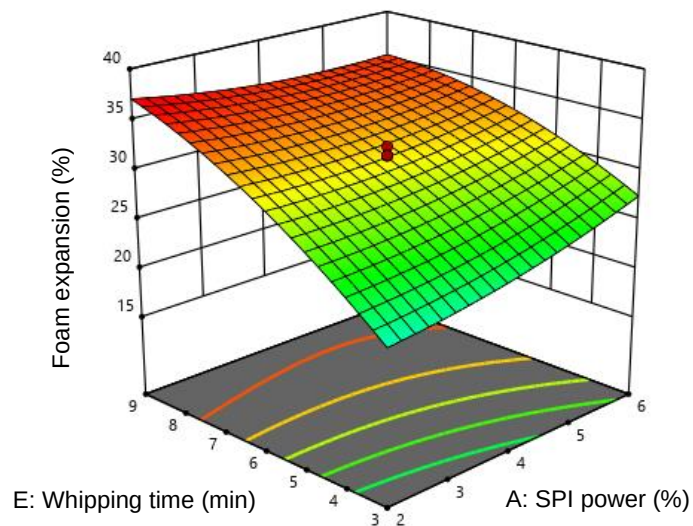
a) At constant GMS, CMC and WT



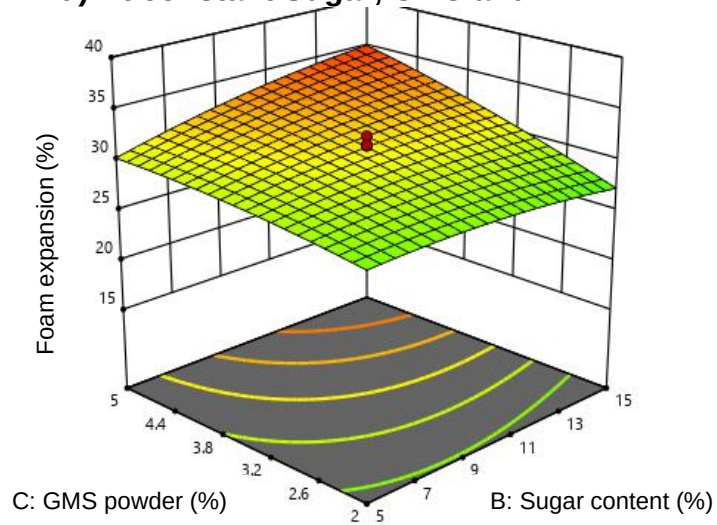
b) At constant sugar, CMC and WT



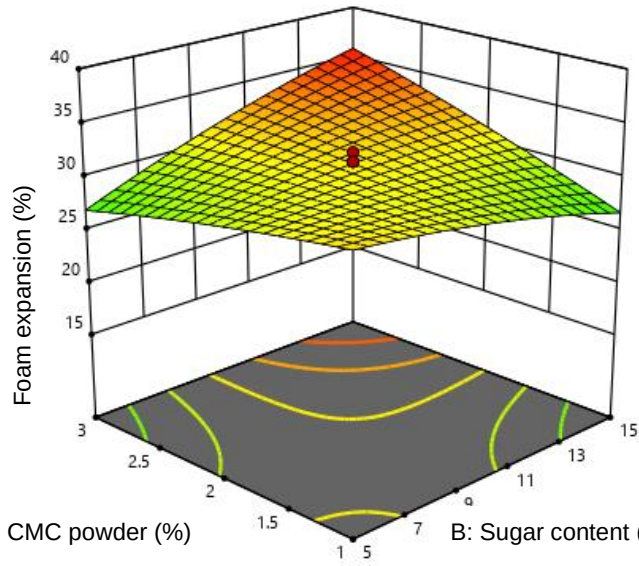
c) At constant GMS, sugar and WT



d) At constant Sugar, CMC and WT

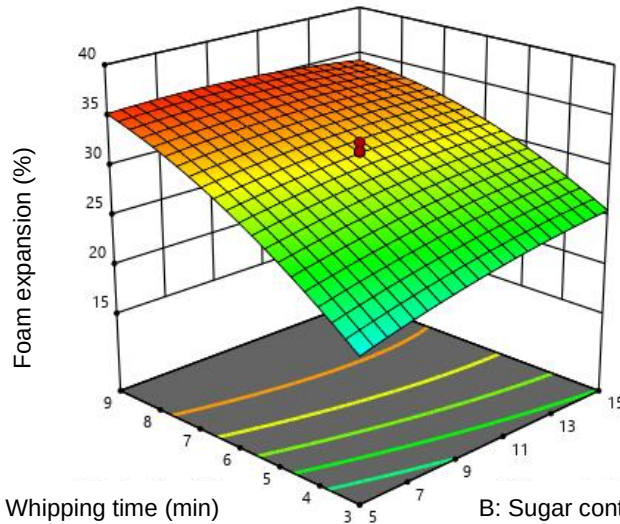


e) At constant GMS, SPI and WT



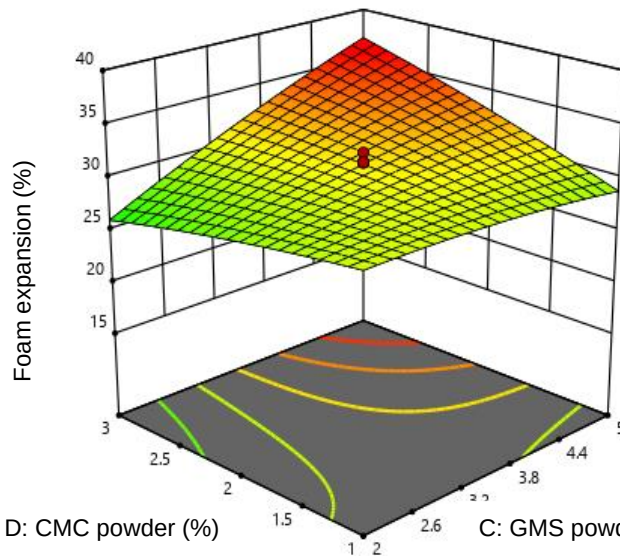
D: CMC powder (%) B: Sugar content (%)

f) At constant GMS, SPI and CMC



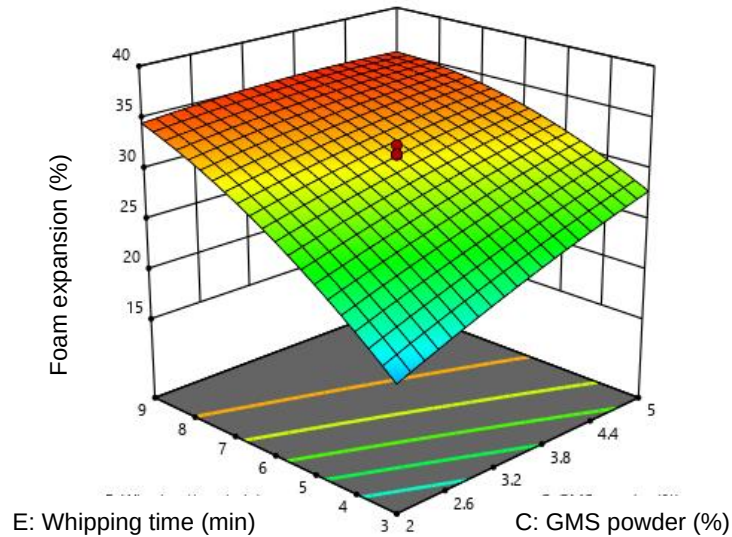
E: Whipping time (min) B: Sugar content (%)

g) At constant SPI, GMS and CMC

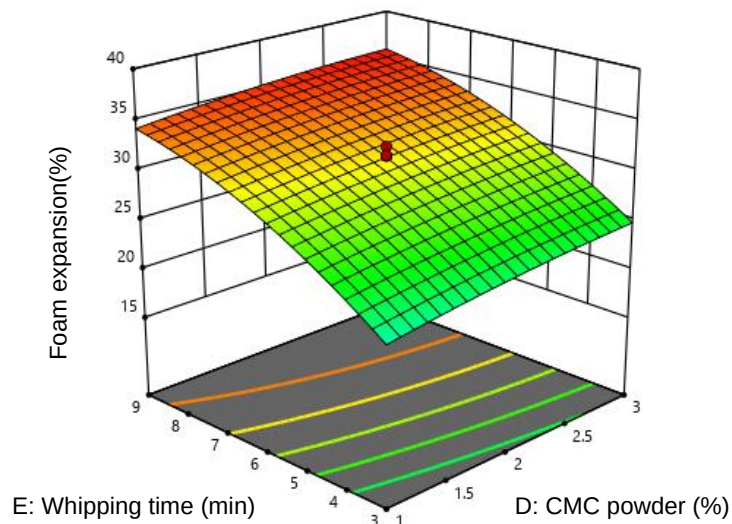


D: CMC powder (%) C: GMS powder (%)

h) At constant SPI, sugar and WT



i) At constant SPI, sugar and CMC



j) At constant SPI, sugar and GMS

Fig. 4.6 Effect of artificial foaming agents, stabilizer, sugar content and whipping time on foam expansion during foaming of Nagpur mandarin juice

To represent the cumulative influence of five variables on the expansion of foams, two variables were generated for the corresponding model, the reaction surface and the contour plots (Fig. 4.6 a, b, c, d, e, f, g, h, I and j). From Fig. 4.6, it reveals that the foam expansion increased with increase in concentration of soy protein isolate, GMS, CMC and whipping time. Similar trends were reported by Kandasamy *et al.* (2012a) for papaya, Sankat and Castaigne (2004) for banana, Bag *et al.* (2011) for bael fruit pulp.

4.2.2 Effect of artificial foaming agentsonfoam density of juice

The foam density of Nagpur mandarin juice concentrates varied from 0.61 to 0.82 g/cm³ as shown in Table 4.10.

Table 4.10 Foam density of juice with using artificial foaming agent with process parameters.

Sr. No.	Soy Protein Isolate (90%) (%)	Sugar content (%)	GMS (%)	CMC (%)	Whipping Time (min)	Foam Density (g/cm ³)
1	6.00	15.00	2.00	3.00	3.00	0.71
2	6.00	5.00	5.00	3.00	3.00	0.70
3	2.00	15.00	5.00	1.00	9.00	0.67
4	6.00	15.00	5.00	1.00	3.00	0.70
5	6.00	15.00	2.00	1.00	9.00	0.71
6	6.00	5.00	2.00	3.00	9.00	0.69
7	2.00	5.00	5.00	3.00	9.00	0.63
8	2.00	15.00	2.00	3.00	9.00	0.61
9	6.00	5.00	5.00	1.00	9.00	0.66
10	2.00	15.00	5.00	3.00	3.00	0.64
11	2.00	5.00	2.00	1.00	3.00	0.82
12	0.36	10.00	3.50	2.00	6.00	0.66
13	7.64	10.00	3.50	2.00	6.00	0.62
14	4.00	0.89	3.50	2.00	6.00	0.70
15	4.00	19.11	3.50	2.00	6.00	0.67
16	4.00	10.00	0.77	2.00	6.00	0.72
17	4.00	10.00	6.23	2.00	6.00	0.62
18	4.00	10.00	3.50	0.18	6.00	0.67
19	4.00	10.00	3.50	3.82	6.00	0.67
20	4.00	10.00	3.50	2.00	0.54	0.82
21	4.00	10.00	3.50	2.00	11.46	0.65
22	4.00	10.00	3.50	2.00	6.00	0.66
23	4.00	10.00	3.50	2.00	6.00	0.66
24	4.00	10.00	3.50	2.00	6.00	0.67
25	4.00	10.00	3.50	2.00	6.00	0.66
26	4.00	10.00	3.50	2.00	6.00	0.67
27	4.00	10.00	3.50	2.00	6.00	0.67
28	4.00	10.00	3.50	2.00	6.00	0.67

The maximum foam density was obtained as 0.82 g/cm³ for 4% soy protein isolate, 10% sugar, 3.5% GMS, 2% CMC and 0.54 min

whipping time while minimum foam density was obtained as 0.614 g/cm³ for 2% soy protein isolate, 15% sugar, 2% GMS, 3% CMC and 9 min whipping time. During whipping, air bubble will trapped in the foam and gave rise to to lower foam density (Karim and Wei, 1999for star fruit; Bag *et al.*, 2011 for beal). The more air incorporated during whipping, the lower the foam density (Falade *et al.*, 2003 for cowpea). Foam density was commonly used to evaluate the whipping properties. The foam density displayed a low value when more air was incorporated into the foam during whipping. The presence of more air in the foam increases the whipping ability. The foam density decreases when the concentration of GMS, CMC and sugar increase. The foam density was higher in prolonged drying time leading to poor product quality. Similarly the foam density was found in the range of 0.3 to 0.6 g/cm³ by Norhazirah *et al.* (2017) for *Nigella sativa* beverage.

The experimental data were fitted in polynomial second order Eqn. 3.28. The eqn. 4.5 gives the predicted foam density, as a function of foaming agent soy protein isolate (A), GMS power (B), sugar content (C), foam stabilizer i.e. CMC power (D) and whipping time (E) expressed in coded form. This equation was developed using a reduced quadratic model, which stated by Snedecor and Cochran (1967) to reject factors with F values less than one. From Table 4.11 it shows that for linear, quadratic and interaction terminology, the quadratic model was more suitable for the experimental results, and it was found significant.

The R² value was determined using the least quadratic approach and displayed a strong model fit with the data at 0.9909. Model F of 87.22 suggests that it is an effective model (P < 0.001). P-values less than 5% indicate that the model terms were significant. In this case linear terms (A, B, C and E), interaction terms (AC, AD, AE, BD, BE, CD, CE and DE) and quadratic terms (A², B² and E²) were found significant. The linear term CMC (D), interactive terms of soy protein isolate with sugar (AB), sugar with CMC (BC) and quadratic terms (C² and D²) were found non significant on foam density (Table 4.11).

Table 4.11 ANOVA for effect on foam density of Nagpur mandarin juice using artificial foaming agents.

Source	Sum of Squares	Df	Mean Square	F-value
Model	0.050	15	0.003	87.22***
A-Soy Protein isolate, %	0.001	1	0.001	11.34**
B-Sugar content, %	0.001	1	0.001	22.28**
C-GMS powder, %	0.008	1	0.008	220.71***
E-Whipping time, min	0.021	1	0.020	534.87***
AC	0.001	1	0.000	6.72*
AD	0.001	1	0.001	22.46**
AE	0.004	1	0.004	99.78***
BD	0.009	1	0.009	224.49***
BE	0.001	1	0.001	10.17*
CD	0.003	1	0.003	69.75***
CE	0.004	1	0.004	100.32***
DE	0.001	1	0.001	33.09***
A ²	0.002	1	0.002	41.92***
B ²	0.001	1	0.001	18.59*
E ²	0.009	1	0.009	230.02***
Residual	0.001	12	0.000	
Lack of Fit	0.000	6	0.000	0.89 ^{NS}
Pure Error	0.000	6	0.000	
Cor Total	0.050	27		
Std. Dev.	0.006			
C.V. %	0.677			
R²	0.9909			
Adjusted R²	0.9796			
Predicted R²	0.8853			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS

- Non significant

The predicted R² of 0.8853 was also compatible with the modified R² of 0.9796 in realistic terms. This was less than 0.2 disparity which shows not to be included in the design with the non-significant terms. This layout was also used for concept space navigation. The results of analysis of variance shows that the process parameters such as foaming agents,

foam stabilisers, sugar and whipping were highly significant at 1% level in linear terms.

The comparative effect of each factor on foam density was observed and presented in the ANOVA (Tables 4.11) and also by the magnitudes of coefficients of the coded variables. The F values indicated that GMS and whipping time was the most influencing factor ($P < 0.001$) followed by soy protein isolate and sugar content which was less effective ($P < 0.01$) over foam density. The regression equation, in terms of the coded variable values, is used to explain the impact of method variables on foam density

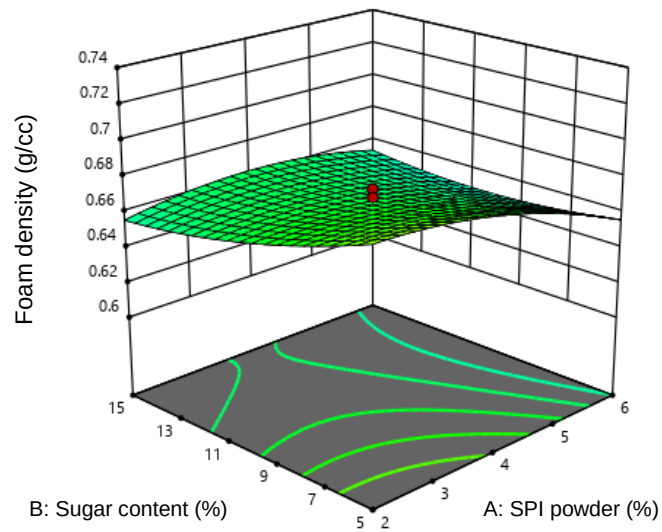
$$\begin{aligned} \text{Foam density (kg/cm}^3\text{)} = & 0.669 - 0.007A - 0.010B - 0.030C - \\ & 0.049E + 0.009AC - 0.013AD + 0.024AE - \\ & 0.045BD + 0.011BE - 0.024CD + 0.024CE \\ & - 0.015DE - 0.009A^2 + 0.006B^2 - 0.020E^2 \\ & (R^2 = 0.8853)(4.5) \end{aligned}$$

Replacing A, B, C, D, and E with (Sp-4)/2, (Su-10)/5, (Gm - 3.5)/1.5, and (Wt -6)/3, respectively [Eqn. 3.27] in Eqn. (4.5), the foam density in real terms of soy protein isolate, sugar, GMS and whipping time is given in the following Eqn.

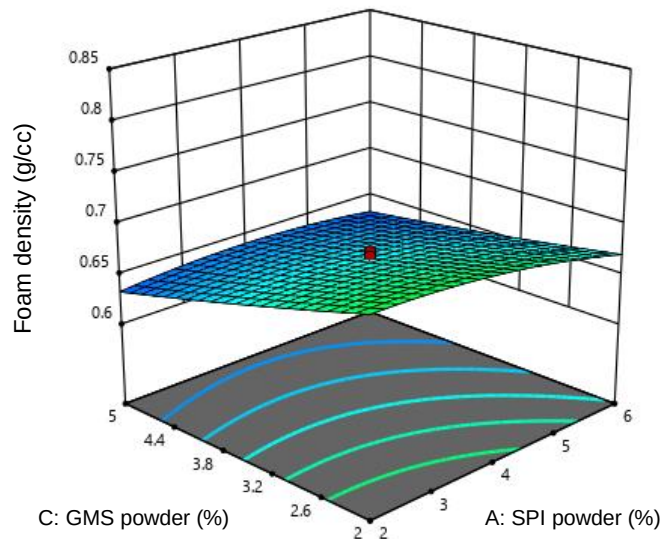
$$\begin{aligned} \text{Foam density (kg/cm}^3\text{)} = & 0.687 - 0.0142\text{Sp} + 0.0147\text{Su} - 0.039\text{Gm} + \\ & 0.126\text{Wt} + 0.006\text{SpGm} + 0.002\text{SpCm} + \\ & 0.0002\text{SpWt} - 0.007\text{SuCm} - 0.001\text{SuWt} - \\ & 0.005\text{GmCm} + 7.76 \times 10^{-5} \text{GmWt} - 0.010 \\ & \text{CmWt} - 0.002\text{Sp}^2 + 0.0002\text{Su}^2 + 0.002\text{Wt}^2 \\ & (R^2 = 0.993) \quad (4.6) \end{aligned}$$

The significant linear negative terms of Eqn. 4.5 indicated that foam density decreased with increased soy protein isolate, sugar content, GMS and whipping time. The most prominent factor which affects foam density was found whipping time followed by GMS, sugar content and soy protein isolate. The presence of negative interaction terms indicate the

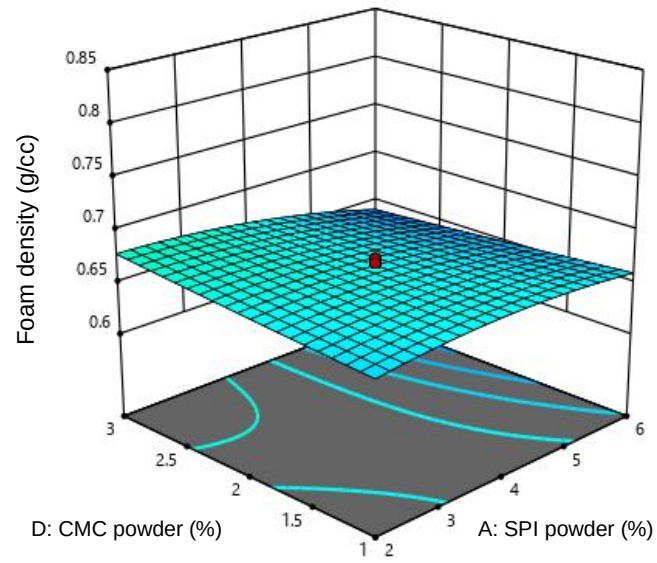
decreased foam density. All the coefficients of foam density were decreased with increased in coefficients of foam expansion.



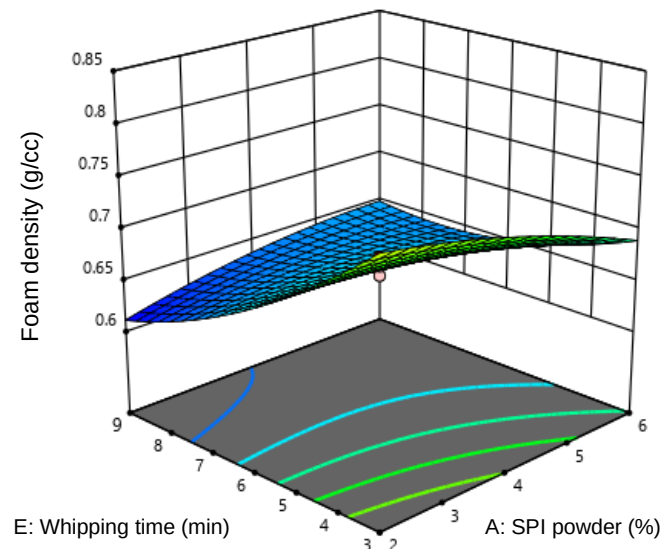
a) At constant GMS, CMC and WT



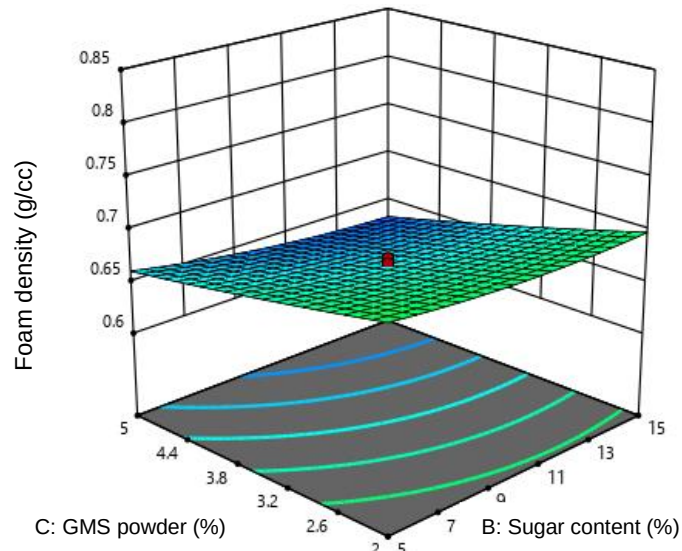
b) At constant sugar, CMC and WT



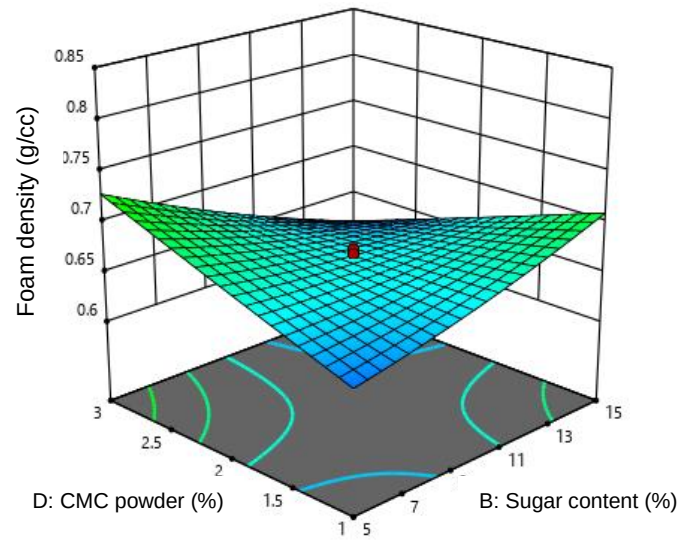
c) At constant GMS, sugar and WT



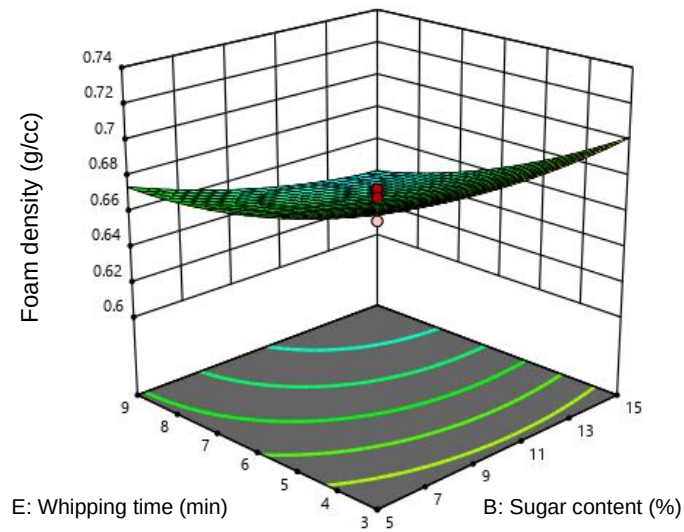
d) At constant Sugar, GMS and CMC



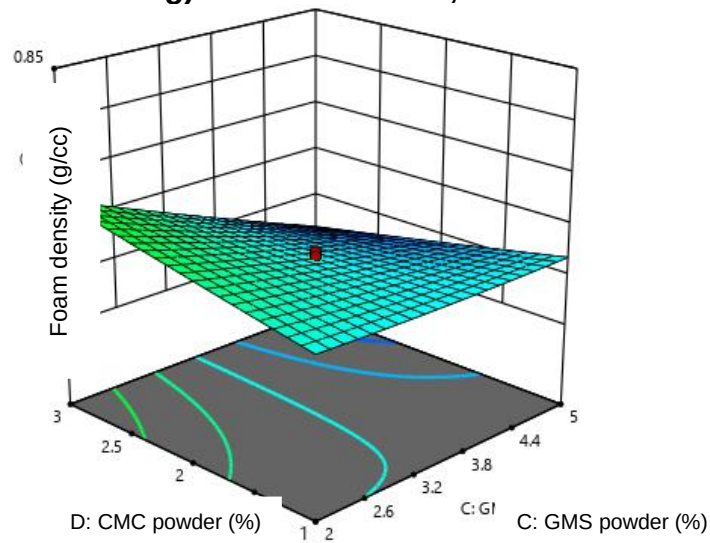
e) At constant SPI, GMS and CMC



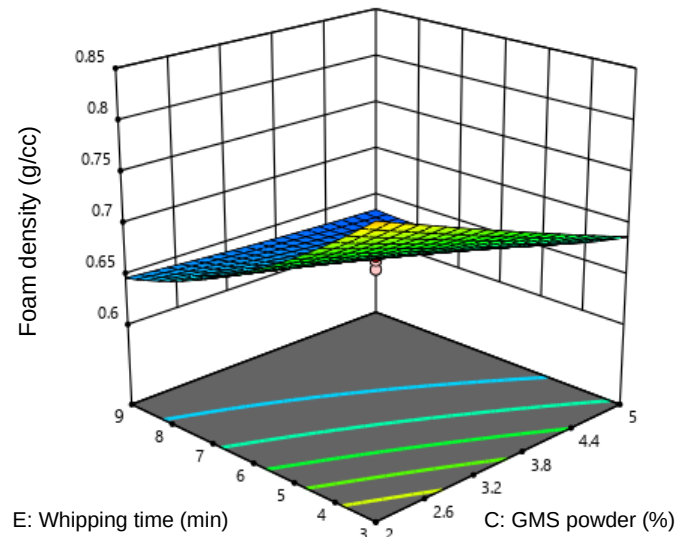
f) At constant SPI, GMS and WT



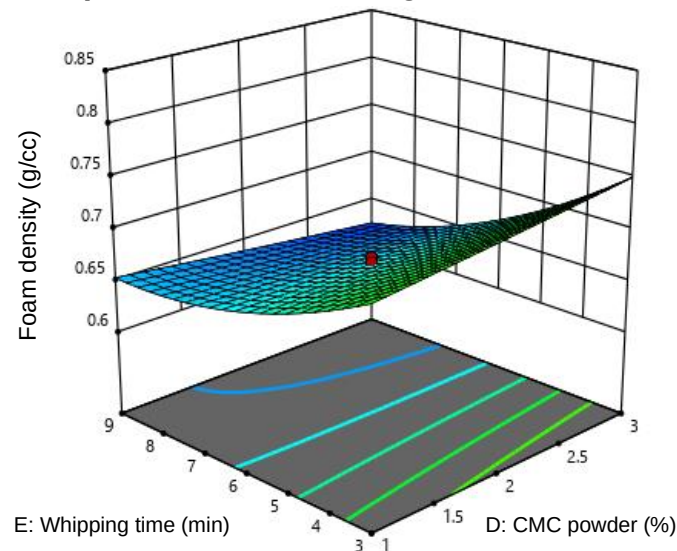
g) At constant SPI, GMS and CMC



h) At constant SPI, sugar and WT



i) At constant SPI, Sugar and CMC



j) At constant SPI, sugar and GMS

Fig. 4.7 Effect of artificial foaming agents, stabilizer, sugar content and whipping time on foam density during foaming of Nagpur mandarin juice

It is observed from Figure 4.7, that the foam density decreased with increase in concentration of soy protein isolate, GMS and CMC by keeping other variables constant. The lower foam density indicated the higher whipping ability which results more foam formation. This was due to the foaming ability of foaming agents added to the juice.

The proteins tends to unfold or denature during whipping, which exposes two oppositely charged ends of protein molecule such as hydrophobic and hydrophilic ends. Thus these charged ends align

themselves between air and water securing the air bubbles with their hydrophilic end directing towards water and hydrophobic towards air. In this way the solution entraps air and thus the foam gets stabilized by the proteins present in the SPI by increasing its height and reducing its density.

The decrease in foam density from original value of 0.61 to 0.82 g/cm³ indicated the volume of air incorporated into the juice through effective whipping. Shimoyama *et al.* (2008) found similar results by using soy protein isolate concentration upto 5%, the foam density was 0.8 g/cm³. The foam density was inversely proportional to the GMS concentration (Ismail *et al.*, 2016). The foam density was found 0.50 to 0.71 g/cm³ for muskmelon (Asokapandian *et al.*, 2016), 0.96 g/cm³ to 0.54 cm³ for mango (Rajkumar *et al.*, 2007b).

4.2.3 Effect of artificial foaming agents on foam stability of juice

The data regarding foam stability at varying concentration of artificial foaming agents, foam stabilizer, sugar and time of whipping was presented in Table 4.12.

From Table 4.12, it reveals that the foam stability of the foamed Nagpur mandarin juice concentrates varied from 74.37 to 94.37%. The maximum foam stability was obtained as 94.37% for 4% soy protein isolate, 10% sugar content, 3.50% GMS, 3.82% CMC and 6 min whipping time. Similarly the minimum foam stability was obtained as 74.37% for 4% soy protein isolate, 10% sugar content, 3.5% GMS, 0.18% CMC and 6 min whipping time.

From Table 4.12, it was also observed that the absence of foam stabilizer showed a greater degree of juice separation. The incorporation of carboxy methyl cellulose as foam stabilizer improved the foam stability by reducing the foam density. Drainage leads to progressive thinning of the lamellae and therefore enhances the probability of film collapse. The addition of carboxy methyl cellulose increased foam stability by improving the interfacial viscoelasticity of foam lamellae (Heller and Kuntamukkula, 1987). The hydrophobic nature of stabilizers also strengthens the bubble

walls, thus in turn stabilize the foam structure from collapsing (Papalamprou *et al.*, 2005). A similar trend was also observed in foam mat drying of apple juice (Raharitsifa *et al.*, 2006), bael pulp (Bag *et al.*, 2011), star fruit (Karim and Wai, 1999), *Phaseolus vulgaris* or *Phaseolus coccineus* (Makri and Doxastakis, 2006) and egg white (Muthukumaran, 2007).

Table 4.12 Foam stability of juice with using artificial foaming agent with process parameters.

Sr. No.	Soy protein isolate (99%) (%)	Sugar content (%)	GMS (%)	CMC (%)	Whipping time (min)	Foam Stability (%)
1	6.00	15.00	2.00	3.00	3.00	84.37
2	6.00	5.00	5.00	3.00	3.00	85.37
3	2.00	15.00	5.00	1.00	9.00	84.33
4	6.00	15.00	5.00	1.00	3.00	87.37
5	6.00	15.00	2.00	1.00	9.00	84.33
6	6.00	5.00	2.00	3.00	9.00	92.36
7	2.00	5.00	5.00	3.00	9.00	90.24
8	2.00	15.00	2.00	3.00	9.00	88.37
9	6.00	5.00	5.00	1.00	9.00	86.70
10	2.00	15.00	5.00	3.00	3.00	89.32
11	2.00	5.00	2.00	1.00	3.00	78.87
12	0.36	10.00	3.50	2.00	6.00	89.37
13	7.64	10.00	3.50	2.00	6.00	92.36
14	4.00	0.89	3.50	2.00	6.00	89.37
15	4.00	19.11	3.50	2.00	6.00	85.52
16	4.00	10.00	0.77	2.00	6.00	80.33
17	4.00	10.00	6.23	2.00	6.00	90.24
18	4.00	10.00	3.50	0.18	6.00	74.37
19	4.00	10.00	3.50	3.82	6.00	94.37
20	4.00	10.00	3.50	2.00	0.54	90.02
21	4.00	10.00	3.50	2.00	11.46	90.25
22	4.00	10.00	3.50	2.00	6.00	89.37
23	4.00	10.00	3.50	2.00	6.00	87.37
24	4.00	10.00	3.50	2.00	6.00	91.37
25	4.00	10.00	3.50	2.00	6.00	87.67
26	4.00	10.00	3.50	2.00	6.00	92.37
27	4.00	10.00	3.50	2.00	6.00	90.35
28	4.00	10.00	3.50	2.00	6.00	88.96

The regression analysis was carried out for the experimental data and fitted in second order polynomial equation 3.28. The Eqn. 4.7 provides the expected foam stability as a component of a foaming agent of soy protein isolates (A), GMS power (B), sugar content (C) and foam stabilizer i.e. CMC power (D) expressed in coded form. This equation was developed by using reduced quadratic model as stated by Snedecor and Cochran (1967).

Table 4.13 ANOVA for effect on foam stability of Nagpur mandarin juice using artificial foaming agents.

Source	Sum of Squares	Df	Mean Square	F-value
Model	192.57	8	24.07	12.37***
A-Protein isolate	7.90	1	7.90	4.06*
B-Sugar content	11.22	1	11.22	5.77*
D-CMC powder	121.11	1	121.11	62.24***
E-Whipping time	26.16	1	26.16	13.45**
AC	35.01	1	35.01	17.99**
AD	15.48	1	15.48	7.96*
BC	46.27	1	46.27	23.78**
BE	18.99	1	18.99	9.76**
Residual	36.97	19	1.95	
Lack of Fit	16.59	13	1.28	0.38 ^{NS}
Pure Error	20.38	6	3.40	
Cor Total	229.53	27		
Std. Dev.	1.43			
C.V. %	1.67			
R ²	0.9465			
Adjusted R ²	0.8890			
Predicted R ²	0.7555			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS - Non significant

The analysis of variance for the experimental data shows model F value of 16.44 ($p < 0.001$) which implies that model was significant and a non-significant lack of fit F value 0.31 indicates that the quadratic model was successfully used to fit the experimental data. The R² value was determined using the least square methodology and displayed to be good

fit of model to the data at 0.9465. The most predominant parameter is CMC followed by whipping time, soy protein isolate and sugar content on foam stability. In this case linear terms (A, B, D, E), interaction terms (AC, AD, BC and BE) are significant model terms and other linear, interactive and quadratic terms found non significant effect on foam stability. In comparison, 0.7555 was expected R^2 with 0.8890 of modified R^2 in reasonably agreement (Table 4.13).

The most influencing factor on foam stability was found with CMC ($P < 0.001$) followed by whipping time ($P < 0.01$) while soy protein isolate and sugar content ($P < 0.05$) was less effective parameter on consistency of the foam. The regression equation which describes the effects of process variables on the stability of the foam in terms of variable coded values is given as

$$\begin{aligned} \text{Foam stability (\%)} &= 85.810 + 0.770A - 0.910B + 2.970D + 1.380E + \\ &\quad 2.180AC - 1.560AD + 2.510BC + 1.730BE \\ &\quad (R^2 = 0.7555)(4.7) \end{aligned}$$

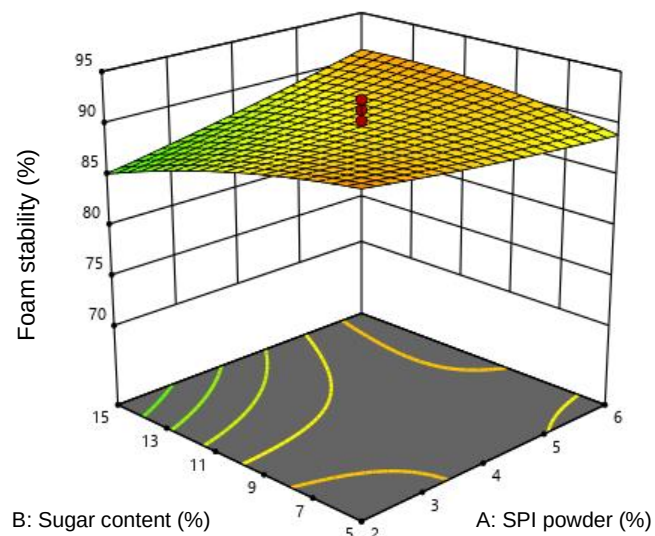
Replacing A, B, D, and E with (Sp-4)/2, (Su-10)/5, (Cm -2)/1 and (Wt -6)/3 respectively [Eqn. 3.27] in Eqn. (4.7), the foam stability in real terms of soy protein isolate, sugar, GMS, CMC and whipping time is given in the following Eqn.

$$\begin{aligned} \text{Foam stability (\%)} &= 56.880 + 1.640\text{Sp} - 1.170\text{Su} + 18.700\text{Cm} + \\ &\quad 0.110\text{Wt} - 0.070\text{SpGm} - 1.010\text{SpCm} + \\ &\quad 0.290\text{SuGm} + 0.040\text{SuWt} \\ &\quad (R^2 = 0.9465) \quad (4.8) \end{aligned}$$

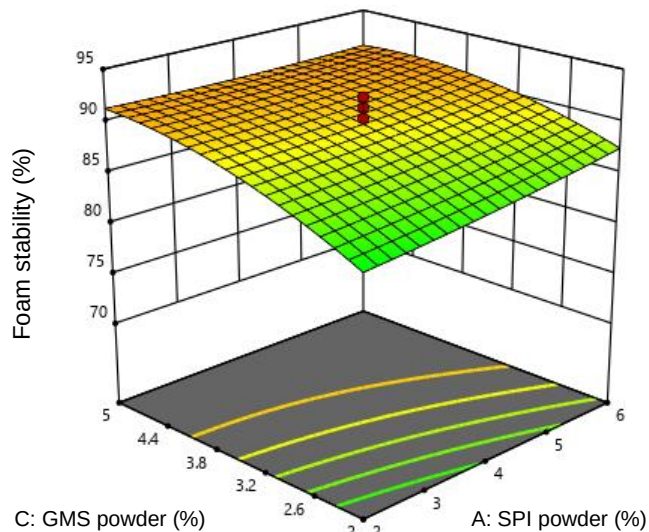
The linear positive terms in coded Eqn 4.7 indicated that foam stability increased with increase in foaming agent. The CMC is most predominant factor which affects the foam stability followed by whipping time, sugar content and soy protein isolate. The sugar content increases with decrease in foam stability. The presence of positive interaction terms

between soy protein isolate and GMS, SPI and CMC, sugar content and GMS, sugar content and whipping time were significant on foam stability.

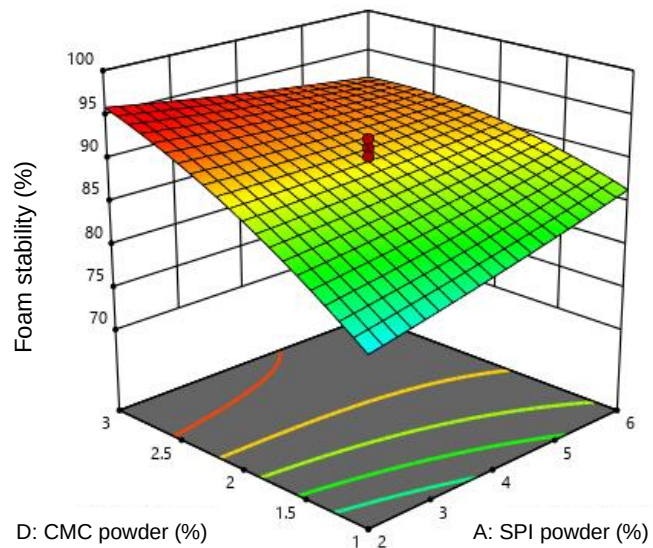
The variations of foam stability of Nagpur mandarin juice foam with different combinations of the process parameters are graphically shown in the 3-D surface plot (Fig. 4.8a, b, c, e, f, g, h, i, and j). From the figure 4.8, it was observed that the addition of foam stabilizer plays a significant role in the stability of foam ($P < 0.01$).



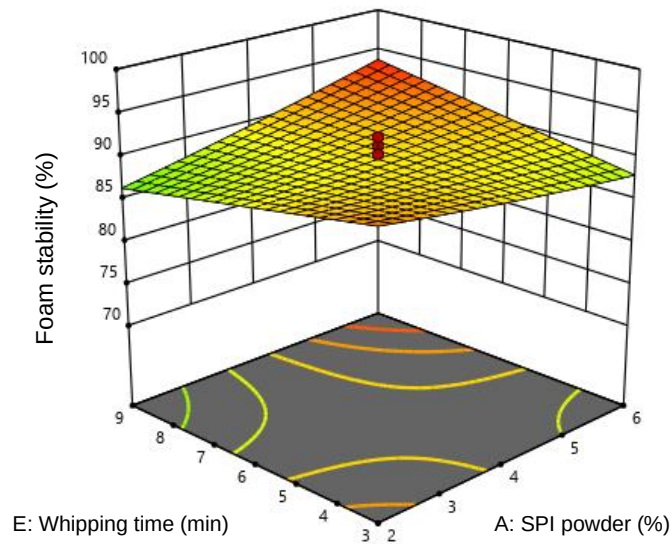
a) At constant GMS, CMC and WT



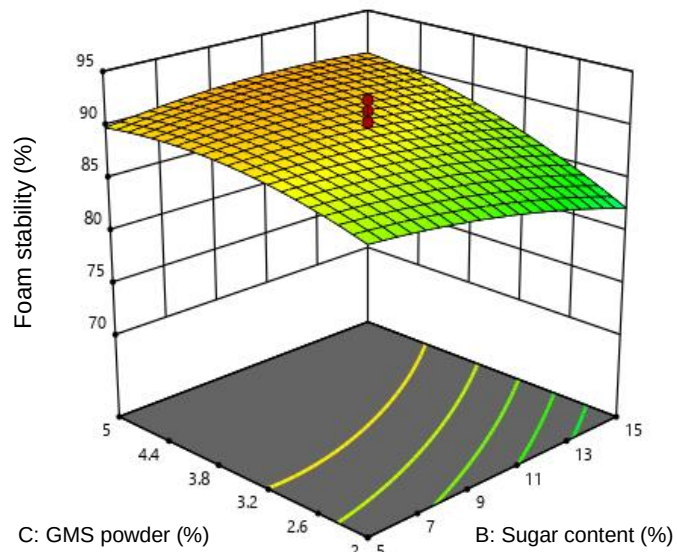
b) At constant sugar, CMC and WT



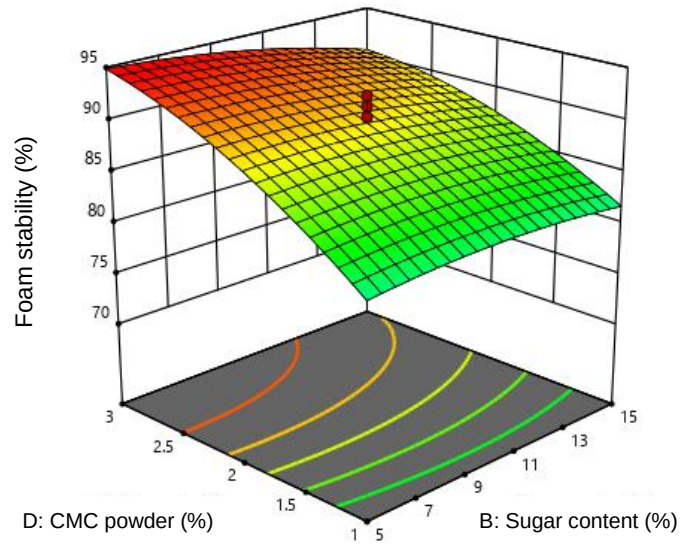
c) At constant GMS, sugar and WT



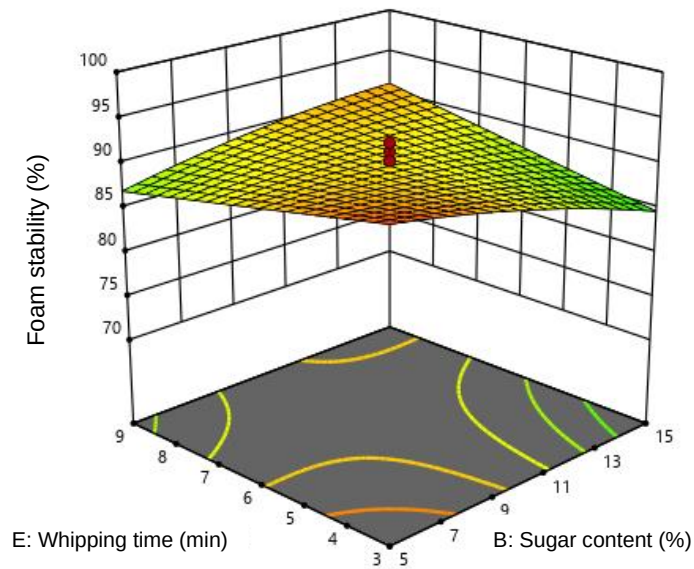
d) At constant Sugar, GMS and CMC



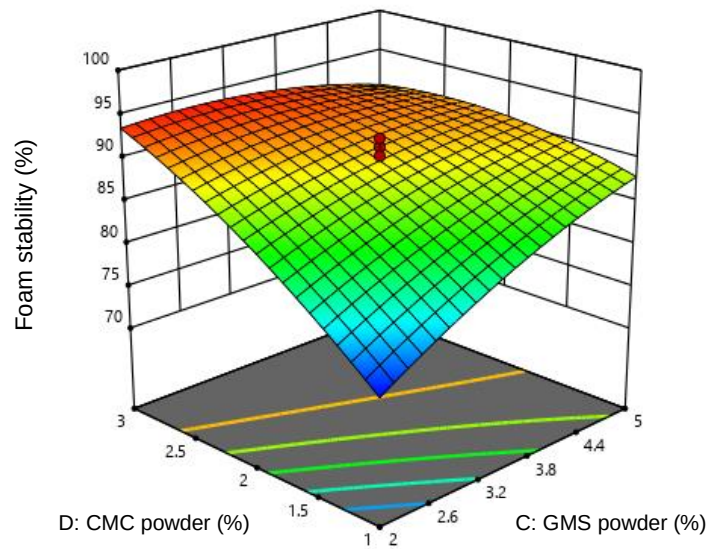
e) At constant SPI, CMC and WT



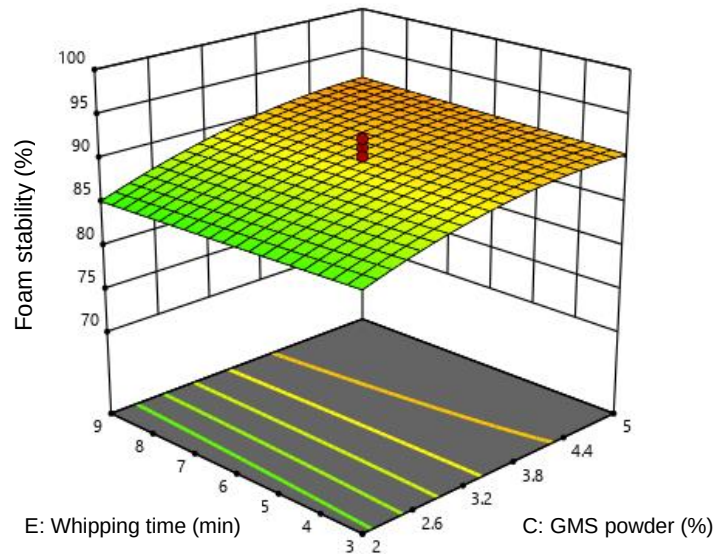
f) At constant SPI, GMS and WT



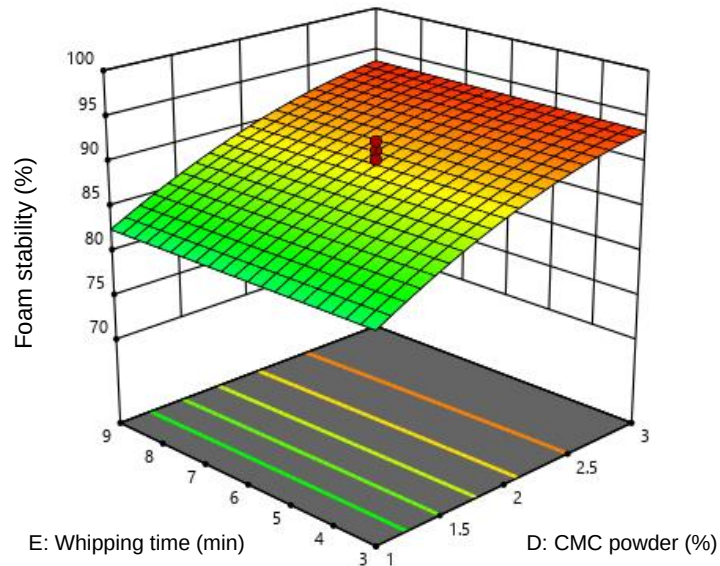
g) At constant SPI, GMS and CMC



h) At constant SPI, sugar and WT



h) At constant SPI, sugar and CMC



i) At constant SPI, sugar and GMS

Fig. 4.8 Effect of artificial foaming agents, stabilizer, sugar content and whipping time on foam stability (%) during foaming of Nagpur mandarin juice

Foam stability represents the capacity of the foam to retain the water and a way to assess how quickly the fluid flows (Kampfet *al.*, 2003). The durable structure of the foam was dried rapidly and the drying substance easily extracted from the tray. If foams break or decline, drying period was increased and consistency of foam was reduced. The stability/drainage volume of foam was influenced by the thickness of the interface, foam size distribution, interface permeability, and surface

tension. The methyl cellulose concentration affected on the foam stability of the foamed mandarin juice. The increased rate was observed for the same as methyl cellulose stabilizes the foam structure. These results are comparable with Brygidyret *al.* (1977) for tomato puree and Labelle (1966) for orange juice. It was also observed that at higher whipping time, the foam stability was decreased due to rupturing of foam bubbles and releasing of liquid phase intact in foam bubbles. DeVries (1958) and Prins (1988) mentioned in this sense that foam was more robust at high viscosity, which easily avoid the breaking of interface wall.

4.3 Optimization of Process Parameters with Artificial Foaming Agent.

Constrains for optimization of process parameters of Nagpur mandarin with range and importance of responses are presented in Table 4.14.

Table 4.14 Constraints for optimization of various process parameters of foamed Nagpur mandarin juice using artificial foaming agents

Process parameter	Target	Experimental		Importance
		Range		
		Low	High	
A: Soy Protein isolate, (%)	minimize	2	6	4
B: Sugar content, (%)	is in range	5	15	5
C: GMS powder, (%)	minimize	2	5	5
D: CMC powder, (%)	minimize	1	3	5
E: Whipping time, (min)	is in range	3	9	4
Foam Expansion, (%)	maximize	15.25	36.25	5
Foam density, (g/cm ³)	minimize	0.61	0.82	5
Foam stability, (%)	maximize	74.37	94.37	5

In order to optimize the process parameters for preparation of foamed Nagpur mandarin juice concentrate by numerical optimization; which finds a point that maximizes the desirability function. The optimized condition for various process parameters are presented in Table 4.15.

Table 4.15 Optimized solution of various process parameters of foamed Nagpur mandarin juice using artificial foaming agents

No.	SPI (%)	SC (%)	GMS (%)	CMC (%)	WT (min)	FE (%)	FD (g/cm ³)	FS (%)	D
1	2.07	5.08	2.75	1.72	7.92	36.25	0.63	83.38	0.75

SPI is soy protein isolate, SC is sugar content, GMS is glycerol mono starate, CMC carboxy methyl cellulose, WT is whipping time, FE is foam expansion, FD is foam density, FS is foam stability anf D is desirability

The optimum values of process variables obtained by numerical optimization are as follows:

Soy protein isolate (%)	: 2.07~ 2.10
Sugar content (%)	:5.08 ~ 5.10
GMS (%)	: 2.75 ~ 2.75
CMC (%)	: 1.72 ~ 1.75
Whipping time (min)	: 7.921 ~ 8.00

Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for the juice. The contour plots for all responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions. These constraints resulted in 'feasible zone' of the optimum conditions (shaded area in the superimposed contour plots). The superimposed contour plots having common superimposed area for all responses were shown in Fig. 4.12.

The optimum operating conditions for soy protein isolate 2.10%, sugar content 5.10% GMS concentration 2.75%, CMC 1.75% and whipping time 8 min corresponding to these values of process variables, the value of foam expansion was 36.254%, foam density 0. 648 g/cm³, foam stability 84.028% and overall desirability 0.754 as shown in Table 4.15.

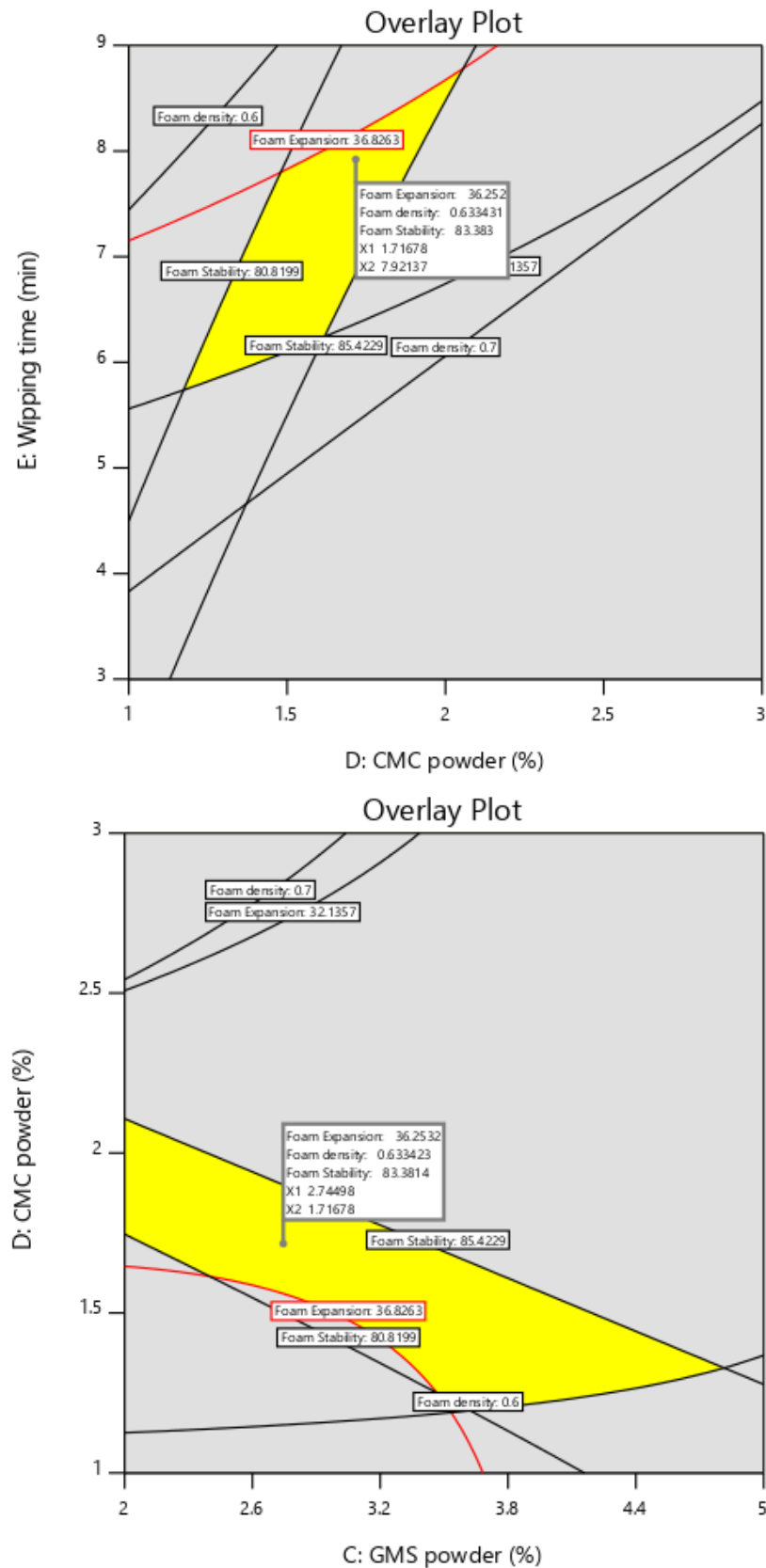


Fig. 4.9 Superimposed contour plots of different responses for optimization of foaming of Nagpur mandarin juice using artificial foaming agents

4.4 Verification of the Model for Foaming Properties of Nagpur Mandarin Juice using Artificial Foaming Agent

The experiment was performed in order to check the adequacy of foaming properties for predicting the response value in the optimum process conditions. Table 4.16 summarizes the experimental values and predicted values (meaning 3 experiments). It was observed that the experimental values were very similar to the predicted values. Therefore, it was concluded that the model are quite adequate to assess the behaviour of the foaming properties.

Table 4.16 Predicted and experimental values of response

Response	Predicted mean	Experimental mean Value $\pm$ SD	SE	% Variation	Mean difference
Foam expansion, %	36.25	34.45 $\pm$ 0.63	1.01	3.76	2.80
Foam density, g/cm ³	0.65	0.65 $\pm$ 0.01	0.01	0.03	0.02
Foam stability, %	84.03	83.26 $\pm$ 1.77	2.85	10.47	2.77

4.5 Effect of Natural Foaming Agents, Sugar content and Whipping Time on the Foam Properties of Nagpur Mandarin Juice

A study on the foaming properties of different foaming agents on Nagpur mandarin juice was carried out to optimize the foaming parameters. Different foaming agents such as guar gum (0.3 to 0.9%), soy protein isolate (2 to 6%), sugar content (5 to 15%) and whipping time (3 to 9 min) were selected for the preliminary study and literature. The analysis was done using CCD design for the experiment of 28 run under response surface methodology explained in section 3.10. The CCD was used to optimize the foaming parameters based on the foaming properties such as foam expansion (FE), foam density (FD) and foam stability (FS).

4.5.1 Effect of natural foaming agentson foam expansion of juice

The observation for foam expansion by different combination of process parameters were recorded which is shown in Table 4.17 and were analyzed for regression analysis (Table 4.18).

Table 4.17 Foam expansion of Nagpur mandarin juicewith natural foaming agent.

Sr. No.	Guar gum powder (%)	Soy Protein Isolate (90%) (%)	Sugar content (%)	Whipping Time (min)	Foam Expansion (%)
1	0.30	2.00	5.00	3.00	11.24
2	0.90	2.00	5.00	3.00	17.81
3	0.30	6.00	5.00	3.00	22.28
4	0.90	6.00	5.00	3.00	27.01
5	0.30	2.00	15.00	3.00	15.25
6	0.90	2.00	15.00	3.00	26.47
7	0.30	6.00	15.00	3.00	24.24
8	0.90	6.00	15.00	3.00	28.74
9	0.30	2.00	5.00	9.00	23.66
10	0.90	2.00	5.00	9.00	31.19
11	0.30	6.00	5.00	9.00	30.39
12	0.90	6.00	5.00	9.00	34.64
13	0.30	2.00	15.00	9.00	29.25
14	0.90	2.00	15.00	9.00	33.33
15	0.30	6.00	15.00	9.00	32.13
16	0.90	6.00	15.00	9.00	34.50
17	0.18	4.00	10.00	6.00	23.86
18	1.02	4.00	10.00	6.00	31.66
19	0.60	1.17	10.00	6.00	21.88
20	0.60	6.83	10.00	6.00	32.74
21	0.60	4.00	2.93	6.00	28.23
22	0.60	4.00	17.07	6.00	28.06
23	0.60	4.00	10.00	1.76	6.83
24	0.60	4.00	10.00	10.29	34.54
25	0.60	4.00	10.00	6.00	30.56
26	0.60	4.00	10.00	6.00	28.57
27	0.60	4.00	10.00	6.00	29.74
28	0.60	4.00	10.00	6.00	28.91

The foam expansion was varied from 34.64 to 06.83% within various combinations of variables. The maximum foam expansion was obtained as 34.64% for 0.90% guar gum powder, 6.00% soy protein isolate, 5.00% sugar content and 9.00 min whipping time. Similarly the minimum foam expansion was obtained as 06.83% for 0.60% guar gum powder, 4.00% soy protein isolate, 10.00% sugar and 1.76 min whipping time.

Table 4.18 ANOVA for effect on foam expansion of Nagpur mandarin juice with natural foaming agent.

Source	Sum of Squares	Df	Mean Square	F-value
Model	1227.99	7	175.43	41.46***
A-Guar Gum	154.29	1	154.29	36.47***
B-Soy protein isolate	189.51	1	189.51	44.79***
C-Sugar content	26.75	1	26.75	6.32*
D-Whipping time	722.32	1	722.32	170.73***
BC	14.27	1	14.27	3.37*
BD	18.64	1	18.64	4.41*
D ²	102.21	1	102.21	24.16***
Residual	84.62	20	4.23	
Lack of Fit	82.24	17	4.84	6.12NS
Pure Error	2.37	3	0.79	
Cor Total	1312.61	27		
Std. Dev.	2.06			
C.V. %	7.70			
R²	0.9355			
Adjusted R²	0.9130			
Predicted R²	0.8298			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS - Non significant

The analysis of variance for the experimental data set shows model F value of 41.46 ($p < 0.001$) which implies the model is significant and a non significant lack of fit indicated that the quadratic model was successfully used to fit the experimental data. F values indicated that guar gum, soy protein isolate and whipping time were the most influencing parameter in linear way whereas effect of sugar content was less. The R² value was calculated by least square technique and it was 0.9355. The

higher F values for linear terms ($p < 0.001$) and moderate values for quadratic terms ($p < 0.01$ and $p < 0.05$) indicated the highly significant effect on foam expansion. The lack of fit F value was non significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with value of predicted R^2 of 0.8298 which shows with reasonable agreement with adjusted R^2 of 0.9130. Therefore, this model was used to navigate the design space.

The P value was found less than 5% which indicate the model terms are significant. In this case linear terms (A, B, C and D), interaction terms (BC and BD) and quadratic terms (D^2) were significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The effect of the interactive terms of (AB, AC, AD and CD) and quadratic terms (A^2 , B^2 and C^2) were found non significant effect on foam expansion.

The results of analysis of variance of Eqn 4.9, suggested that foam expansion of juice was highly significant at the 1% for linear terms of foaming agents and whipping time. The second order polynomial regression equation fitted to experimental data for foam expansion. The Eqn 4.9 generated by deleting the high error nonsignificant terms in order to predict foam expansion of coded and actual values are given below:

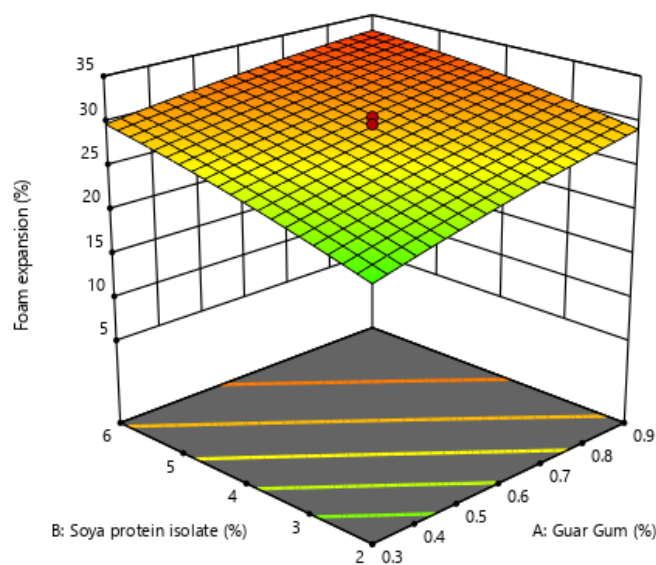
$$\begin{aligned} \text{Foam expansion (\%)} &= 28.360 + 2.560A + 2.810B + 1.060C + \\ &5.490D - 0.944BC - 1.080BD - 1.930D^2 \\ &(R^2=0.830) \quad (4.9) \end{aligned}$$

Replacing A, B, C and D with $(Gg - 0.6)/0.3$, $(Sp-4)/2$, $(Su-10)/5$ and $(Wt - 6)/3$, respectively [Eqn 3.29] in Eqn. (4.9), the foam expansion in real terms of guar gum, soy protein isolate, sugar and whipping time is given in the following Eqn.

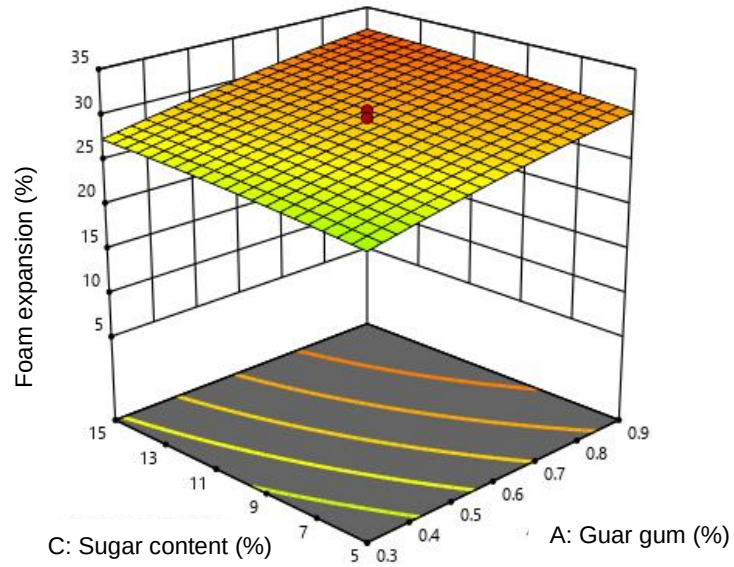
$$\begin{aligned} \text{Foam expansion (\%)} &= -11.229 + 8.452Gg + 3.429Sp + 0.589Su + \\ &5.122Wt - 0.094SpSu - 0.180SpWt - \\ &0.214Wt^2 \\ &(R^2 = 0.936) \quad (4.10) \end{aligned}$$

The positive terms of Eqn 4.9 indicated that foam expansion increased with increase in linear terms. The linear terms such as whipping time, soy protein isolate, guar gum and sugar content was found significant. The most prominent factors affect on foam expansion was found whipping time followed by soy protein isolate, guar gum and sugar content.

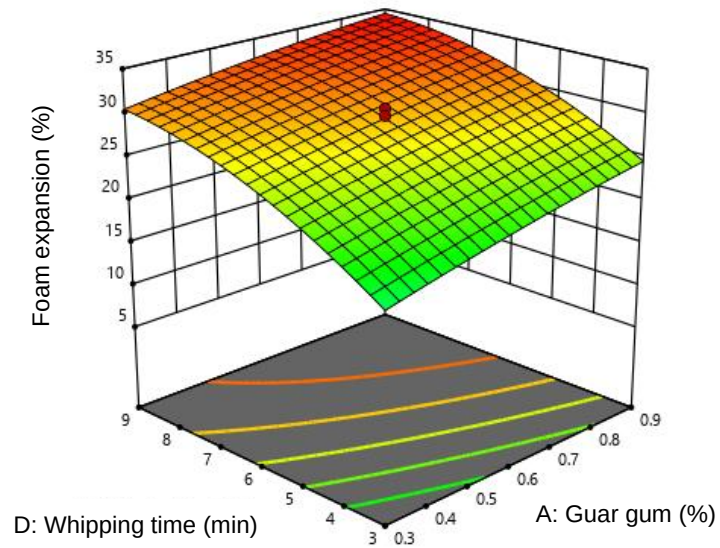
To visualize the combined effect of process variables on foam expansion, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values. It was observed from Fig 4.10 (A) that effect of SPI as well as guar gum on foam expansion was very high, due to protein present in the guar gum and soy protein isolate. Similar results were observed for the different protein based foaming agents (Kandasamy *et al.*, 2012a; Sankat and Castaigne, 2004; Rajkumaret *al.*, 2007a; Akintoye and Oguntunde, 1991; Krasaekoopt and Bhatia, 2012). The combined effect of soy protein isolate, guar gum and whipping time was more significant at higher levels. Similar results were also reported by Kaushal *et al.* (2013), Falade *et al.* (2003), Thaisong and Rojanakorn (2011), Bag *et al.* (2011), Zhengn *et al.* (2009), Kandasamy *et al.* (2012b), Zheng *et al.* (2011), Azizpour *et al.* (2014) for various fruit pulp.



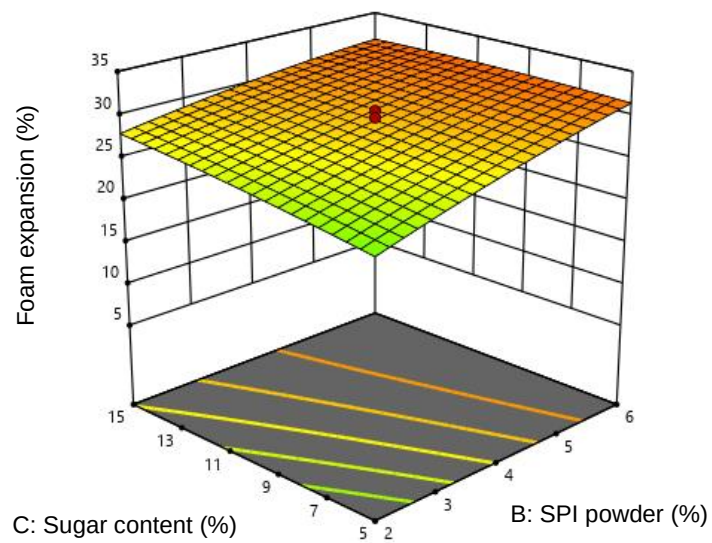
a) At constant sugar and WT



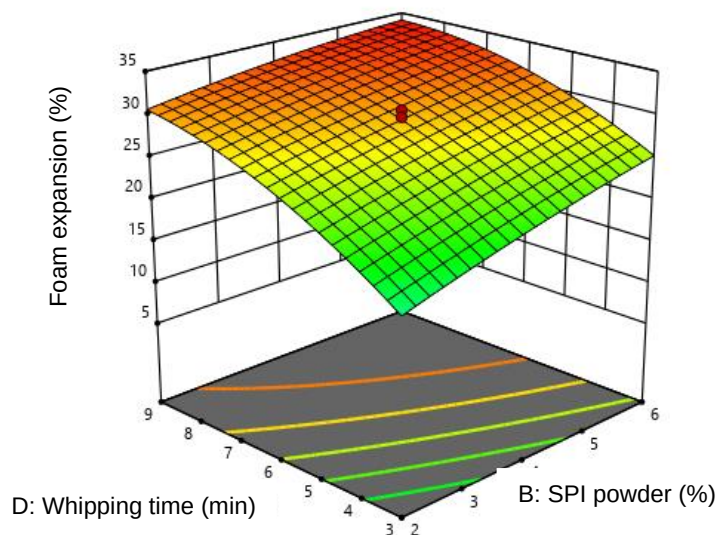
b) At constant SPI and WT



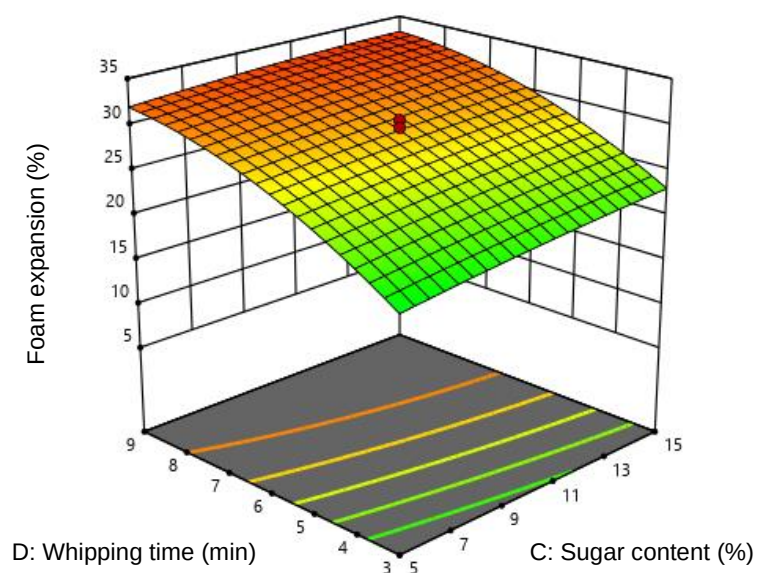
c) At constant SP and sugar



d) At constant guar gum and WT



e) At constant guar gum and sugar



f) At constant guar gum and SP

Fig. 4.10 Effect of natural foaming agents, sugar content and whipping time on foam expansion (%) during foaming of Nagpur mandarin juice

4.5.2 Effect of natural foaming agentson foam density of juice

During whipping, airfused into the juice and the density of foam was determined as the ratio of mass of foam to volume of foam after whipping. The foam density varied from 0.63 to 0.91 g/cm³. It was observed from literature that 0.3 to 0.6 g/cm³ was the recommended range of foam density suitable for foam mat drying (Kudra and Ratti,

2006). The lowest concentrations of (0.3%) of guar gum, (2%) of SPI, (5%) of sugar content produced foam with highest foam density. The effect of guar gum, SPI, sugar content and whipping time on foam density is graphically represented using the 3-D surface plots shown in Fig. 4.11.

Table 4.19 Foam density of Nagpur mandarin juice with natural foaming agent.

Sr. No.	Guar gum powder (%)	Soy Protein Isolate (90%) (%)	Sugar content (%)	Whipping Time (min)	Foam Density (g/cm ³)
1	0.30	2.00	5.00	3.00	0.91
2	0.90	2.00	5.00	3.00	0.80
3	0.30	6.00	5.00	3.00	0.75
4	0.90	6.00	5.00	3.00	0.71
5	0.30	2.00	15.00	3.00	0.82
6	0.90	2.00	15.00	3.00	0.71
7	0.30	6.00	15.00	3.00	0.74
8	0.90	6.00	15.00	3.00	0.69
9	0.30	2.00	5.00	9.00	0.74
10	0.90	2.00	5.00	9.00	0.67
11	0.30	6.00	5.00	9.00	0.68
12	0.90	6.00	5.00	9.00	0.63
13	0.30	2.00	15.00	9.00	0.69
14	0.90	2.00	15.00	9.00	0.65
15	0.30	6.00	15.00	9.00	0.66
16	0.90	6.00	15.00	9.00	0.64
17	0.18	4.00	10.00	6.00	0.74
18	1.02	4.00	10.00	6.00	0.66
19	0.60	1.17	10.00	6.00	0.76
20	0.60	6.83	10.00	6.00	0.65
21	0.60	4.00	2.93	6.00	0.70
22	0.60	4.00	17.07	6.00	0.70
23	0.60	4.00	10.00	1.76	0.90
24	0.60	4.00	10.00	10.29	0.63
25	0.60	4.00	10.00	6.00	0.67
26	0.60	4.00	10.00	6.00	0.69
27	0.60	4.00	10.00	6.00	0.68
28	0.60	4.00	10.00	6.00	0.69

Foam density was commonly used to evaluate the whipping properties. The foam density displayed a low value when more air was incorporated into the foam during whipping. The whipping ability was increase due to presence of air in foam. The foam density decreases when the concentration of soy protein and guar gum increase with increased in whipping time. Low density foam accelerates the process of water removal during drying as it provides large surface area for drying (Thuwapanichayanan *et al.*, 2012). Due to the addition of high gum concentrations, the key mechanism of this phenomenon may be the greatly increased viscosity of the aqueous state, so that air does not reach the system during whipping and decrease foam density (Makri and Doxastakis, 2006), similar study was indicated on star and bael fruit foams (Karim and Wai, 1999; Bag *et al.*, 2011). The foam density was found 0.57 to 0.8 g/cm³ for button mushroom (Pasban *et al.*, 2014) and 0.45 to 0.85 g/cm³ for cantaloupe pulp using xanthan gum (Salahi *et al.*, 2014).

The statistical analysis individual and interaction effect of foaming parameters on foam density are shown in Table 4.20. The model F value was observed as 41.46 and implied that the model was significant. There was only 0.01% chance that a model F value was large this occur due to noise. The coefficient of determination (R^2) was found 0.9355 and it was also found significant.

The linear and quadratic terms were found highly significant at $p < 0.001$. The linear terms (A, B, C and D), interaction terms (BC and BD) and quadratic terms (D^2) are significant at $p < 0.01$ is observed from Table 4.20. The interactive terms AB, AC, AD and CD and quadratic terms (A^2 , B^2 and C^2) was found non significant on foam density The modified response surface model is obtained by neglecting the coefficients of non-significant terms (level of significance greater than 5%) from the quadratic model (Box & Draper 2007).

Table 4.20 ANOVA for effect on foam density of Nagpur mandarin juice with natural foaming agent.

Source	Sum of Squares	Df	Mean Square	F-value
Model	0.116	7	0.017	41.46***
A-Guar Gum, %	0.015	1	0.015	36.47***
B-Soy protein isolate, %	0.018	1	0.018	44.79***
C-Sugar content, %	0.003	1	0.003	6.32*
D-Whipping time, min	0.068	1	0.068	170.73***
BC	0.001	1	0.002	3.37*
BD	0.002	1	0.002	4.41*
D ²	0.010	1	0.010	24.16***
Residual	0.008	20	0.001	
Lack of Fit	0.008	17	0.001	6.12 ^{NS}
Pure Error	0.001	3	0.000	
Cor Total	0.124	27		
Std. Dev.	0.002			
C.V. %	2.81			
R²	0.936			
Adjusted R²	0.913			
Predicted R²	0.830			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS - Non significant

The following equation describes the effect of significant process variables on foam density of the juice in terms of coded and actual values:

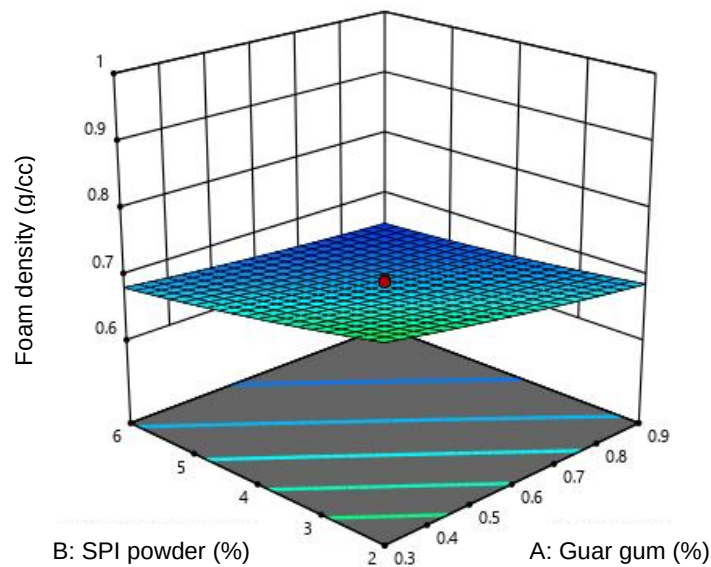
$$\begin{aligned} \text{Foam density (kg/cm}^3\text{)} &= 0.695 - 0.025A - 0.027B - 0.010C - \\ &0.053D + 0.009BC + 0.011BD + \\ &0.019D^2 \\ (R^2 &= 0.830) \quad (4.11) \end{aligned}$$

Replacing A, B, C and D with (Gg -0.6)/0.3, (Sp-4)/2, (Su-10)/5 and (Wt -6)/3, respectively [Eqn. 3.29] in Eqn. (4.11), the foam density in

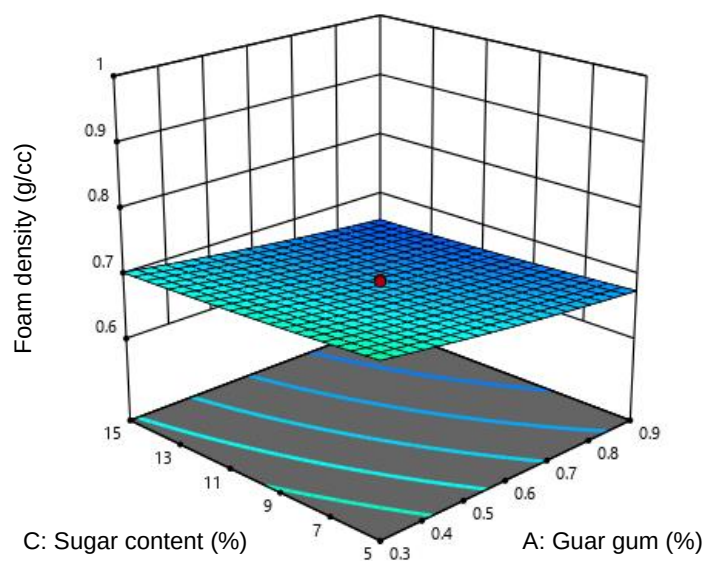
real terms of guar gum, soy protein isolate, sugar and whipping time are given in the following equation.

$$\begin{aligned} \text{Foam density (kg/cm}^3\text{)} &= 1.079 - 0.082Gg - 0.033Sp - 0.006Su \\ &\quad - 0.050Wt + 0.001SpSu + 0.002SpWt \\ &\quad + 0.002Wt^2 \\ (R^2 &= 0.940) \quad (4.12) \end{aligned}$$

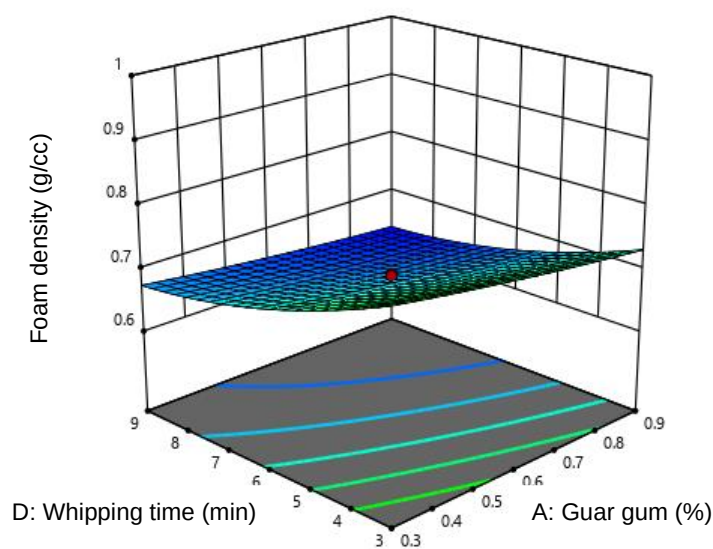
The negative coefficients of the first order terms of gum, soy protein isolate, sugar content and whipping time given in equation 4.11 indicates that the foam density decreased with increase in variables while positive coefficients of interaction and quadratic terms indicates that foam density increased with increase of these variables. The most prominent factors affect on foam density was found whipping time followed by soy protein isolate, guar gum and sugar content.



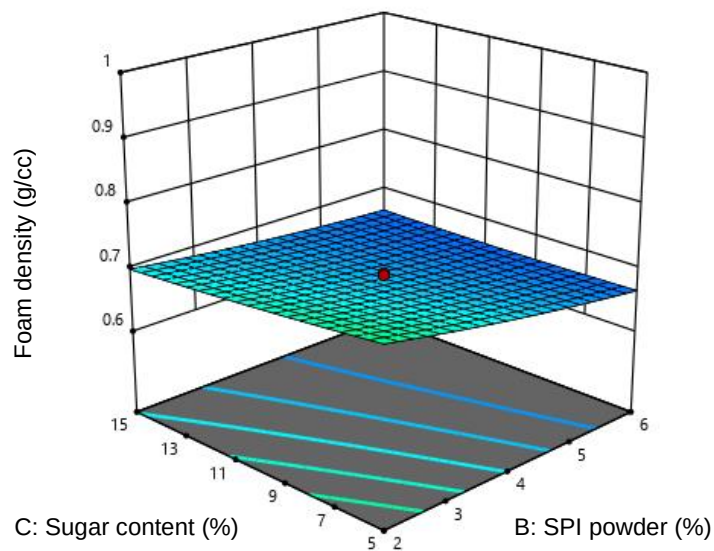
a) At constant sugar and WT



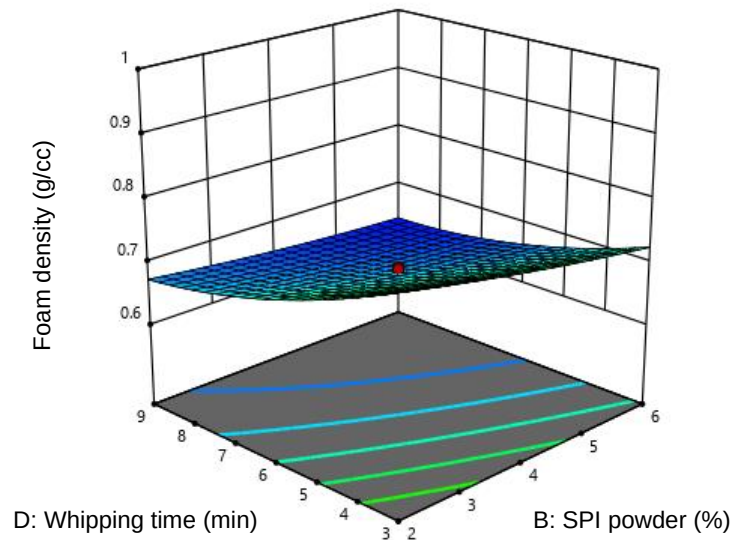
b) At constant SP and WT



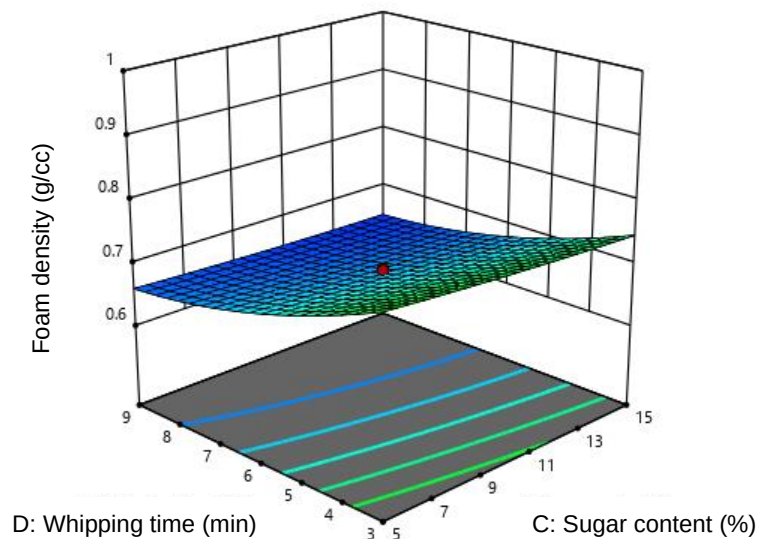
c) At constant SP and sugar



d) At constant guar gum and WT



e) At constant guar gum and sugar



f) At constant guar gum and SP

Fig. 4.11 Effect of natural foaming agents, sugar content and whipping time on foam density (g/cm^3) during foaming of Nagpur mandarin juice

Figure 4.11 indicates the foam density decreased with increase in SPI and guar gum concentration at constant whipping time. Lower value of foam density symbolized the higher amount of air trapped in the juice. The density was found to decrease gradually with increase in SPI, guar gum and whipping time. The decreasing trend was observed in foam density with addition of SPI, due to the reduction in the interfacial tension and surface tension of liquid to form an interfacial film. Previous research

also reported that the air bubbles were not stable at lower foaming agent concentration because the critical thickness required for the interfacial film was not be formed (Karim and Wai 1999). The increase in the density was due to bubble collapse and mechanical deformation during increased whipping time (Lau and Dickinson 2005). Similar trends were observed for bael pulp (Bag *et al.*, 2011), plantain (Falade and Okocha 2012) and cowpea (Falade *et al.*, 2003).

4.5.3 Effect of natural foaming agent on foamed juice stability

The foam drainage volume indicates the water holding capacity of the foam and is used to determine the foam stability. The stability was varied in the ranged from 76.33 to 90.31%.

The foam stability of mandarin juice was found in the range from 77.97 to 90.31% as shown in Table 4.21. The maximum foam stability was obtained as 90.31% for 0.90% guar gum, 6% soy protein isolate, 15% sugar and 9.00 min whipping time. Similarly the minimum foam stability was obtained as 77.97% for 0.30% guar gum, 2% soy protein isolate, 5% sugar and 3.00 min whipping time. The foam stability increases with increase in the soy protein and guar gum. As the foam stability was found higher, the drying time was reduced.

The proteins and polysaccharides (soy protein isolate and guar) were present together in juice which provides stability to the foam and also increases the shelf life of developed product. Therefore, it was found that the formation of complex with substantially improved emulsifying characteristics was shown with the interactions between proteins and polysaccharides. Similar findings were observed by De Kruif and Tuinier(2001), Mishra *et al.* (2001), Akhtar and Dickinson (2003), Tavares and Silva (2003); Martinez *et al.* (2005), Herceg *et al.* (2007) and Ercelebi and Ibanoflu (2009).

A second order polynomial Eqn. 4.13 was fitted and it gives the predicted per cent foam expansion, as a function of foaming agent guar gum (A), soy protein isolate (B), sugar content (C) and whipping time (D) expressed in coded form. This equation was obtained using reduced

quadratic model in which F values was less than one then the model terms were rejected as described by Snedecor and Cochran (1967).

Table 4.21 Foam stability of Nagpur mandarin juice with natural foaming agent

Sr. No.	Guar gum powder (%)	Soy Protein Isolate (90%) (%)	Sugar content (%)	Whipping Time (min)	Foam Stability (%)
1	0.30	2.00	5.00	3.00	77.97
2	0.90	2.00	5.00	3.00	79.32
3	0.30	6.00	5.00	3.00	81.95
4	0.90	6.00	5.00	3.00	85.01
5	0.30	2.00	15.00	3.00	79.07
6	0.90	2.00	15.00	3.00	80.11
7	0.30	6.00	15.00	3.00	83.29
8	0.90	6.00	15.00	3.00	86.93
9	0.30	2.00	5.00	9.00	82.54
10	0.90	2.00	5.00	9.00	87.96
11	0.30	6.00	5.00	9.00	84.62
12	0.90	6.00	5.00	9.00	88.83
13	0.30	2.00	15.00	9.00	81.84
14	0.90	2.00	15.00	9.00	85.50
15	0.30	6.00	15.00	9.00	86.33
16	0.90	6.00	15.00	9.00	90.31
17	0.18	4.00	10.00	6.00	78.29
18	1.02	4.00	10.00	6.00	84.99
19	0.60	1.17	10.00	6.00	81.52
20	0.60	6.83	10.00	6.00	86.62
21	0.60	4.00	2.93	6.00	86.80
22	0.60	4.00	17.07	6.00	87.34
23	0.60	4.00	10.00	1.76	85.33
24	0.60	4.00	10.00	10.29	89.63
25	0.60	4.00	10.00	6.00	84.60
26	0.60	4.00	10.00	6.00	86.93
27	0.60	4.00	10.00	6.00	85.07
28	0.60	4.00	10.00	6.00	83.63

The data for foam stability were analysed for stepwise regression analyses as shown in Table 4.22. The quadratic model was found best fitted to the experimental data and was found statistical significant for

linear, quadratic and interaction terms. The R^2 value was calculated by least square technique and found 0.9572 showing good fit of model to the data. The model F value of 44.69 implies that the model was significant ($P < 0.001$). The lack of fit F value (0.35) and coefficient of determination (R^2) was found 0.9572, which indicates the goodness of fit. Moreover the predicted R^2 of 0.9058 was in reasonable agreement with adjusted R^2 of 0.9357. This revealed that the non significant terms have not been included in the model. Therefore, this model was used to navigate the design space.

Table 4.22 ANOVA for effect on foam stability of Nagpur mandarin juice with natural foaming agent.

Source	Sum of Squares	Df	Mean Square	F-value
Model	356.03	9	39.56	44.69***
A-Guar Gum, %	65.85	1	65.85	74.39***
B-Soy protein isolate, %	119.58	1	119.58	135.08***
D-Whipping time, min	106.19	1	106.19	119.96***
AD	4.17	1	4.17	4.72*
BC	3.72	1	3.72	4.20*
BD	4.47	1	4.47	5.05*
A ²	20.61	1	20.61	23.28***
B ²	22.55	1	22.55	25.47***
C ²	5.41	1	5.41	6.11*
Residual	15.93	18	0.88	
Lack of Fit	10.16	15	0.68	0.35 ^{NS}
Pure Error	5.77	3	1.92	
Cor Total	371.97	27		
Std. Dev.	0.94			
C.V. %	1.12			
R²	0.9572			
Adjusted R²	0.9357			
Predicted R²	0.9058			

*** Significant at 0.1% Level, ** Significant at 1% Level, * Significant at 5% Level and NS - Non significant

From the statistical values, it was observed that the linear terms and quadratic terms of guar gum, SPI and whipping time (A, B and D) were found highly significant with $p < 0.001$. The interaction terms of (AD, BC and BD) were found to significant at $p < 0.05$ whereas the quadratic

terms (A^2 and B^2) were highly significant and (C^2) was slightly significant. Other linear ©, interactive (AB and AC) and quadratic (D^2) terms does not provide any significant difference on foam stability.

After neglecting the insignificant terms by backward elimination procedure, the final empirical model in terms of coded and actual factors that have significant effect on foam stability was presented as follows:

$$\begin{aligned}\text{Foam stability (\%)} = & 85.230 + 1.660A + 2.230B + 2.100D + \\ & 0.511AD + 0.482BC - 0.529BD - 0.897A^2 - \\ & 0.939B^2 + 0.460C^2 \\ & (R^2 = 0.9058) \quad (4.13)\end{aligned}$$

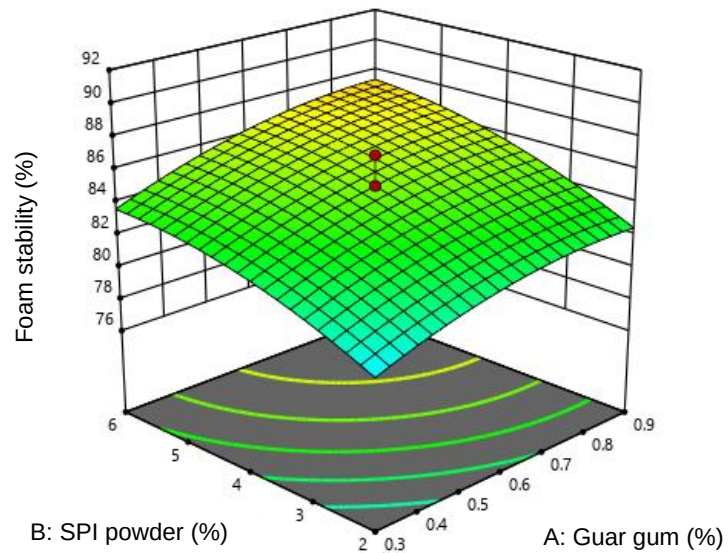
Replacing A, B, C and D with $(Gg - 0.6)/0.3$, $(Sp - 4)/2$ and $(Wt - 6)/3$, respectively [Eqn. 3.29] in Eqn. (4.13), the foam stability in real terms of guar gum, soy protein isolate and whipping time is given in the following equation.

$$\begin{aligned}\text{Foam stability (\%)} = & 65.550 + 15.240Gg + 3.560Sp + 0.710Wt + \\ & 0.570GgWt + 0.010SpSu - 0.090SpWt - \\ & 10.930Gg^2 - 0.260Sp^2 + 0.001Su^2 \\ & (R^2 = 0.9572) \quad (4.14)\end{aligned}$$

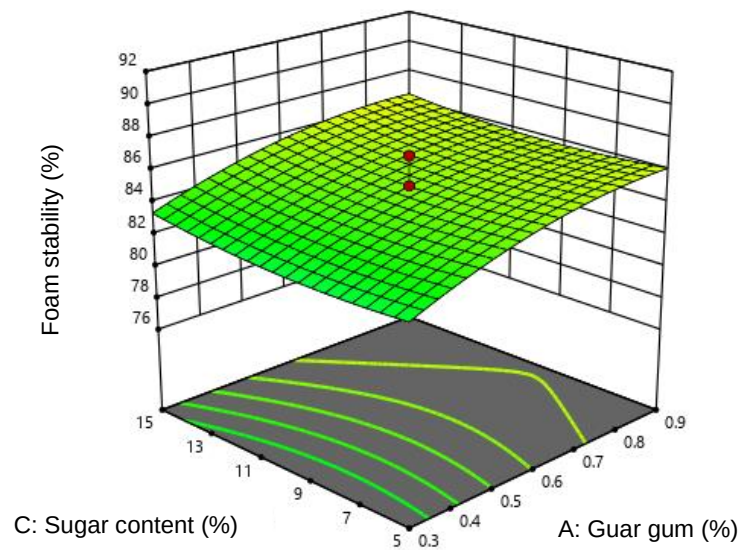
From the model fitted for foam stability, linear effects of guar gum, SPI followed by whipping time were significant. The linear positive terms of Eqn. 4.13 indicated that foam stability increased with increase in guar gum, soy protein isolate, sugar content and whipping time. The presence of negative interaction terms between soy protein isolate and whipping time decreases the foam stability. The negative values indicated that higher values of these variables further reduced foam stability. The most prominent factors affect on foam stability was found soy protein isolate followed by guar gum and whipping time.

Figure 4.12 shows the interaction between foaming agents (SPI and guar gum), sugar and whipping time on foam stability of Nagpur mandarin juice. From the plot, it was observed that the concentrations of guar gum and soy protein isolate increased the foam stability was also

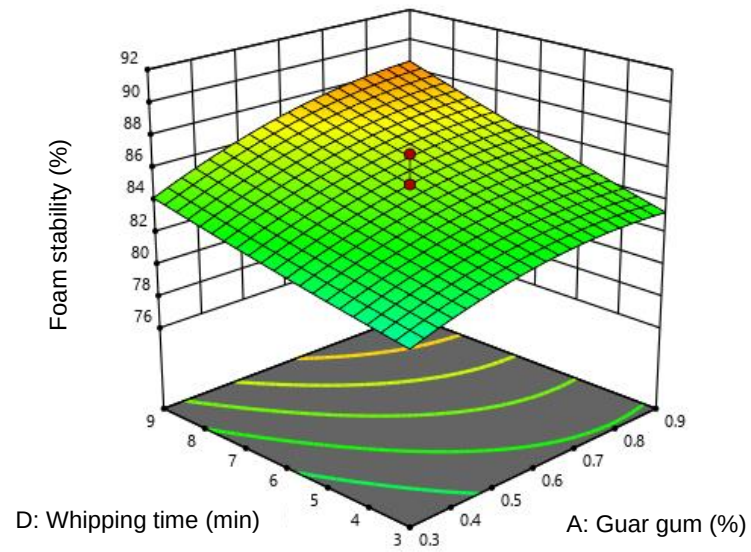
increases. The effect of guar gum was related to increasing the viscosity of the solution, and improving the elasticity of the bubble wall results from the surface activity and glycoprotein structure of guar gum (Carp *et al.* 1997; Karim and Wai 1999; Eduardo *et al.*, 2001; Karazhiyan *et al.*, 2009).



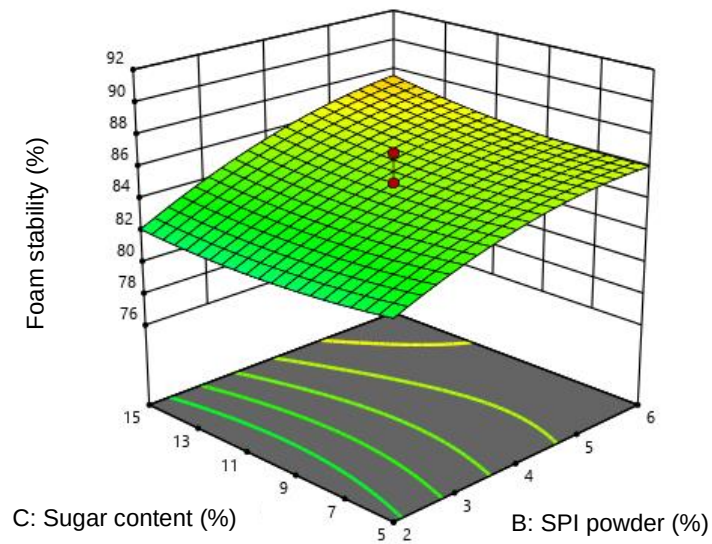
a) At constant sugar and WT



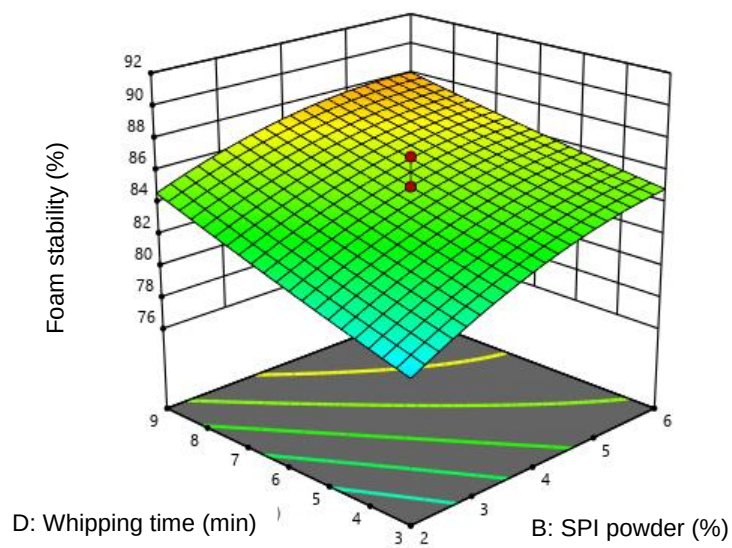
b) At constant SP and WT



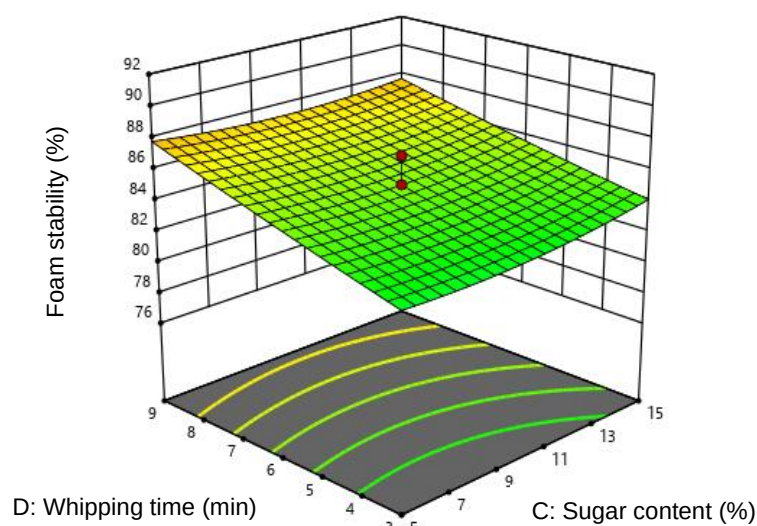
c) At constant SP and sugar



d) At constant guar gum and WT



e) At constant guar gum and sugar



f) At constant guar gum and SP

Fig. 4.12 The contour and response surface showing the effect of natural foaming agents, sugar content and whipping time on foam stability (%) during foaming of juice

4.6 Optimization of Process Parameters for Nagpur Mandarin Juice using Natural Foaming Agents

A graphical multi response optimization technique was employed to determine the optimum conditions for the foaming parameters of Nagpur mandarin juice. Based on the desirability of the process variables, the best solution was selected for optimization of the process variables.

The optimum condition was selected for the set of experimental values having minimum foam density and maximum foam expansion and stability. Minimum foam density gives a maximum foam expansion and high stability of foam without liquid separation from the foam. Equal importance is given to all parameters in order to optimize the process conditions for the foaming process by numerical optimization technique.

Table 4.23 Constraints for optimization of various process parameters of foamed Nagpur mandarin juice with natural foaming agent

Process parameter	Target	Experimental		Importance
		Range		
		Low	High	
A:Guar gum, %	minimize	0.3	0.9	3
B:Soy protein Isolate, %	minimize	2	6	3
C:Sugar content, %	is in range	5	15	3
D:Whipping time, min	minimize	3	9	3
Foam expansion, %	maximize	6.83	34.64	3
Foam density, g/cm ³	minimize	0.63	0.90	3
Foam stability, %	maximize	76.33	90.31	3

Table 4.24 Optimized process parameters of foamed Nagpur mandarin juice with natural foaming agents.

SN	GG (%)	SPI (%)	SC (%)	WT (min)	FE (%)	FD (g/cm ³)	FS (%)	D
1	0.45	3.32	10.00	5.82	25.76	0.71	83.04	0.629

GG is guar gum, SPI is soy protein isolate, SC is sugar content, WT is whipping time, FE is foam expansion, FD is foam density, FS is foam stability and D is desirability

The optimum range of process parameters for foamed Nagpur mandarin juice concentrate is presented in Table 4.23 and the solution generated for the experiments are presented in Table 4.24. The superimposed contour plots having common superimposed area for all responses were shown in Fig. 4.13.

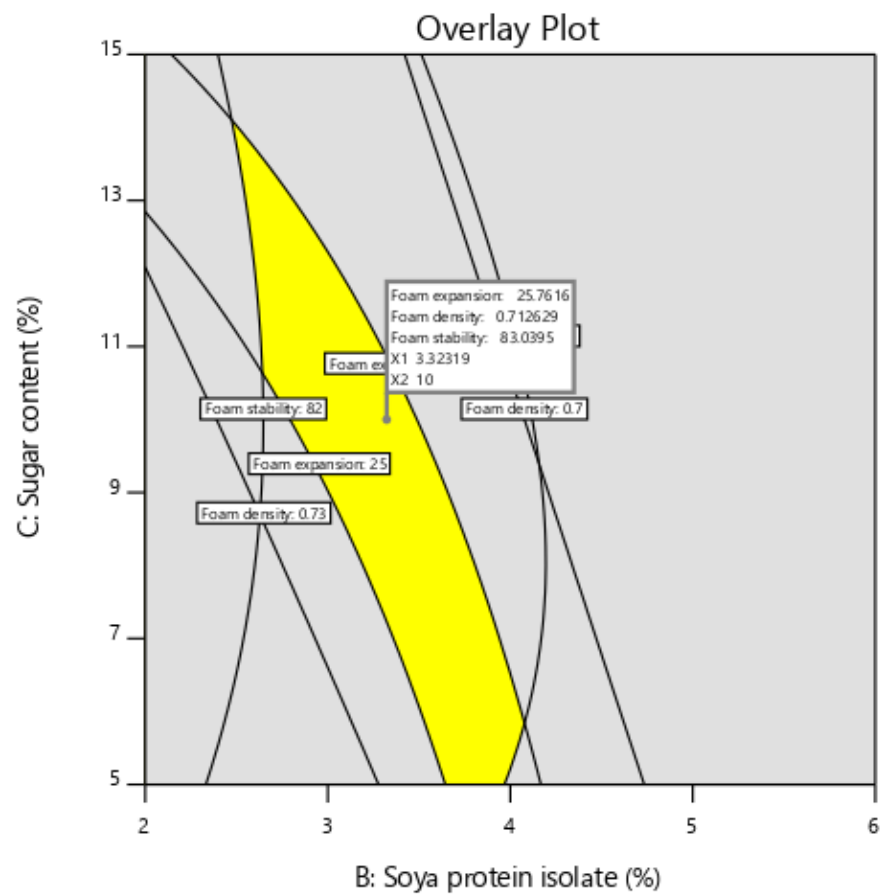
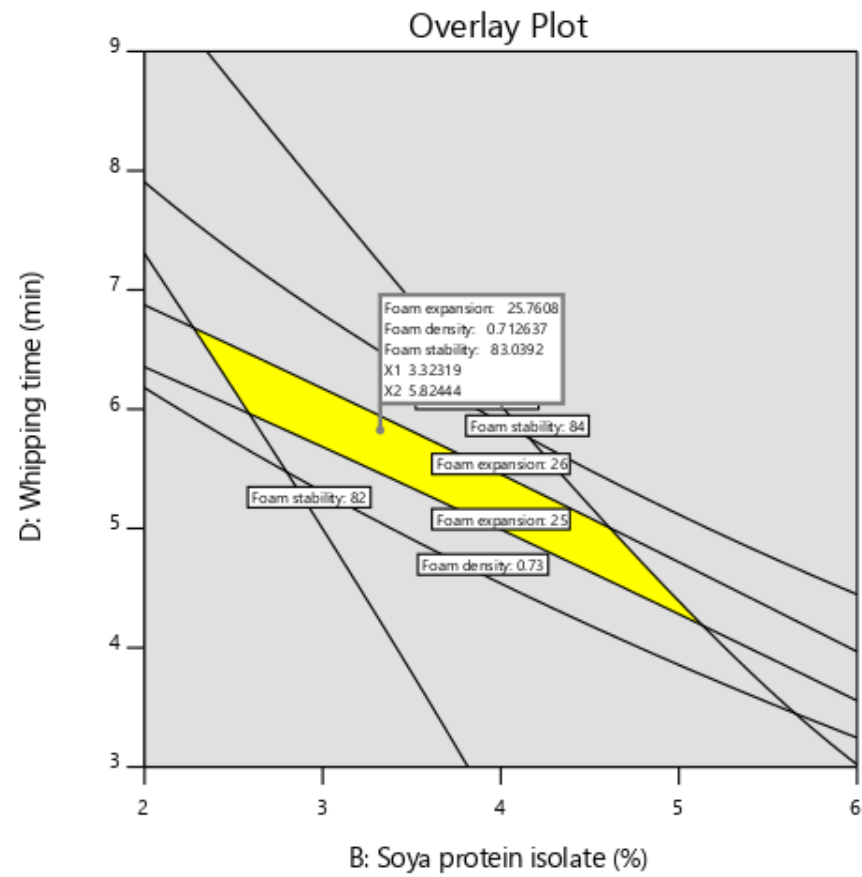


Fig. 4.13 Superimposed contour plots of different foam responses

The optimum values of process variables obtained by numerical optimization as follows:

Guar Gum (%)	: 0.45
Soy protein isolate (%)	: 3.32 ~ 3.30
Sugar content (%)	:10
Whipping time (min)	: 5.82 ~ 6

The optimum operating conditions for guar gum 0.45%, soy protein isolate 3.30%, sugar content 10% and whipping time 6 min corresponding to these values of process variables, the value of foam expansion was 25.76%, foam density 0.71 g/cm³, foam stability 83.04% and overall desirability 0.629 presented in Table 4.24.

4.7 Verification of the Model for Foaming Properties of Nagpur Mandarin Juice during Foaming using Natural Foaming Agent

The adequacy of the model is examined by an additional experiment using the derived optimal conditions. The predicted value and experimental values are presented in Table 4.25. The experimental values were found very close to the predicted values. Therefore, it was concluded from above discussions that are quite adequate to assess the behaviour of the foaming properties.

Table 4.25 Predicted and experimental values of response

Response	Predicted mean	Exp. mean Value ± SD	SE	% Variation	Mean difference
Foam expansion, %	25.85	24.17± 2.06	2.14	8.91	1.68
Foam density, g/cm ³	0.71	0.728± 0.02	0.02	0.09	0.02
Foam stability, %	83.14	84.20± 0.94	1.04	4.49	1.06

II Effect of Microwave Drying on Drying Characteristics of Nagpur Mandarin Foamed Juice

The foamed juice of Nagpur mandarin was developed by using artificial and natural foaming agent with optimized parameters. This foamed juice was dried in microwave oven at varying microwave power 180, 360, 540, 720 and 900 W at different drying bed thickness 2, 4 and 6 mm. The results of drying characteristics during drying of foamed juice are presented in following section.

4.8 Initial Moisture Content

The initial moisture content of Nagpur mandarin juice was determined by using oven drying method as described in Section 3.6. The average initial moisture content of fresh Nagpur mandarin juice, with artificial and natural foaming agents was found 92.46%, 79.94% and 77.59% (wb), respectively.

4.9 Microwave Drying Behaviour of Nagpur Mandarin Foamed Juice using Artificial Foaming Agent.

The foam was prepared using SPI 2.10%, sugar content 5.50% GMS 2.75%, CMC 1.75% and whipping time of 8 min for further drying at various microwave power from 180 to 900 W and drying bed thickness from 2 to 6 mm. During drying of foamed juice the investigations were carried out on (i) drying characteristics, (ii) estimation of effective moisture diffusivity and activation energy and (iii) drying efficiency.

4.9.1 Drying characteristics of mandarin foamed juice using artificial foaming agent.

The microwave drying behaviour was investigated for Nagpur mandarin foamed juice using artificial foaming agent dried at different microwave power of 180, 360, 540, 720 and 900 W with drying bed thickness 2, 4 and 6 mm. The experimental data were presented in Appendix B. The variation in moisture content of foamed Nagpur

mandarin juice with drying time, drying rate and effective moisture diffusivities were calculated and presented in following sections.

4.9.1.1 Variation in moisture content of foamed juice with drying time using artificial foaming agents.

The curves showing variation in moisture content with drying time for Nagpur mandarin foamed juice are shown in Fig. 4.14. The juice was dried at different microwave power of 180 to 900 W with drying bed thickness 2, 4 and 6 mm.

Table 4.26 Overall regression coefficients with R^2 using artificial foaming agent

S. N.	Microwave power, W	Thickness of drying bed, mm	Regression coefficient		Coefficient of determination, R^2
			A	k	
1.	180	2.0	390.627	0.108	0.995
2.	360	2.0	391.733	0.146	0.996
3.	540	2.0	432.158	0.230	0.989
4.	720	2.0	452.963	0.209	0.994
5.	900	2.0	482.092	0.274	0.998
6.	180	4.0	394.143	0.084	0.999
7.	360	4.0	336.873	0.049	0.950
8.	540	4.0	470.551	0.176	0.997
9.	720	4.0	625.641	0.286	0.996
10	900	4.0	422.846	0.272	0.997
11	180	6.0	511.366	0.089	0.999
12	360	6.0	505.768	0.158	0.994
13	540	6.0	381.974	0.161	0.993
14	720	6.0	469.608	0.256	0.996
15	900	6.0	389.539	0.166	0.999

The initial moisture content of the foamed juice was in range of 411.51 to 398.50% (db) for all investigated samples and after drying up to constant bone dry weight, the moisture content was reduced in the range

of 4.77 to 1.39% (db) (Fig 4.14) (Appendix B). It was also observed from these curves that moisture content of foamed juice decreased exponentially with drying time under all drying conditions and drying time reduced by increasing microwave power. Similar types of results were reported by various researcher viz. Darvishi and Hazbavi (2012) for date plum, Aral *et al.* (2016) for radix eremut, Rajkumar *et al.* (2007a) for alfanso mango and Alibas (2014b) for celery leaves.

The drying data were statistically analysed and regression equations of exponential form were predicted as

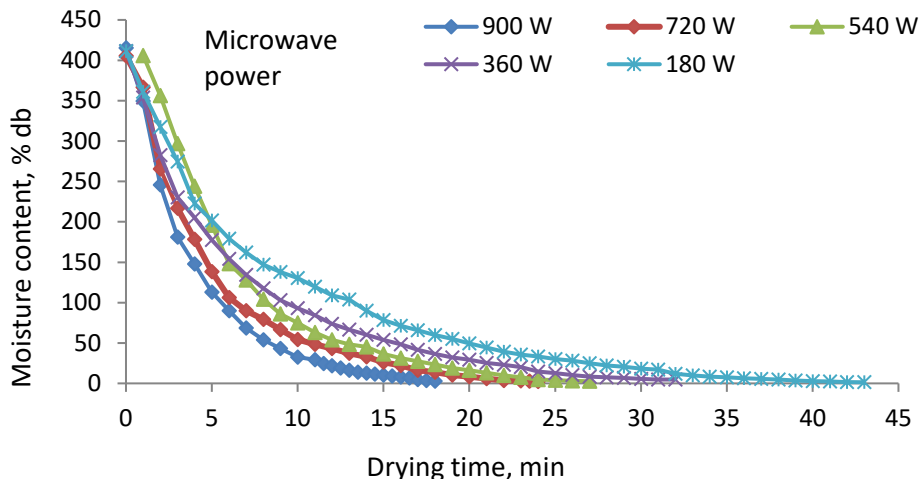
$$MC = Ae^{-kt} \quad (4.15)$$

Where, MC is moisture content of the foamed juice during drying, t is time in min, A and k are constants.

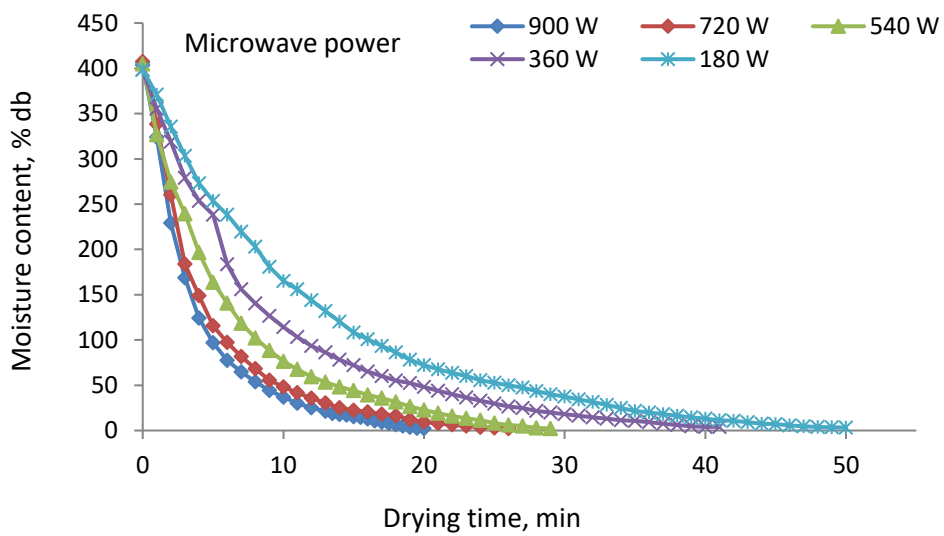
From Table 4.26, it shows that the regression equation is best fitted to drying data with $R^2 > 0.950$ for different microwave power (180 to 900 W) at varying drying bed thickness (2 to 6 mm).

Table 4.27 Drying time and final moisture content with artificial foaming agent in microwave drying.

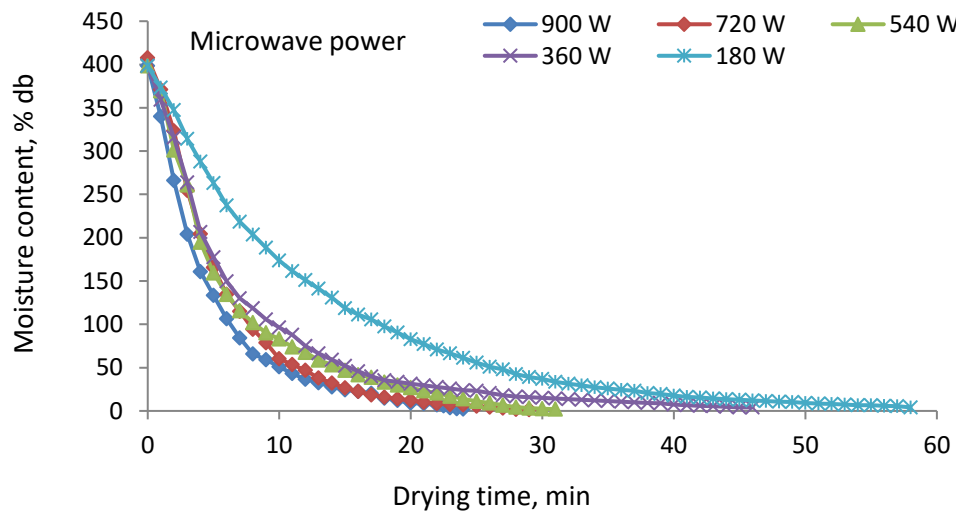
Sr. No.	Microwave power, W	Drying bed thickness, mm	Drying time, min	Final moisture content, % (db)
1	180	2	43.00	1.40
2	360	2	32.00	4.17
3	540	2	26.00	1.88
4	720	2	24.00	2.73
5	900	2	18.00	2.74
6	180	4	50.00	3.32
7	360	4	41.00	4.01
8	540	4	29.00	2.37
9	720	4	25.00	3.10
10	900	4	20.00	2.24
11	180	6	58.00	4.31
12	360	6	45.00	4.32
13	540	6	31.00	2.01
14	720	6	29.00	1.40
15	900	6	25.00	3.03



a) moisture content at varying microwave power for 2 mm drying bed thickness



b) moisture content at varying microwave power for 4 mm drying bed thickness



c) moisture content at varying microwave power for 6 mm drying bed thickness

Fig 4.14 Effect of drying time on moisture content at varying microwave power and drying bed thickness of Nagpur mandarin foamed juice using artificial foaming agents.

From Table 4.27, it shows that the minimum drying time of 18 min was recorded at highest microwave power (900 W) and the maximum drying time of 58 min was recorded at lowest microwave power (180 W). The final moisture content was found from 1.40 to 4.32% (db). It was also observed that, if thickness of drying bed increases then drying time also increases. In general, drying time (58 to 18 min) decreased with increase in microwave power (180 to 900 W) and decrease drying bed thickness (6 to 2 mm) (Fig.4.14).The microwave power was found more predominant factor which affects the drying time.

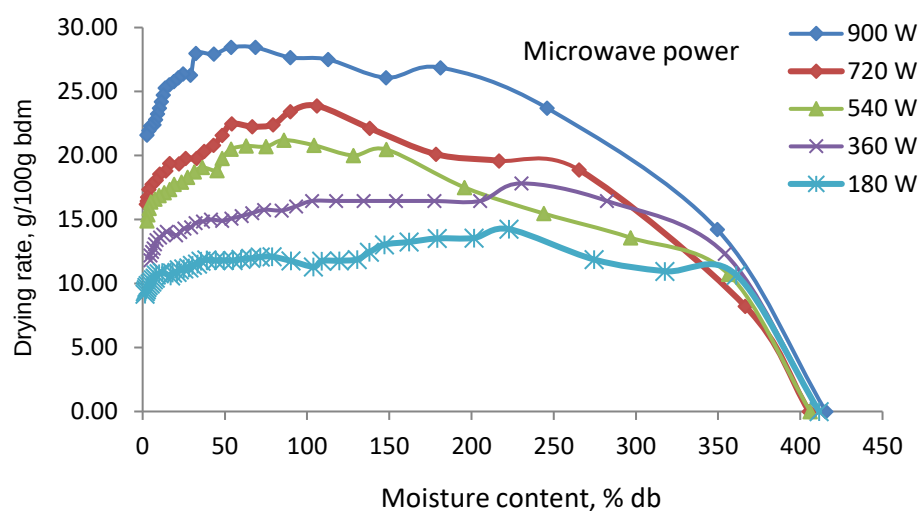
4.9.1.2 Variation in drying rate with respect to moisture content of foamed juice using artificial foaming agents.

It was observed from the Fig. 4.15, that as the drying proceeds, the moisture content of the sample decreased and the rate of drying where also decreased.

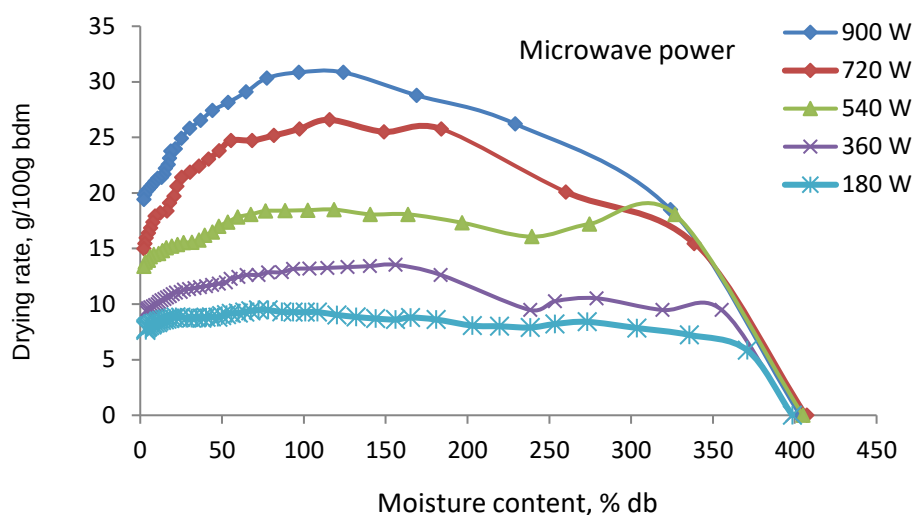
Table 4.28 Predicted equations of drying rate during microwave drying of Nagpur mandarin foamed juice using artificial foaming agent

SN	MP, W	DBT, mm	Equation predicted	R ²
1	180	2	$y = -0.000x^2 + 0.045x + 9.772$	0.752
2	360	2	$y = -0.000x^2 + 0.067x + 12.31$	0.860
3	540	2	$y = -0.000x^2 + 0.066x + 16.35$	0.933
4	720	2	$y = -0.000x^2 + 0.083x + 17.44$	0.960
5	900	2	$y = -0.000x^2 + 0.083x + 23.32$	0.947
6	180	4	$y = -8E-05x^2 + 0.020x + 8.110$	0.774
7	360	4	$y = -0.000x^2 + 0.050x + 9.739$	0.845
8	540	4	$y = -0.000x^2 + 0.076x + 13.62$	0.808
9	720	4	$y = -0.000x^2 + 0.133x + 16.81$	0.943
10	900	4	$y = -0.000x^2 + 0.148x + 20.34$	0.962
11	180	6	$y = -9E-05x^2 + 0.023x + 7.337$	0.756
12	360	6	$y = -0.000x^2 + 0.095x + 9.568$	0.863
13	540	6	$y = -0.000x^2 + 0.075x + 12.94$	0.978
14	720	6	$y = -0.000x^2 + 0.057x + 16.32$	0.866
15	900	6	$y = -0.000x^2 + 0.103x + 17.17$	0.921

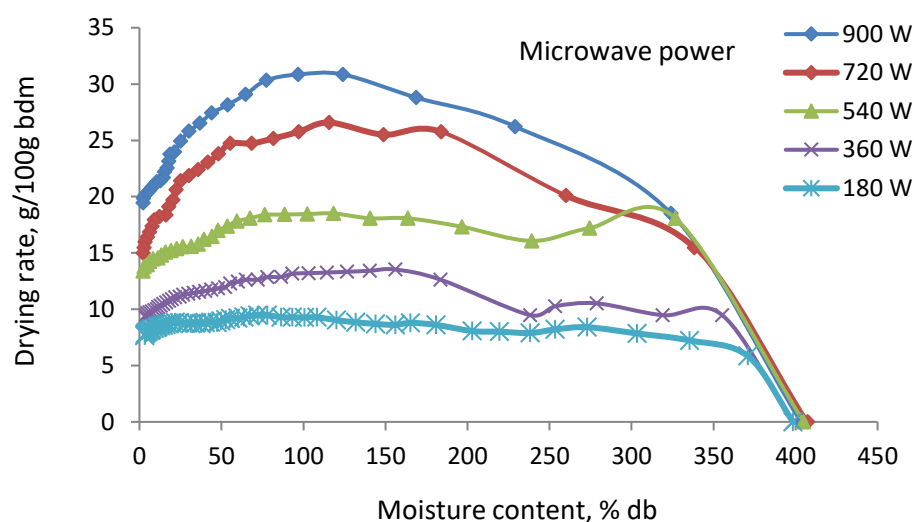
MP is microwave power, DBT is drying bed thickness, y is drying rate and x is moisture content



a) Drying rate at varying microwave power for 2 mm drying bed thickness



b) Drying rate at varying microwave power for 4 mm drying bed thickness



c) Drying rate at varying microwave power for 6 mm drying bed thickness

Fig 4.15 Effect of moisture content on drying rate at varying microwave power and drying bed thickness of foamed juice using artificial foaming agent

As the microwave power increases, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in microwave power. This resulted into substantial decrease in drying time. Hence, escaping of molecules becomes easier from the medium and faster.

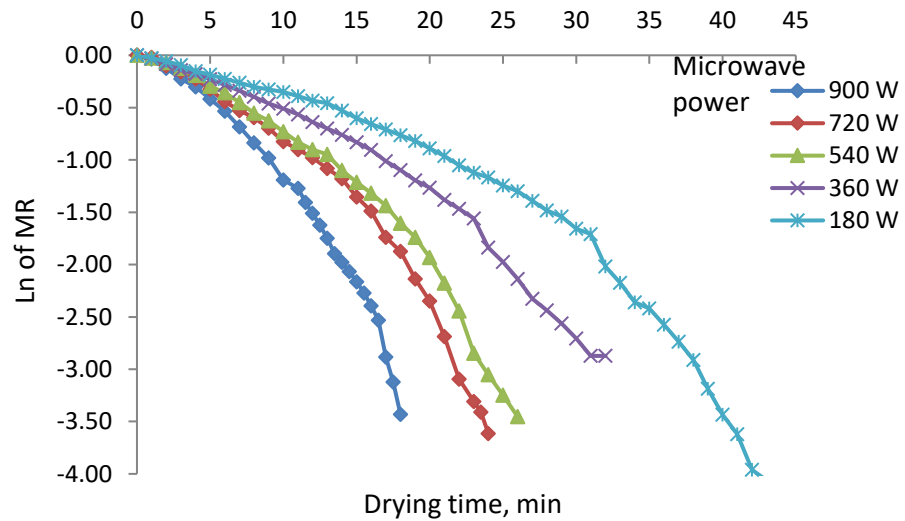
The drying rates were more after an initial short period of the process probably due to evaporation and moisture from the surface of the mandarin juice layer and later decreased with decreasing moisture content, for all the drying conditions once the drying process was governed by moisture diffusion. Further, it was observed from the figures that no constant rate period was found, the entire drying took place in falling rate period during drying of foamed juice. Similar results were reported by Shukla *et al.* (2014) for green peas, Akpinar and Bicer, (2004) for vegetables. Chayjan and Kaveh (2016) reported that the drying rate increased at the beginning of the process due to sample heating.

The predicted equation of drying rate observed in second order during microwave drying of foamed juice are presented in Table 4.28 with R^2 value. It was found that for all experiments, the $R^2 > 0.75$ which shows a good correlation between the data collected.

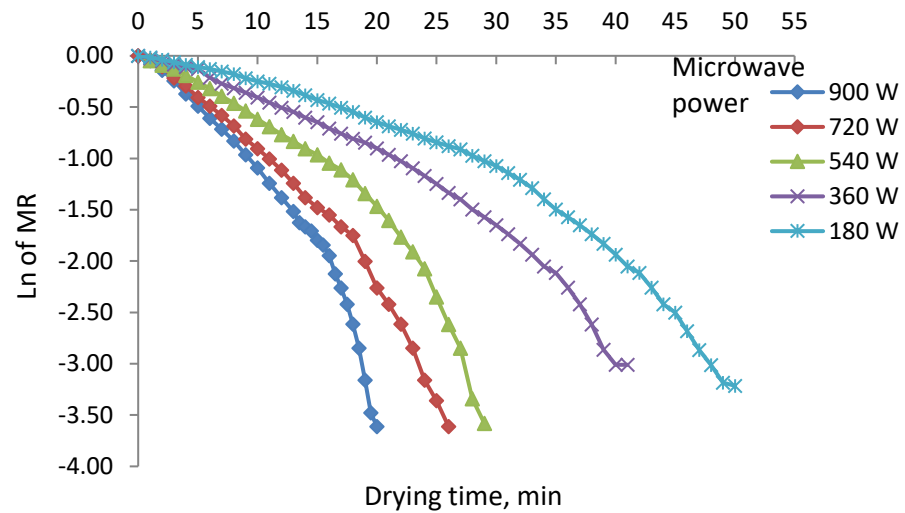
4.9.1.3 Effective moisture diffusivity (D_{eff}) using artificial foaming agents

It has been discussed in earlier that the entire drying process in the present study occurred falling rate period (section 4.9.1.2). Further analysis of the falling rate period was carried out to estimate effective moisture diffusivity (D_{eff}), in order to study the influence of moisture content on the effective moisture diffusivity and to estimate the activation energy for different microwave power during drying. The predicted equation of moisture diffusivity is presented in Table 4.29 with $R^2 > 0.90$.

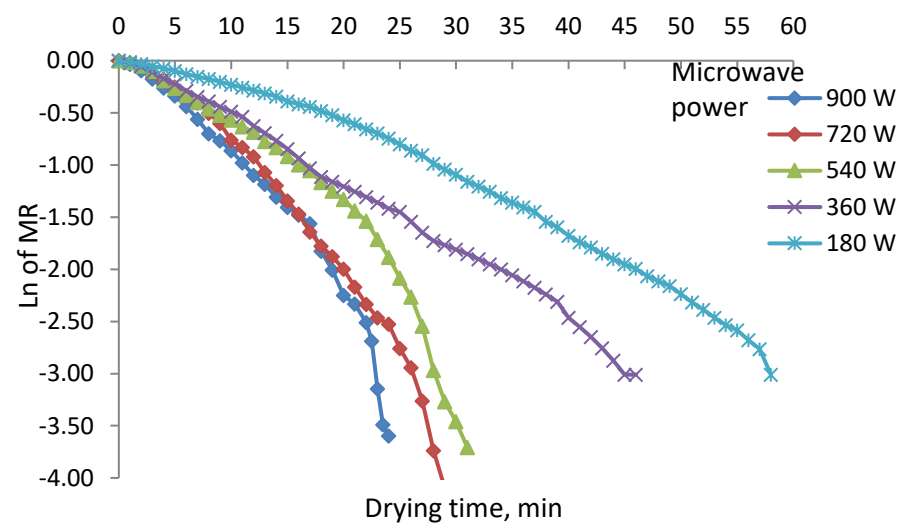
The variation of moisture content with drying time under different microwave power using artificial foaming agents are presented in Appendix-B. The drying data were used to compute moisture ratio (MR) using Eqn. (3.38).



a) Ln of MR at varying microwave power for 2 mm drying bed thickness



b) Ln of MR at varying microwave power for 4 mm drying bed thickness



c) Ln of MR at varying microwave power for 6 mm drying bed thickness

Fig 4.16 Effect of drying time on Ln (MR) at varying microwave power and drying bed thickness of foamed juice using artificial foaming agent.

Table 4.29 Moisture diffusivity in microwave drying of foamed juice using artificial foaming agents

S. N.	MP, W	DT, mm	Diffusivity equation	Actual Diffusivity, (D_{eff}) $\times$ $10^{-9}, m^2/s$	Predicted Diffusivity, (D_{eff}) $\times$ $10^{-9}, m^2/s$	R ²
1	180	2	$y = -0.0023x^2 + 0.015x - 0.191$	0.933	2.195	0.991
2	360	2	$y = -0.0023x^2 - 0.017x - 0.064$	0.933	0.101	0.996
3	540	2	$y = -0.0046x^2 - 0.007x - 0.900$	1.866	1.992	0.992
4	720	2	$y = -0.0059x^2 - 0.0005x - 0.115$	2.394	4.085	0.993
5	900	2	$y = -0.0083x^2 - 0.0226x - 0.059$	3.367	6.179	0.992
6	180	4	$y = -0.0013x^2 + 0.004x - 0.113$	1.623	1.566	0.994
7	360	4	$y = -0.0014x^2 - 0.014x - 0.071$	2.272	3.659	0.994
8	540	4	$y = -0.004x^2 + 0.0082x - 0.160$	6.491	5.753	0.983
9	720	4	$Y = 0.0035x^2 - 0.0417x - 0.065$	7.303	7.846	0.995
10	900	4	$y = -0.0074x^2 - 0.0085x - 0.153$	12.009	9.940	0.978
11	180	6	$y = -0.0005x^2 - 0.022x + 0.037$	1.826	5.327	0.998
12	360	6	$y = -0.0002x^2 - 0.055x + 0.039$	7.303	7.420	0.995
13	540	6	$y = -0.0039x^2 + 0.014x - 0.180$	10.954	9.514	0.982
14	720	6	$y = -0.0032x^2 - 0.038x + 0.002$	12.414	11.607	0.993
15	900	6	$y = -0.0047x^2 - 0.0185x - 0.103$	14.605	13.700	0.978

The natural logarithms of moisture ratio (ln MR) were plotted against average drying time (t) for different microwave power. It was observed from the Fig. 4.16 that the relationship was non-linear in nature for all drying conditions. This non-linearity in the relationship might be due to reasons like shrinkage in the product, variation in moisture diffusivity with moisture content and change in product temperature during drying. Similar findings were observed by Hawlader *et al.* (1991) and Kannan and Bandopadhyay, (1995). The non-linearity of the curves, an indicative of the variation in moisture diffusivity with moisture content, was used to estimate effective moisture diffusivity of foamed Nagpur mandarin juice, under different drying conditions. Fourier number (F_0) and effective

moisture diffusivity (D_{eff}) were estimated for corresponding values are presented in Appendix B.

This indicates that as moisture content decreased, the permeability to vapour increased, provided the pore structure remained open. The temperature of the product rises rapidly in the initial stages of drying, due to more absorption of microwave heat, as the product has a high loss factor at higher moisture content. Similar trend in the variation in the moisture diffusivity with moisture content were reported by Sharma and Prasad (2004), Sharma *et al.* (2005), Workneh *et al.* (2011) and Prabhanjan *et al.* (1995).

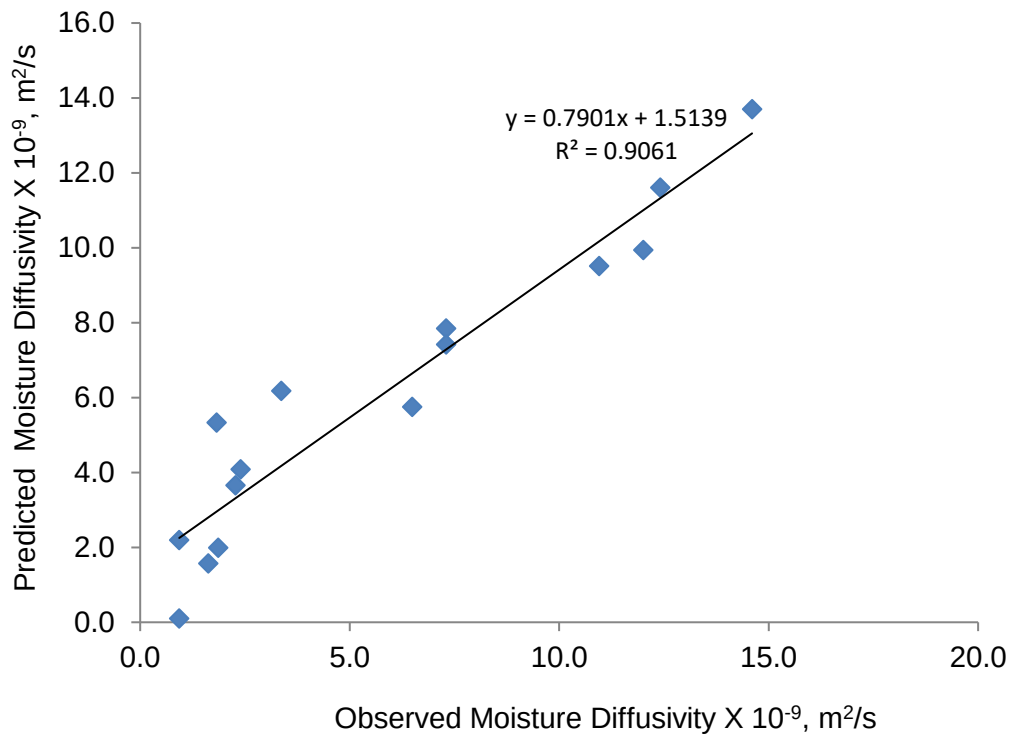


Fig. 4.17 Experimental and predicted values of moisture diffusivities

The experimental D_{eff} values during drying of foamed Nagpur mandarin juice were obtained by the modified method of slopes as described in section 3.17.2. The average actual effective moisture diffusivity (D_{eff})_{avg} values of foamed Nagpur mandarin juice using artificial foaming agents dried at different microwave power varied considerably with moisture content and microwave power from 0.993×10^{-9} to 3.367×10^{-9} , 1.623×10^{-9} to 10.009×10^{-9} and 1.826×10^{-9} to 14.605×10^{-9} m²/s

for 2, 4 and 6 mm drying bed thickness and predicted moisture diffusivity was found in the range of 0.101×10^{-9} to 6.179×10^{-9} , 1.566×10^{-9} to 9.940×10^{-9} and 5.327×10^{-9} to $13.700 \times 10^{-9} \text{ m}^2/\text{s}$ for 2, 4 and 6 mm drying bed thickness, respectively (Table 4.39), which lies within the general range of 10^{-12} to $10^{-8} \text{ m}^2/\text{s}$ for drying of food materials (Doymaz, 2010). Similarly the effective moisture diffusivities (D_{eff}) of date range for carrot pomace from 1.57×10^{-8} to $2.61 \times 10^{-8} \text{ m}^2/\text{s}$ (Abano *et al.*, 2019). It was observed from Table 4.28, that the moisture diffusivity values increased with both parameters i.e. microwave power and drying bed thickness.

4.9.1.4 Activation energy

The dependence of effective moisture diffusivity on microwave power was obtained by Arrhenius equation (Eqn 3.17). The activation energy was calculated by plotting $\ln(D_{\text{eff}})$ vs the reciprocal of the microwave power ($1/P$) as presented in Fig. 4.18 and a straight line with a negative slope were obtained which implies that the diffusivity of the samples decrease linearly with increase in ($1/P$) during microwave drying. The value of activation energy shows the sensitivity of the diffusivity against microwave power. From Table 4.30, the activation energy was found varied from 19.54 to 17.48 W/g with increase in drying bed thickness from 2 to 6 mm.

Table 4.30 Activation energy for microwave drying of foamed juice using artificial foaming agent

Sr. no	Drying bed thickness, mm	Slope of Arrhenius plot	R, kJ /kg mol K	Activation energy, W/g
1	2	-260.69	8.31	19.54
2	4	-419.52	8.31	18.11
3	6	-466.50	8.31	17.48

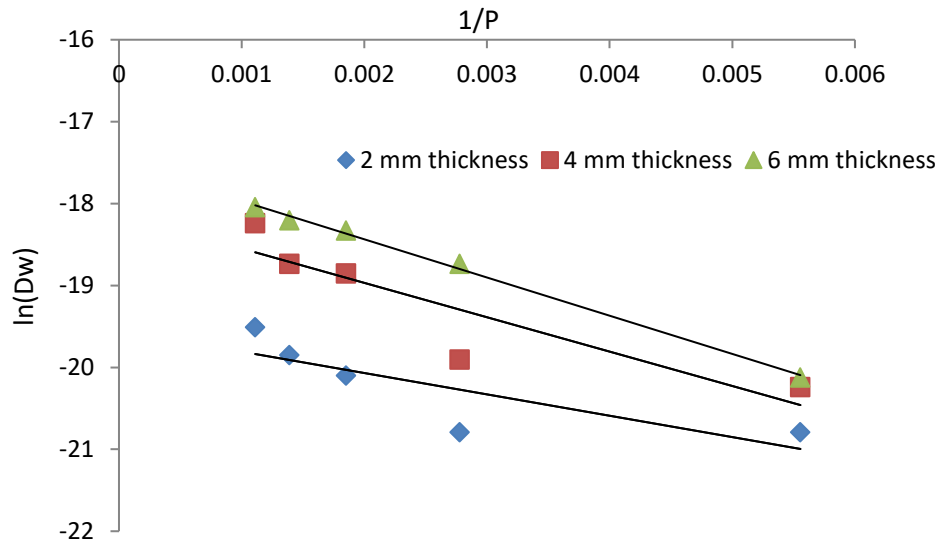


Fig 4.18 Relationship between moisture diffusivity with reciprocal of absolute microwave power using artificial foaming agent

These values are closed to the E_a values reported by various researchers viz. 12 to 32.82 W/g for trabzon persimmon (Celen, 2019), 13.45 to 19.58 W/g for zhaotong lignite (Zhao *et al.*, 2019), 13.52 and 14.20 W/g for celery leaves (Alibas, 2014) and 20.98 W/g for olive pomace (Sadi and Meziane, 2015)

4.9.1 Drying characteristics of Nagpur mandarin foamed juice using natural foaming agent.

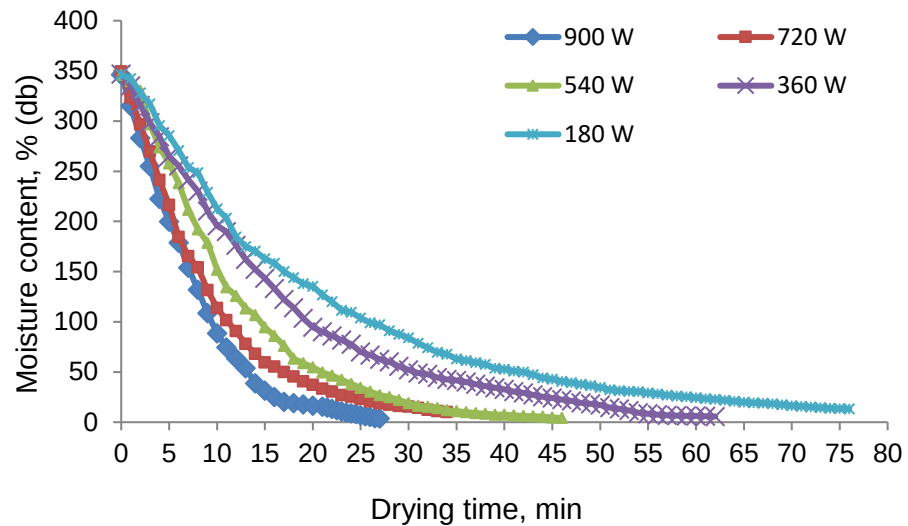
The microwave drying behaviour was investigated for foamed Nagpur mandarin juice using natural foaming agent (guar gum 0.45%, SPI 3.30%, sugar content 10% and whipping time 6 min) dried at different microwave power of 180, 360, 540, 720 and 900 W with drying bed thickness 2, 4 and 6 mm. The experimental data obtained are presented in Appendix C. The variation in moisture content of foamed Nagpur mandarin juice with drying time, drying rate and effective moisture diffusivities as well as effect of drying bed thickness were calculated and presented in following sections.

4.9.2.1 Variation in moisture content of foamed juice with drying time using natural foaming agents.

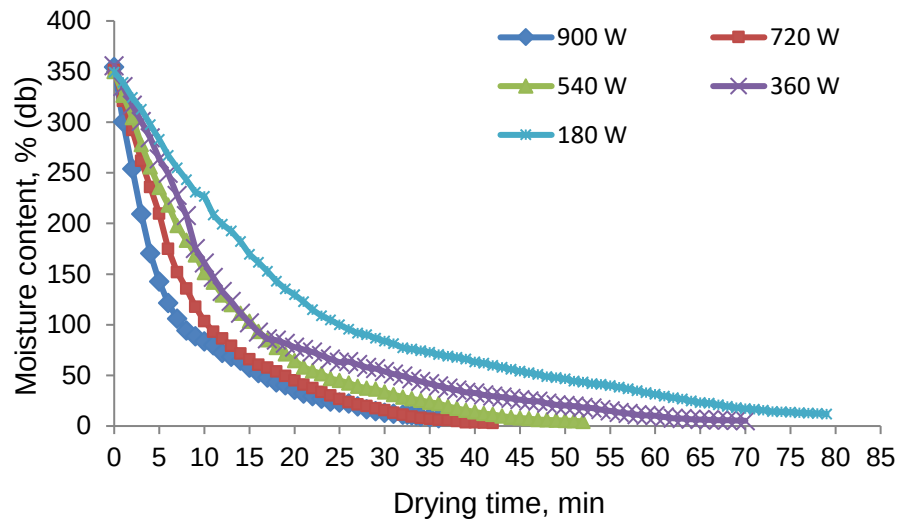
The typical curves showing variation in moisture content with drying time for foamed juice are shown in Fig. 4.19. The juice was dried at different microwave power of 180, 360, 540, 720 and 900 W with drying bed thickness 2, 4 and 6 mm. The initial moisture content of the foamed juice was 77.79 to 77.31% (wb) for all samples and after drying up to constant bone dry weight, the moisture content was reduced in the range of 2.09 to 4.89% (db) (Fig 4.19) (Appendix C).

Table 4.31 Overall regression coefficients with R^2 using natural foaming agent

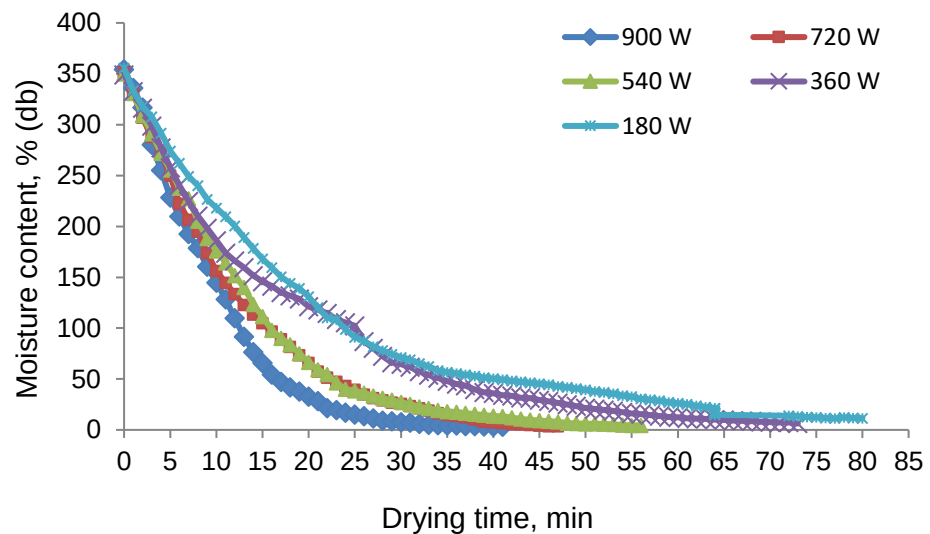
S. N.	Microwave power, W	Thickness of drying bed, mm	Regression coefficient		Coefficient of determination, R^2
			A	k	
1.	180	2.0	353.55	0.05	0.997
2.	360	2.0	361.00	0.06	0.998
3.	540	2.0	382.44	0.09	0.994
4.	720	2.0	369.81	0.12	0.995
5.	900	2.0	363.04	0.13	0.995
6.	180	4.0	347.10	0.05	0.993
7.	360	4.0	368.99	0.06	0.997
8.	540	4.0	361.53	0.08	0.998
9.	720	4.0	366.90	0.10	0.996
10	900	4.0	365.25	0.11	0.998
11	180	6.0	348.95	0.05	0.995
12	360	6.0	371.88	0.06	0.997
13	540	6.0	372.09	0.08	0.995
14	720	6.0	366.73	0.08	0.997
15	900	6.0	384.12	0.11	0.990



a) moisture content at varying microwave power for 2 mm drying bed thickness



b) moisture content at varying microwave power for 4 mm drying bed thickness



c) moisture content at varying microwave power for 6 mm drying bed thickness
Fig 4.19 Effect of drying time on moisture content at varying microwave power and drying bed thickness of Nagpur mandarin foamed juice using natural foaming agents.

It was also observed from these curves that moisture content of Nagpur mandarin juice decreased exponentially with drying time under all drying conditions and drying time reduced by increasing microwave power. Similar types of results were reported by various researcher viz. Darvishi and Hazbavi (2012) for date plum, Aral *et al.* (2016) for radix eremut, Rajkumar *et al.* (2007a) for Alfanso Mango and Alibas (2014) for celery leaves.

From Table 4.31, it shows that the regression equation is best fitted to drying data with $R^2 > 0.99$ for different microwave power (180 to 900 W) at varying drying bed thickness (2 to 6 mm).

From Fig. 4.19, it was observed that the minimum drying time of 27 min was recorded at highest microwave power (900 W) and the maximum drying time of 80 min was recorded at lowest microwave power (180 W). It was also observed that, if thickness of drying bed increases than drying time also increases. In general, drying time (80 to 27 min) decreased with increase in microwave power (180 to 900 W) and decrease drying bed thickness (6 to 2 mm). The final moisture content was found in the range of 3.19 to 11.28% (db) (Table 4.32).

Table 4.32 Drying time and final moisture content with natural foaming agent in microwave drying

Sr. No.	Microwave power, W	Drying bed thickness, mm	Drying time, min	Final moisture content, % (db)
1	180	2	76.00	11.28
2	360	2	62.00	5.69
3	540	2	46.00	4.30
4	720	2	34.00	3.30
5	900	2	27.00	3.19
6	180	4	79.00	10.90
7	360	4	70.00	5.20
8	540	4	52.00	4.61
9	720	4	42.00	3.27
10	900	4	36.00	3.39
11	180	6	80.00	9.45
12	360	6	73.00	6.29
13	540	6	56.00	4.48
14	720	6	47.00	3.50
15	900	6	41.00	3.23

4.9.2.2 Variation in drying rate with respect to moisture content using natural foaming agents.

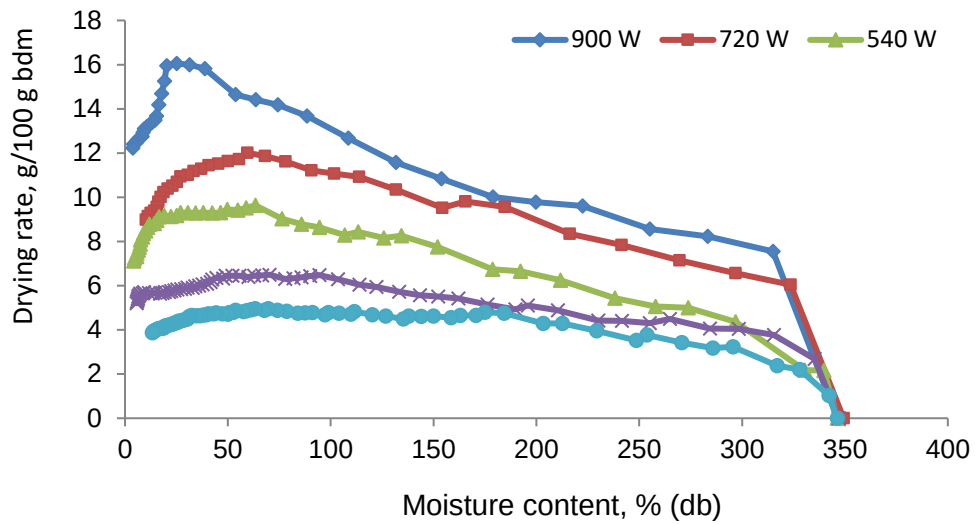
It was observed from the Fig. 4.20 that as the drying proceeds, the moisture content of the sample decreased and the rate of drying also decreased. As the microwave power increases, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in microwave power. This resulted into substantial decrease in drying time. Hence, escaping of molecules becomes easier from the medium and faster.

Table 4.33 Predicted equations of drying rate during microwave drying of foamed juice using natural foaming agent

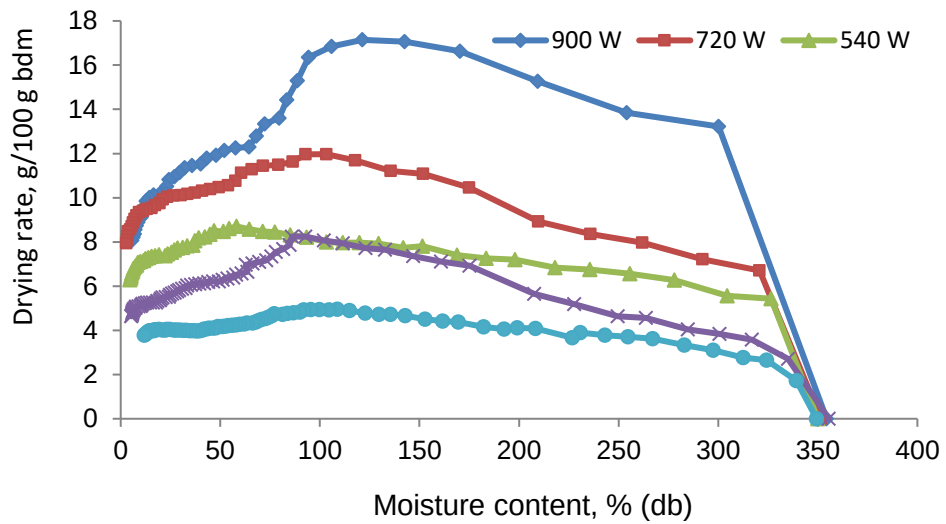
SN.	MP, W	DBT, mm	Equation predicted	R ²
1	180	2	$y = -7E-05x^2 + 0.016x + 3.958$	0.916
2	360	2	$y = -7E-05x^2 + 0.012x + 5.582$	0.863
3	540	2	$y = -0.000x^2 + 0.014x + 8.324$	0.915
4	720	2	$y = -0.000x^2 + 0.023x + 10.97$	0.853
5	900	2	$y = -0.000x^2 + 0.015x + 12.43$	0.886
6	180	4	$y = -7E-05x^2 + 0.017x + 3.592$	0.885
7	360	4	$y = -5E-05x^2 + 0.007x + 5.192$	0.821
8	540	4	$y = -9E-05x^2 + 0.017x + 7.066$	0.747
9	720	4	$y = -0.000x^2 + 0.017x + 9.336$	0.731
10	900	4	$y = -0.000x^2 + 0.020x + 10.12$	0.772
11	180	6	$y = -6E-05x^2 + 0.016x + 3.973$	0.623
12	360	6	$y = -5E-05x^2 + 0.007x + 5.019$	0.849
13	540	6	$y = -1E-04x^2 + 0.018x + 7.194$	0.691
14	720	6	$y = -7E-05x^2 + 0.008x + 7.971$	0.843
15	900	6	$y = -1E-04x^2 + 0.009x + 10.29$	0.783

Where MP is microwave power, DBT is drying bed thickness, y is drying rate and x is moisture content

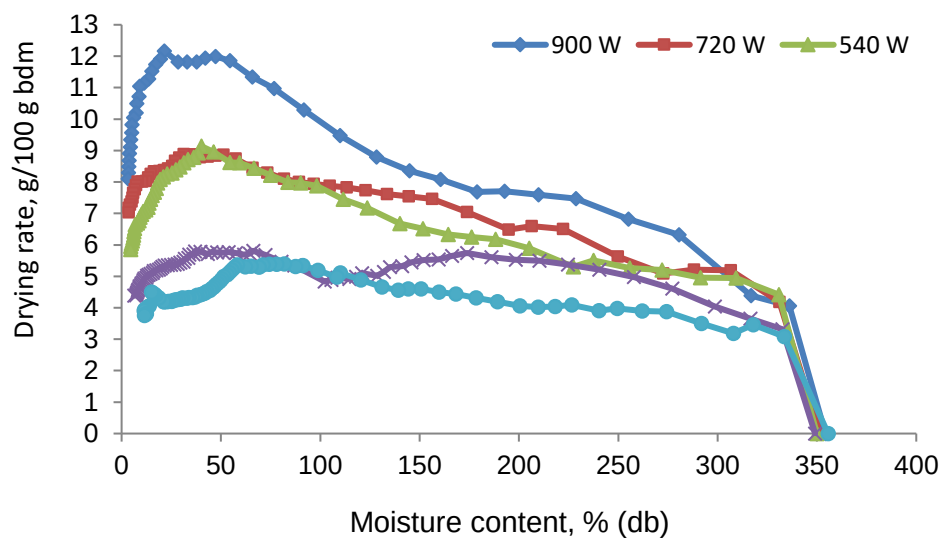
Further, it was observed from Fig 4.20 that no constant drying rate was found during drying of foamed juice using natural foaming agent, the entire process of drying took place in falling rate period. The predicted



a) Drying rate at varying microwave power for 2 mm drying bed thickness



b) Drying rate at varying microwave power for 4 mm drying bed thickness



c) Drying rate at varying microwave power for 6 mm drying bed thickness

Fig. 4.20 Effect of moisture content on drying rate at varying microwave power and drying bed thickness of Nagpur mandarin foamed juice using natural foaming agents.

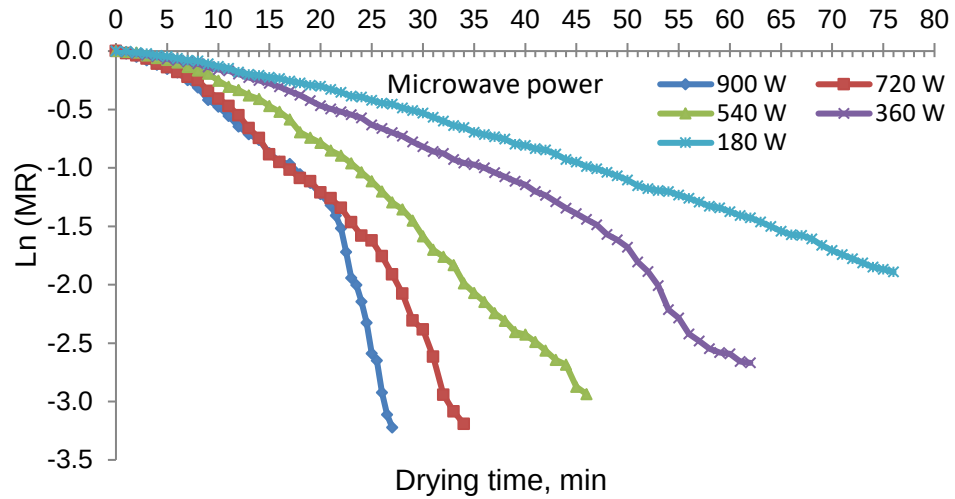
equation of drying rate during microwave drying of foamed Nagpur mandarin juice are given at Table 4.33. The drying rate curves presented in Fig. 4.20 were statistically analyzed and regression equation of second order with $R^2 > 0.69$ is given in Table 4. 31. The microwave drying of foamed Nagpur mandarin juice using natural foaming agent followed a typical trend. As the microwave power increases, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in microwave power.

This resulted into substantial decrease in drying time. Similar findings were observed by various researchers which for kiwifruit (Femenia *et al.*, 2009); hazelnut (Uysal *et al.*, 2009); carrot pomace (Kumar *et al.*, 2011); amelia mango (Dissa *et al.*, 2009); pineapple, mango, guava and papaya (Marques *et al.*, 2009) and apple pomace (Wang *et al.*, 2007).

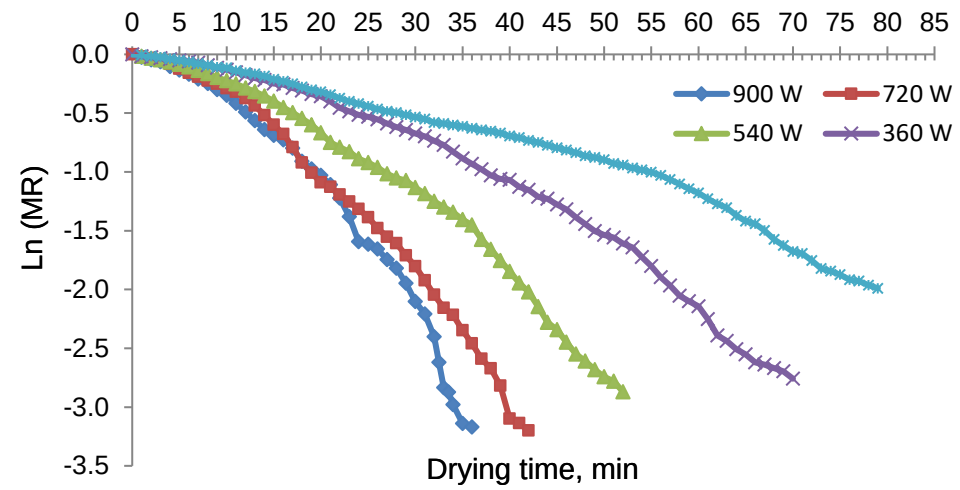
4.9.2.3 Effective moisture diffusivity (D_{eff}) using natural foaming agents

As discussed earlier that the entire drying process in the present study occurred during falling rate period (section 4.9.2.2). Further analysis of the falling drying rate period was carried out to estimate effective moisture diffusivity (D_{eff}), in order to study the influence of moisture content on the effective moisture diffusivity and to estimate the activation energy for different microwave power during drying. The predicted equation of moisture diffusivity at varying microwave power is presented in Table 4.34.

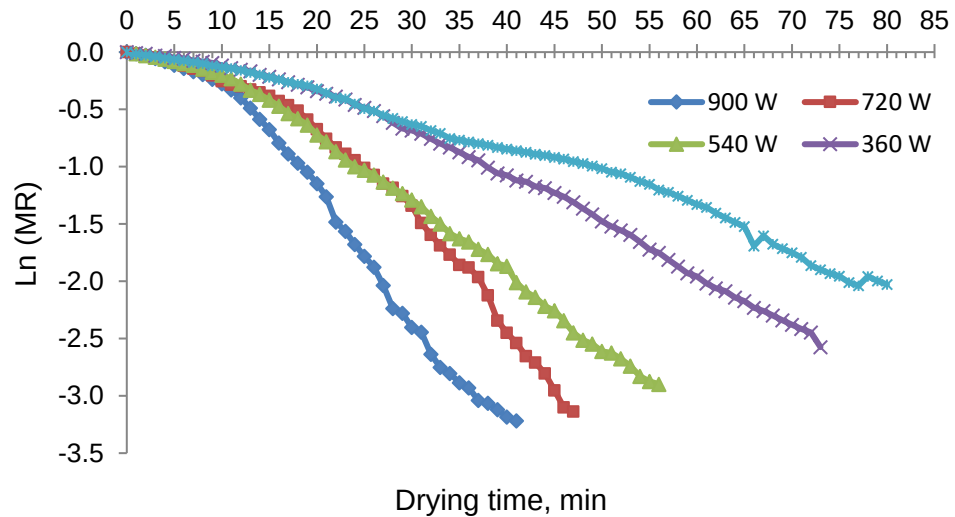
The variation of moisture content with drying time under different microwave power using natural foaming agents are presented in Appendix-C. The drying data were used to compute moisture ratio (MR) using Eqn. (3.38). The natural logarithms of moisture ratio ($\ln MR$) were plotted against average drying time (t) for different microwave power. It was observed from the Fig. 4.21 that the relationship was non-linear in nature for all drying conditions. This nonlinearity in the relationship might be due to reasons like shrinkage in the product, variation in moisture



a) Ln of MR at varying microwave power for 2 mm drying bed thickness



b) Ln of MR at varying microwave power for 4 mm drying bed thickness



c) Ln of MR at varying microwave power for 6 mm drying bed thickness

Fig. 4.21 Effect of drying time on Ln of MR at various microwave power and drying bed thickness of foamed Nagpur mandarin juice using natural foaming agents.

diffusivity with moisture content and change in product temperature during drying (Hawladar *et al.*, 1991; Kannan and Bandopadhyay, 1995). The non linearity of the curves, an indicative of the variation in moisture diffusivity with moisture content, was used to estimate effective moisture diffusivity of foamed Nagpur mandarin juice dried at different microwave power at corresponding moisture content, under different drying conditions. Fourier number (F_0) and effective moisture diffusivity (D_{eff}) were estimated for corresponding moisture content and are presented in Appendix C.

It was observed from Table 4.34, that the moisture diffusivity values increased with both parameters i.e. microwave power and drying bed thickness. The average effective diffusivity during the microwave drying of foamed Nagpur mandarin juice using natural foaming agent at various microwave power and drying bed thickness as determined experimentally (Table 4.34) and predicted as shown in Fig. 4.22. It was found from the figure that there is a good co-relation between the observed and the predicted values of water diffusivities.

The experimental D_{eff} values during microwave drying of foamed juice were obtained by the modified method of slopes described in section 3.17.2. The average actual effective moisture diffusivity (D_{eff})_{avg} values of juice using natural foaming agents dried at different microwave power varied considerably with moisture content and microwave power from 0.041×10^{-9} to 2.110×10^{-9} , 0.325×10^{-9} to 3.732×10^{-9} and 0.365×10^{-9} to 3.286×10^{-9} m²/s for 2, 4 and 6 mm drying bed thickness and predicted moisture diffusivity ranged from 0.043×10^{-9} to 2.266×10^{-9} , 0.032×10^{-9} to 2.997×10^{-9} and 0.763×10^{-9} to 3.727×10^{-9} m²/s for 2, 4 and 6 mm drying bed thickness, respectively during drying using natural foaming agents (Table 4.32). Similarly the effective diffusivity for green pepper was varied from 8.315×10^{-8} to 2.363×10^{-7} m²/s in microwave drying (Darvishi *et al.*, 2014); 0.705 and 2.618×10^{-9} m²/s for green bell pepper (Doymaz and Ismail, 2010); 2.25 to 2.74×10^{-8} m²/s for red pepper (Doymaz and Pala, 2002) and 0.31 and 87.39×10^{-9} m²/s for red bell pepper (Arslan and Ozcan, 2010, Arslan and Ozcan, 2011).

Table 4.34 Moisture diffusivity in microwave drying of Nagpur mandarin foamed juice using natural foaming agent

S. N.	MP, W	DT, mm	Diffusivity equation	Actual Diffusivit y, (D _{eff}) x 10 ⁻⁹ ,m ² /s	Predicted Diffusivit y, (D _{eff}) x 10 ⁻⁹ ,m ² /s	R ²
1	180	2	$y = -0.0001x^2 - 0.016x + 0.034$	0.041	0.698	0.999
2	360	2	$y = -0.0006x^2 - 0.0048x - 0.052$	0.243	0.043	0.991
3	540	2	$y = -0.0009x^2 - 0.0275x + 0.086$	0.365	0.784	0.996
4	720	2	$y = -0.0022x^2 - 0.0138x - 0.029$	0.893	1.525	0.992
5	900	2	$y = -0.0052x^2 + 0.0402x - 0.190$	2.110	2.266	0.967
6	180	4	$y = -0.0002x^2 - 0.0075x - 0.046$	0.325	0.032	0.991
7	360	4	$y = -0.0005x^2 - 0.0084x - 0.010$	0.811	0.774	0.998
8	540	4	$y = -0.0008x^2 - 0.0147x - 0.004$	1.298	1.515	0.997
9	720	4	$y = -0.0012x^2 - 0.0265x + 0.043$	1.947	2.256	0.997
10	900	4	$y = -0.0023x^2 - 0.0048x - 0.054$	3.732	2.997	0.994
11	180	6	$y = -0.0001x^2 - 0.0147x + 0.006$	0.365	0.763	0.993
12	360	6	$y = -0.0003x^2 - 0.0173x + 0.071$	1.095	1.504	0.998
13	540	6	$y = -0.0004x^2 - 0.0366x + 0.13$	1.461	2.245	0.997
14	720	6	$y = -0.0013x^2 - 0.0065x - 0.018$	4.747	2.986	0.999
15	900	6	$y = -0.0009x^2 - 0.0529x + 0.201$	3.286	3.727	0.986

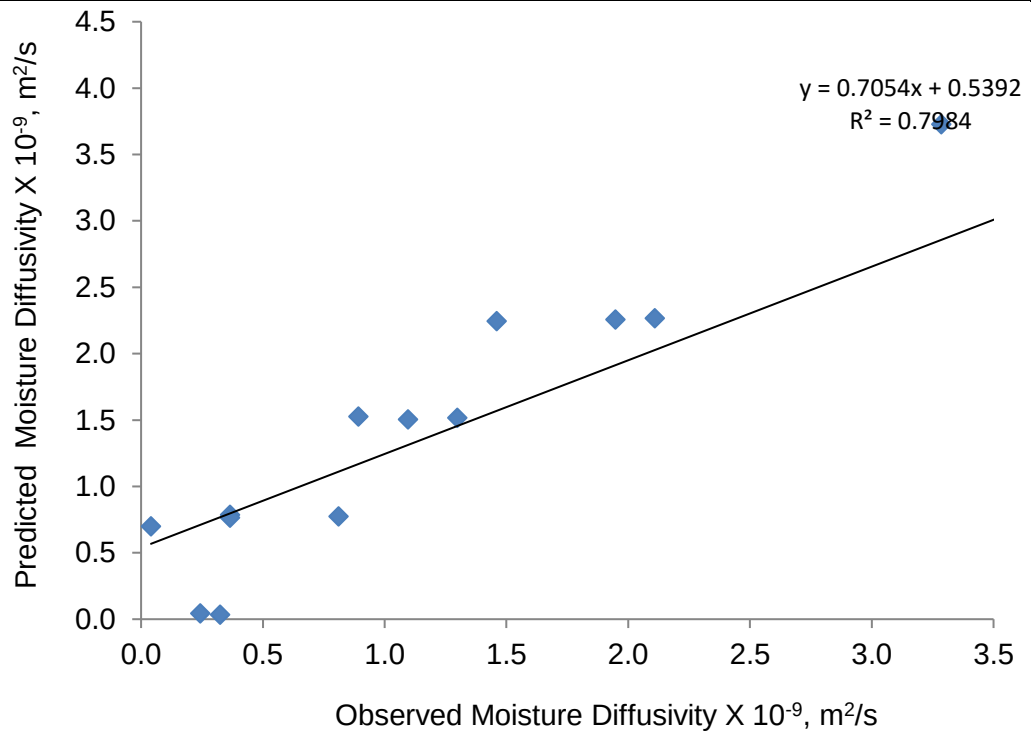


Fig. 4.22 Experimental and predicted values of moisture diffusivities using natural foaming agent

4.9.2.4 Activation energy

It is universally accepted that microwave power renders a dominant influence on moisture diffusivity. In general, this is manifested by a progressive increase in the effective moisture diffusivity with increasing temperature (Zogzas *et al.*, 1994).

The microwave power dependence on average effective moisture diffusivity ($D_{\text{eff}}\text{avg}$) during microwave drying was expressed as Arrhenius type relationship. The activation energy for moisture diffusion were obtained from the slope of plot of $\ln [(D_{\text{eff}}\text{avg})]$ versus reciprocal of power in $1/W$ (Fig. 4.23) and found 19.68, 19.29 and 18.94 W/g using natural foaming agent (Table 4.35) for 2.0, 4.0 and 6.0 mm drying bed thickness, respectively. It reveals from the figure that moisture diffusivity of Nagpur mandarin juice decreased linearly with increase in $1/P$ using natural foaming agent.

Table 4.35 Activation energy for microwave drying of foamed juice using natural foaming agent.

Sr. no	Drying bed thickness, mm	Slope of Arrhenius plot	R, kJ /kg mol K	Activation energy, W/g
1	2	-789.61	8.314	19.68
2	4	-520.62	8.314	19.29
3	6	-482.59	8.314	18.94

These values are closed to the E_a values reported by various researchers viz. 12 to 32.82 W/g for trabzon persimmon (Celen, 2019), 13.45 to 19.58 W/g for zhaotong lignite (Zhao *et al.*, 2019), 13.52 and 14.20 W/g for celery leaves (Alibas, 2014) and 20.98 W/g for olive pomace (Sadi and Meziane, 2015)

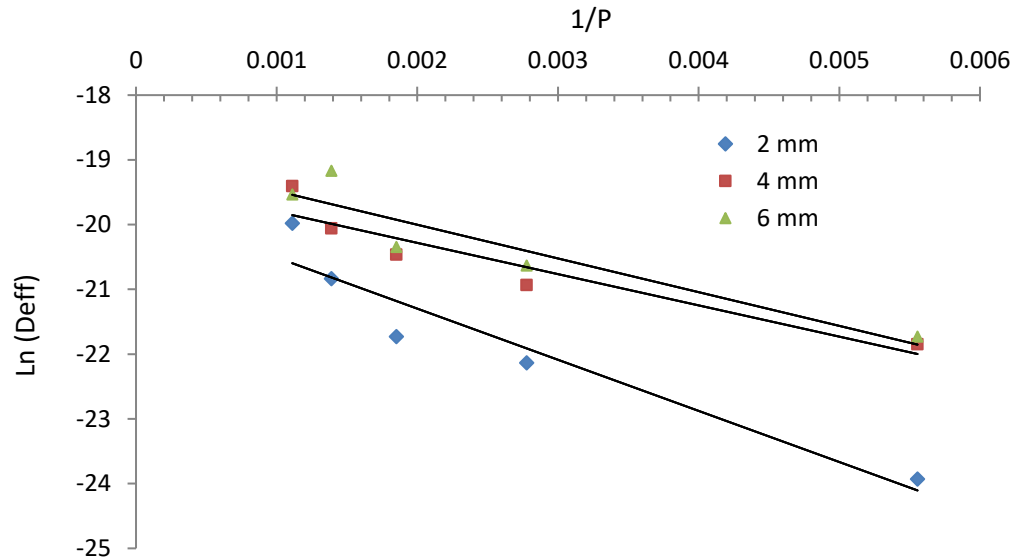


Fig. 4.23 Relationship between moisture diffusivity with reciprocal of absolute microwave power using natural foaming agent

4.9.3 Comparison of drying characteristics

The drying characteristics were compared for two different foaming agents (artificial and natural). It was observed from all experiments that the drying process occurs in the falling rate period from initial moisture content to the final moisture content. There is no constant rate period was observed during the drying process irrespective of the treatments. This was due to the fact that the drying of thin samples at high power dries the product quickly and creates partial barrier to resist movement of moisture.

In all the treatments, the drying rate was increase in initially and gradually reduced during the final stages of drying. Initially the free water present in the solid matrix was easily removed by capillary and vapour diffusion. But the transfer of moisture from the interior of the foam mat to the surface was slower enough to keep the surface wet. Hence, the rate of drying during the final stages decreased gradually with decreasing moisture content. The reduction in the drying rate during the final stages was also explained by the relative increase in concentration of sugars, organic acids and other soluble components. Hence, evaporation from foamed juice was not similar as of pure water. The experimental drying results were also found correlated with the results of previous researchers

for different food products as apple (Kudra and Ratti 2006), banana (Thuwapanichayanan *et al.*, 2008), mango (Rajkumar *et al.*, 2007a) and green leaves (Lopez *et al.*, 2000). Similar effects were observed by researchers on drying of grapes (Yaldiz *et al.*, 2001) and eggplant (Ertekin and Yaldiz 2004).

The initial drying rate of foamed juice was higher, which implied the porous structure of foamed juice. The foamed juice with natural foaming agent (guar gum, SPI and sugar content) shows slower rate of reduction in moisture content than foamed juice with artificial foaming agent (GMS, CMC, SPI and sugar content) during drying were observed. This might be due to high viscous nature and bulk during drying. The time taken for drying was also found less in foamed juice. Foaming renders the drying mass extremely porous and more amenable to drying to its inner most layers. The rapid drying was due to the moisture movement by capillarity in the liquid films by separating foam bubbles. Though, both natural and artificial foaming agents showed better drying characteristics but SPI, guar gum and sugar treated foamed juice took more time than SPI, GMS, CMC and sugar treated juice.

4.9.4 Modelling of drying curve during drying of foamed juice using different foaming agent.

To determine the most suitable drying equation, the moisture ratio data of foamed Nagpur mandarin juice with artificial and natural foaming agent at different microwave power and thickness of drying bed were fitted in eighteen thin layer drying models in their linearized form using regression technique. Among all these models, the best model suitable to fit the data were selected on basis of highest values of R^2 and the lowest value of reduced mean square of the deviation (χ^2) and root mean square error (E_{RMS}), Mean bias error (MBE), Standard error of estimation (SEE) and (P%) should be less than 10% which were calculated using Eqn. (3.54) to Eqn (3.59).

Table 4.36 Overall statistical parameters of drying model for foamed juice using artificial foaming agent

Sr. no.	Drying models	Statistical parameters					
		R ²	χ^2	MBE	E _{RMS}	SEE	P(%)
1	Lewis/ Newtons' model	0.9822	0.0033	0.0014	0.0094	-0.5301	32.4405
2	Henderson and Pabis	0.9881	0.0022	-0.0077	0.0076	-0.7978	26.1543
3	Modified Henderson and Pabis	0.9930	0.0013	-0.0047	0.0057	-2.3986	14.0606
4	Pages' model	0.9822	0.0033	0.0014	0.0094	-0.7967	30.6203
5	Logarithmic	0.9988	0.0002	0.0000	0.0024	-1.1998	1.3744
6	Two- term	0.9893	0.0020	-0.0069	0.0070	-1.5979	24.3106
7	Two-term exponential	0.9913	0.0015	-0.0022	0.0056	-0.7985	20.2203
8	Diffusion approach	0.9967	0.0006	-0.0034	0.0039	-1.1994	13.3830
9	Simplified Fick's diffusion	0.9882	0.0021	-0.0077	0.0076	-1.1979	26.2777
10	Vermaet <i>al.</i>	0.9675	0.0054	0.0200	0.0074	-1.1943	1.6580
11	Midilliet <i>al.</i>	0.9994	0.0001	0.0000	0.0017	-1.5999	0.0886
12	Wang and sing	0.9985	0.0003	0.0016	0.0028	-0.7997	0.5303
13	Thomose	0.9965	0.9431	0.2293	0.1321	0.1581	4.9798
14	Welbulli distribution	0.9994	0.0001	0.0000	0.0017	-1.5999	0.0286
15	Aghlasho <i>et al.</i>	0.9822	0.0033	0.0014	0.0094	-0.7967	30.8004
16	Logistic	0.9973	0.0005	-0.0022	0.0033	-1.1995	9.1850
17	Jena and Das	0.9993	0.0001	0.0005	0.0018	-1.5998	0.3236
18	Demiret <i>al.</i>	0.9973	0.0005	0.0000	0.0034	-1.5997	5.3055

The overall statistical parameters for different models used for drying of foamed juice with artificial and natural foaming agents have been presented in Table 4.36 and 4.37. From Table 4.36, it reveals that the R² value was greater than 0.9675 in artificial foaming agents and from Table 4.37, the R² value is greater than 0.9405 in natural foaming agent for all models. Thus all models were best fitted for drying of foamed Nagpur mandarin juice in various microwave power and drying bed thickness using different foaming agents. Demirhan and Ozbek (2011) determined that the semi-empirical Midilliet *al.* model gave a better fit for

all drying conditions applied for microwave dried celery leaves among the eight thin-layer drying models proposed.

The highest values of coefficient of determination (R^2) and the lowest values of reduced mean square of the deviation (χ^2) and root mean square error (E_{RMS}), Mean bias error (MBE), Standard error of estimation (SEE) and (P%) were obtained for Midilliet *al.* Welbulli distribution and Jena and Das drying model. The details are presented in Appendix D and E. Hence, Midilliet *al.*Welbulli distribution and Jena and Das drying model was found the most satisfactory among the models to represent the thin-layer drying of foamed juice for artificial and natural foaming agent.

Table 4.37 Overall statistical parameters of drying model for foamed juice using natural foaming agent

Sr. no.	Drying models	Statistical parameters					
		R^2	χ^2	MBE	E_{RMS}	SEE	P(%)
1	Lewis/ Newtons' model	0.9405	0.0059	0.0069	0.0105	-0.4609	25.1099
2	Henderson and Pabis	0.9659	0.0034	-0.0084	0.0079	-0.6633	20.0444
3	Modified Henderson and Pabis	0.9932	0.0007	-0.0004	0.0034	-1.9993	1.7198
4	Pages' model	0.9405	0.0059	0.0069	0.0105	-0.6608	25.1143
5	Logarithmic	0.9914	0.0009	0.0000	0.0040	-0.9991	2.4320
6	Two- term	0.9682	0.0032	-0.0077	0.0076	-1.3301	18.6073
7	Two-term exponential	0.9775	0.0025	0.0001	0.0059	-0.6642	13.0986
8	Diffusion approach	0.9950	0.0005	-0.0036	0.0029	-0.9995	6.4039
9	Simplified Fick's diffusion	0.9659	0.0032	-0.0078	0.0076	-0.9971	19.0472
10	Vermaet <i>al</i>	0.9798	0.0021	0.0016	0.0052	-1.1979	11.1991
11	Midilliet <i>al</i>	0.9980	0.0007	0.0000	0.0017	-1.3332	0.5724
12	Wang and sing	0.9876	0.0012	0.0075	0.0046	-0.6654	2.7450
13	Thomose	0.9814	4.2380	0.6911	0.2671	3.5978	11.0256
14	Welbulli distribution	0.9981	0.0002	0.0000	0.0017	-1.3332	0.5893
15	Aghlashoet <i>al</i>	0.9405	0.0058	0.0072	0.0104	-0.6609	24.0464
16	Logistic	0.9559	0.0030	-0.0040	0.0053	-1.0075	11.5207
17	Jena and Das	0.9959	0.0004	0.0001	0.0027	-1.3328	1.2978
18	Demiret <i>al</i>	0.9780	0.0021	-0.0001	0.0058	-1.3314	5.7192

The result shows that the overall highest value of R^2 and the lowest values of χ^2 , E_{RMS} , and MBE were found as 0.9994, 0.00010, 0.000, 0.00168, -1.5999 and 0.08863 in Midilliet *al.* model; 0.9994, 0.00010, 0.000, 0.001695, -1.5999 and 0.08863 in Welbulli distribution model and 0.9993, 0.0001, 0.0005, 0.0018, -1.5998 and 0.3236 in Jena and Das drying model. .

Table 4.38 Drying constants of most satisfactory models at different microwave power and drying bed thickness during drying of foamed juice

Model	DBT (mm)	MP, W	Drying constant							
			Artificial foaming agent				Natural foaming agent			
			K	N	A	B	K	N	A	B
Midilliet <i>al.</i>	2	180	0.012	1.364	0.978	-0.003	0.012	1.398	1.002	0.000
		360	0.027	1.195	0.992	-0.005	0.010	1.576	1.004	0.000
		540	0.070	0.969	1.000	-0.007	0.017	1.438	1.018	-0.001
		720	0.053	0.964	1.009	-0.013	0.017	1.450	1.018	-0.004
		900	0.043	1.393	1.001	-0.003	-0.059	0.325	0.997	-0.057
		180	0.010	1.313	0.996	-0.003	0.003	1.808	0.984	0.001
	4	360	0.026	1.142	1.012	-0.003	0.004	1.853	0.965	0.000
		540	0.039	1.094	1.011	-0.007	0.015	1.413	1.011	-0.002
		720	0.062	1.143	1.014	-0.002	0.000	0.000	1.015	-0.038
		900	0.076	1.109	1.017	-0.004	0.000	0.000	1.027	-0.043
		180	0.006	1.523	0.980	0.000	0.011	1.464	1.001	0.001
		360	0.035	1.182	1.014	0.001	0.002	2.002	0.971	0.002
	6	540	0.052	0.916	1.014	-0.010	0.007	1.693	1.000	0.000
		720	0.065	1.139	1.006	-0.001	0.000	0.000	1.042	-0.037
		900	0.023	1.337	0.992	-0.007	0.000	0.000	1.023	-0.041
Welbulli distribution	2	180	0.013	1.319	-0.189	-1.168	0.012	1.395	-0.005	-1.007
		360	0.026	1.159	-0.272	-1.264	0.010	1.577	-0.005	-1.009
		540	0.057	0.946	-0.398	-1.399	0.017	1.429	-0.047	-1.065
		720	0.034	0.952	-0.937	-1.946	0.018	1.416	-0.153	-1.170
		900	0.043	1.371	-0.074	-1.076	0.007	1.736	-0.304	-1.288
		180	0.010	1.265	-0.304	-1.300	0.003	1.852	0.068	-0.916
	4	360	0.024	1.119	-0.228	-1.240	0.004	1.866	0.018	-0.947
		540	0.034	1.068	-0.383	-1.395	0.016	1.392	-0.104	-1.115
		720	0.060	1.130	-0.074	-1.088	0.011	1.518	-0.195	-1.189
		900	0.072	1.095	-0.132	-1.149	0.006	1.770	-0.173	-1.138
		180	0.006	1.523	0.002	-0.978	0.010	1.487	0.059	-0.942
		360	0.035	1.201	0.035	-0.978	0.002	2.074	0.085	-0.888

Jena and Das	2	540	0.033	0.905	-0.912	-1.926	0.007	1.700	0.007	-0.993
		720	0.065	1.130	-0.033	-1.039	0.007	1.576	-0.278	-1.275
		900	0.022	1.284	-0.306	-1.298	0.006	1.858	-0.028	-1.016
		180	0.030	1.410	0.040	-0.430	0.042	1.186	0.061	-0.202
		360	0.040	1.430	0.020	-0.430	0.062	1.192	0.103	-0.221
		540	0.050	1.350	-0.010	-0.350	0.067	1.205	0.096	-0.220
	4	720	0.030	1.770	0.000	-0.760	0.059	1.422	0.078	-0.434
		900	0.110	1.210	0.100	-0.210	-0.004	-14.546	-0.003	15.555
		180	0.020	1.580	0.030	-0.600	0.042	1.221	0.094	-0.272
		360	0.040	1.290	0.0300	-0.290	0.054	1.243	0.097	-0.289
		540	0.040	1.420	0.020	-0.410	0.053	1.307	0.072	-0.323
		720	0.100	1.100	0.060	-0.100	0.040	1.724	0.054	-0.743
	6	900	0.100	1.150	0.050	-0.150	0.031	2.278	0.041	-1.303
		180	0.040	1.120	0.080	-0.160	0.061	1.003	0.110	-0.039
		360	0.080	0.980	0.070	0.010	0.066	1.077	0.146	-0.146
		540	0.030	1.680	-0.010	-0.670	0.059	1.246	0.106	-0.282
		720	0.100	1.050	0.050	-0.050	0.029	2.139	0.045	-1.161
		900	0.040	1.630	0.040	-0.640	0.065	1.405	0.107	-0.440

This was another confirmation of the suitability of Midllee model to thin layer drying, which has been reported by Bhagyashreeet *al.* (2013) for air drying of long pepper and Kouaet *al.* (2009) for thin layer solar drying of mango, banana and cassava. The Midilliet *al.* model was selected as the suitable model to represent the thin layer drying and was also suggested by others researchers to describe drying of various food products such as for egg plant slices (Chayjan and Kaveh, 2016), for tomato (Celmaet *al.*, 2009), for olive pomace (Meziane, 2011), for savory leaves (Arslan and Ozcan, 2011), for eggplants (Ertekin and Yaldiz, 2004), for potato, apple and pumpkin slices (Akpinar, 2006), for mint leaves (Doymaz, 2006), for Potato slices (Darvishi, 2012), for sultan grapes fruit (Karaaslan *et al.*, 2017), for Sri Lankan black pepper (Amarasingheet *al.*, 2018), for olive pomace (Sadi and Meziane, 2015), for mulberry (Evin, 2011), for turpin slices (Chayjan and Kaveh, 2016), for green bean slices (Doymaz, *et al.*, 2015), for *G. tournefortii*(Evin, 2012) and for coriander leaves (Sarimeseli, 2011).

Weibull distribution was found best descriptive model for all the drying experiments of thin layer drying. Similar results were reported by various researchers (Karaaslan, *et al.*, 2017; Alibas 2014a & b;

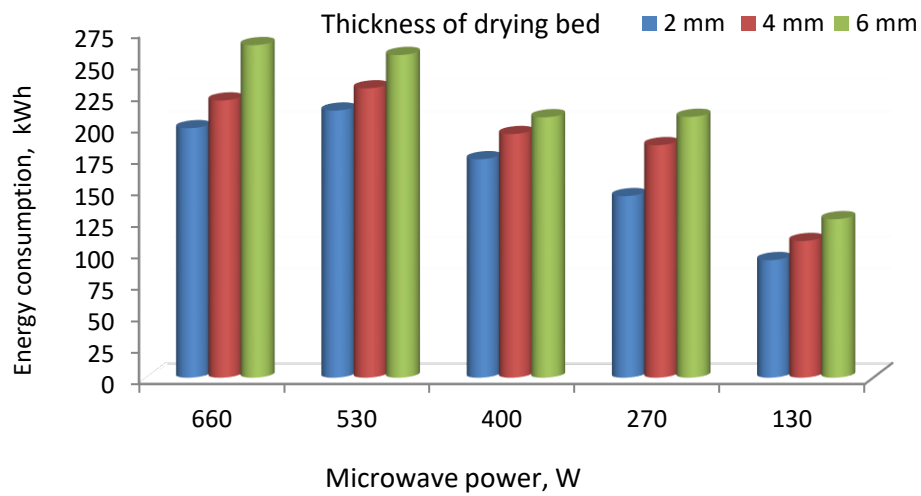
Amarasingheet *al.*, 2018; Al-Harabshehet *al.*, 2009; Evin 2012; Demirhan and Ozbek 2011; Sarimeseli 2011; Alibas, 2012; Karaaslan and Tuncer 2008).

4.9.4 Energy consumption and drying efficiency

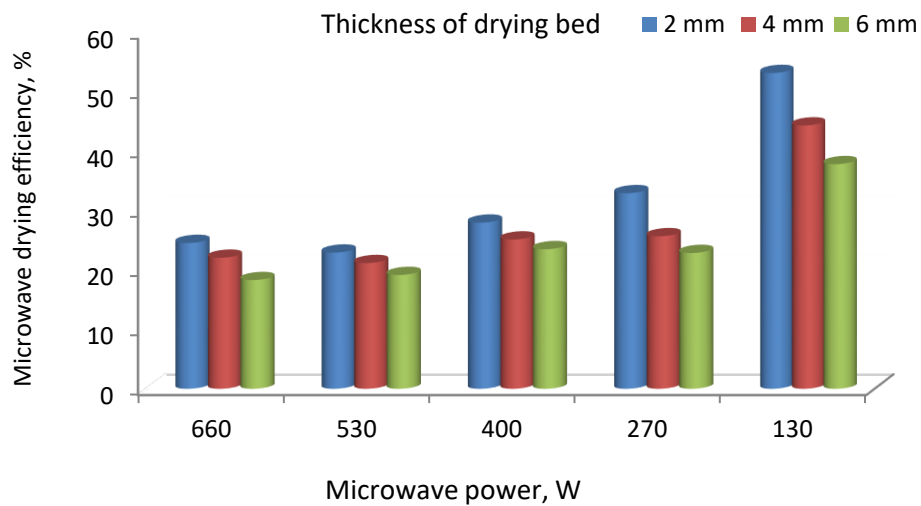
The variations of energy consumption and drying efficiency during drying of foamed juice under various microwave power at varying drying bed thickness is shown in Fig 4.24. Result reveals that the drying efficiency decreased with increase in drying bed thickness. Also it was observed that the drying efficiency increase with decrease in microwave power. The data of energy consumption and drying efficiency is given in APPENDIX F.

The average drying efficiency, total energy requirement for the dryer and the energy needed for drying of foamed juice are given Figure 4.24. The minimum specific energy (0.1523 MJ/Kg H₂O) was computed for drying of foamed Nagpur mandarin juice at microwave power 660 W with 2 mm drying bed thickness and maximum specific energy (0.4529 MJ/Kg H₂O) was computed at 130 W at 6 mm drying bed thickness (Fig 4.24c). Besides, the energy consumption decreasing with increasing drying microwave power output was more effective on energy requirement (Fig 4.24a). The maximum drying efficiency i.e. 53.21% was found at 130 W microwave power for 2 mm drying bed thickness and minimum drying efficiency i.e. 18.47% was found at 660 W microwave power at 6 mm drying bed thickness (Fig 4.24b). Darvishi (2012) reported that the minimum and maximum energy requirements for drying of potato slices were 4.22 MJ/kgH₂O and 10.56 MJ/kgH₂O.

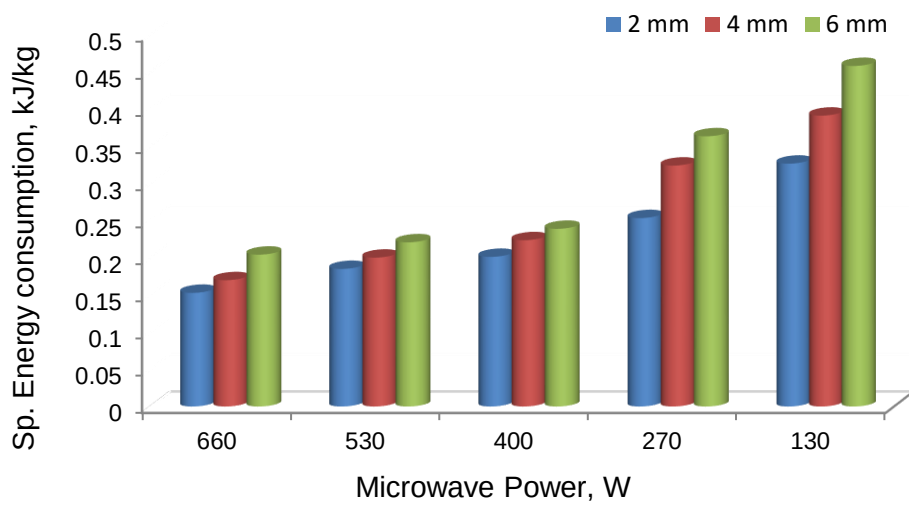
The specific energy consumption values were in the range from 17.52 to 47.35MJ/kg H₂O under applied drying conditions. Similar results for microwave drying were reported for parseley (5.10 to 4.18 MJ kg/H₂O) with microwave power ranging from 297 to 489 W, potato slices (5.882 to 4.645 MJ/kg water)in the microwave power range of 300-500 W (Darvishiet *al.*, 2013) and 52.56 to 25.32 MJ/kg H₂O(Sadi and Meziane 2015).



a) Effect of energy consumption on microwave power at varying thickness



b) Effect of drying efficiency on microwave power at varying thickness



c) Effect of Sp. energy consumption on microwave power at varying thickness

Fig. 4.24 Drying efficiency and energy consumption during microwave drying of foamed juice

The best result with regard to energy consumption was found at 660 W microwave power and drying efficiency was obtained from 130 W power among all drying power.

PART III: Drying of foamed Nagpur mandarin juice in microwave dryer

This section deals with the results of microwave drying for foamed Nagpur mandarin juice. The optimization of microwave power, drying bed thickness and foaming agents (artificial or natural) was done using optimal custom design in full version of Design Expert 11.0.4.1 statistical software.

4.10 Optimization of foaming agents, microwave power and drying bed thickness.

The optimal custom design was adopted for analysis. The influence of process parameter on quality parameters of powder viz. acidity, ascorbic acid, water activity, colour b value, change in colour, overall acceptability and drying time were analysed using ANOVA technique. The experimental values of independent variables were fitted in second order regression model for various responses. In optimal custom design two numerical and one categorical factor as input parameters (foaming agent, microwave power and drying bed thickness) were optimized with the help of Design Expert 11.0.4.1 statistical software (Table 4.39).

4.10.1 Water activity

The water activity is the most important parameter for producing shelf stable product which is to be minimized during processing. The water activity of Nagpur mandarin powder was ranged from 0.24 to 0.69 (Table 4.39). The maximum water activity was found 0.69 for 180 W microwave power and 4 mm thickness with natural foaming agent while minimum water activity was found 0.23 for 900 W microwave power and 2 mm thickness with artificial foaming agent. The minimum water activity was found with maximum microwave power and vice versa. Similar findings were observed for Yogurt powder (Karabulut *et al.*, 2007) and for beverage powder (Affandi, 2017).

Table 4.39 Dependant parameters of Nagpur mandarin powder at varying process parameters.

Run	MP, W	DBT, mm	FA	WA	Acidity %	AA mg/100g	Colour b value	ΔE	OA	DT, min
1	540	2	NFA	0.60	0.26	28.52	17.21	4.70	5.00	46.00
2	360	6	NFA	0.59	0.20	27.69	18.59	7.82	5.90	73.00
3	180	4	NFA	0.69	0.22	26.26	15.41	10.70	6.20	78.00
4	180	6	AFA	0.30	0.84	29.26	18.36	13.01	6.90	58.00
5	180	4	NFA	0.65	0.20	24.59	14.65	9.12	6.00	81.00
6	180	2	AFA	0.26	0.86	33.25	16.05	11.25	7.00	43.00
7	720	6	NFA	0.60	0.32	24.65	17.00	5.21	4.80	47.00
8	540	2	NFA	0.59	0.26	25.55	15.72	4.14	5.60	49.00
9	540	4	AFA	0.27	0.32	35.21	19.35	6.52	8.00	29.00
10	900	4	NFA	0.37	0.14	20.65	15.96	8.07	4.50	36.00
11	540	4	AFA	0.26	0.42	37.21	18.63	6.92	7.20	30.00
12	540	4	NFA	0.54	0.28	28.25	18.91	4.91	5.80	52.00
13	900	6	AFA	0.36	0.60	21.89	11.12	10.62	7.40	25.00
14	900	4	NFA	0.40	0.25	19.96	15.97	8.29	4.70	36.00
15	540	2	AFA	0.27	0.40	36.98	21.25	6.02	7.60	26.00
16	540	4	AFA	0.24	0.49	38.18	18.19	5.98	7.80	28.00
17	540	6	AFA	0.30	0.55	38.84	17.66	4.19	8.10	31.00
18	540	4	AFA	0.25	0.37	37.14	20.49	4.90	8.30	31.00
19	720	6	NFA	0.48	0.43	25.55	15.94	4.02	4.50	47.00
20	900	2	NFA	0.47	0.19	18.99	14.17	9.02	4.30	27.00
21	900	2	AFA	0.24	0.22	21.76	17.48	12.64	7.50	18.00
22	180	2	NFA	0.64	0.22	22.54	13.57	8.79	6.50	75.00

MP is Microwave power, DBT is drying bed thickness, FA is foaming agent, WA is water activity, AA is ascorbic acid, ΔE is change in colour, OA is overall acceptability, DT is drying time, NFA and AFA are natural and AFA is artificial foaming agent

Table 4.40 ANOVA for effect of microwave power, foaming agents and drying bed thickness on water activity of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	0.79	4	0.20	403.73**
A-Microwave power, P	0.02	1	0.02	41.08**
B-Thickness of drying bed, mm	0.01	1	0.01	8.56**
C-Sample	0.69	1	0.69	1407.90**
A ²	0.02	1	0.02	33.78**
Residual	0.01	17	0.00	
Lack of Fit	0.01	10	0.00	1.27 ^{NS}
Pure Error	0.00	7	0.00	
Cor Total	0.80	21		
SD	0.02			
CV	4.52			
R²	0.9896			
Adjusted R²	0.9871			
Predicted R²	0.9827			

** is 1% level of significance * is 5% level of significance and NS is non significance

The lowest water activity was found with artificial foaming agent as compared to natural foaming agents in processed powder. The water activity value was found less than 0.60, which indicated that the powder was safe and stable with respect to microbial growth, chemical, biochemical and physical reactions. The end point of drying is the residual moisture content (water activity) of the final product in microwave drying ensures economic viability and microbiological safety. Similar results were reported by Velasquez *et al.* (2001), Wang & Brennan (1991) and Fontana (2000).

The ANOVA for water activity is presented in Table 4.38 and it was found that the effect of microwave power, foaming agent and drying bed thickness were significant at 1% level of significance. From Table 4.40, the quadratic model was found best fitted to the experimental data and found significant for linear and quadratic terms for water activity. The R² value was found 0.9896 which shows good fit of model with F value of 403.73 (P < 0.01). The linear terms (A, B and C) and quadratic term (A²) were significant while interactive terms of (AB, AC and BC) and quadratic term (B² and C²)

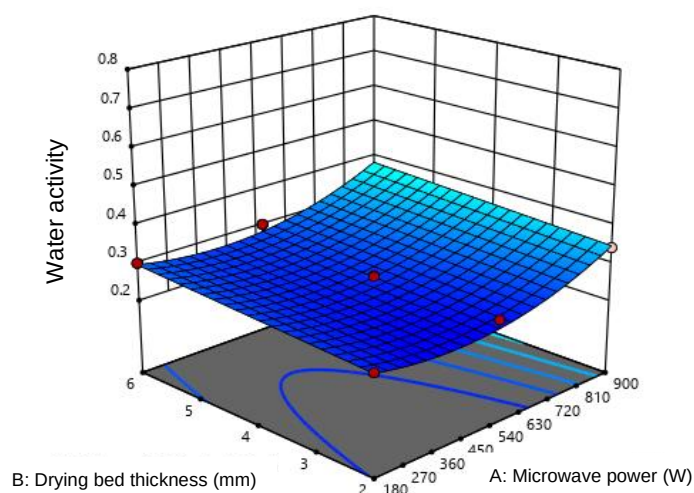
were found non significant. The lack of fit F value was non significant which indicates that the developed model was adequate for predicting the response. Moreover the predicted R^2 of 0.9871 was in reasonable agreement with adjusted R^2 of 0.9827.

This revealed that the non-significant terms were not included in the model. The second order regression model was fitted to the experimental data. This model shows the effect of foaming agents, microwave power and thickness of drying bed on water activity (a_w).

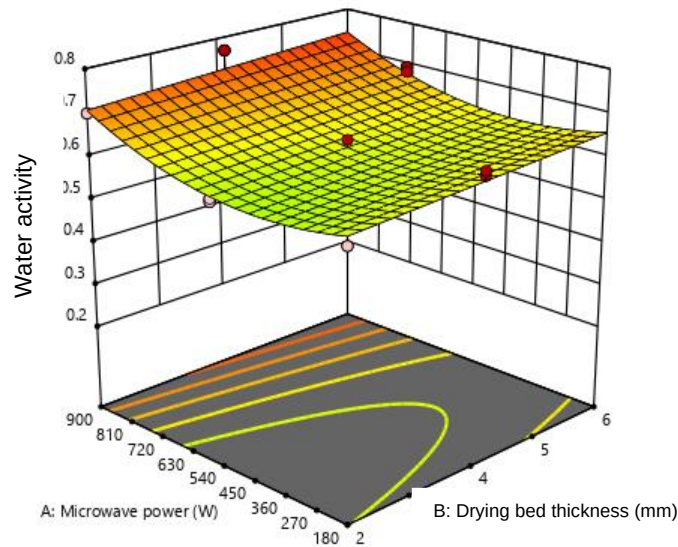
Coded equation for water activity

$$\text{Water activity, } a_w = 0.44 - 0.04A + 0.02B + 0.18C + 0.06A^2 \quad (R^2 = 0.9827) \quad (4.16)$$

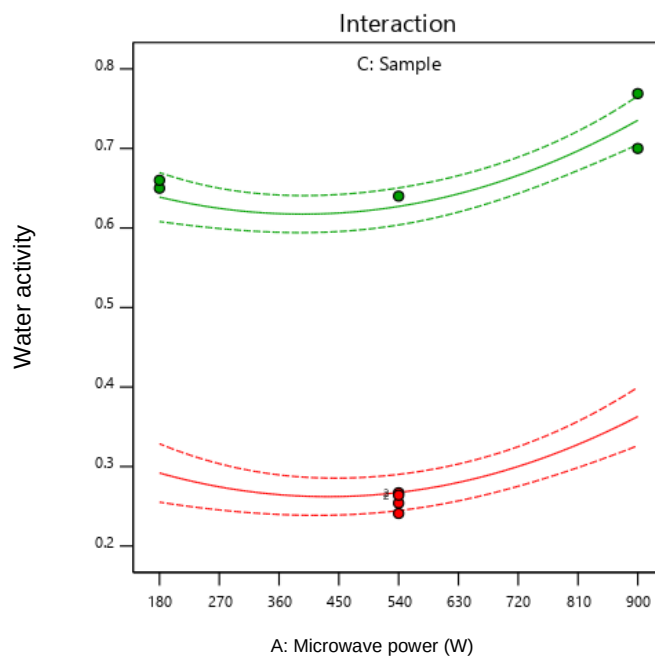
From the model fitted for water activity, linear effects of microwave power, drying bed thickness and foaming agent were found significant. The linear positive terms of Eqn. 4.16 indicated that water activity increases with increase in drying bed thickness and foaming agent. The negative linear term was found in the Eqn 4.16, which shows that the water activity decreases with increase in microwave power. The most influencing factor on water activity was foaming agent followed by microwave power and drying bed thickness.



a). At artificial foaming agent



b). At natural foaming agent



c) At constant drying bed thickness 4 mm

Fig 4.25 Effect of foaming agents, microwave power and drying bed thickness on water activity

To visualize the combined effect of process variables on water activity, the response surface and contour plots were fitted as a function of two variables while keeping third variables at their central values. The effect of microwave power, drying bed thickness and foaming agent on water activity were presented in Fig. 4.25 a, b and c. From Fig. 4.25 a b, it shows that the microwave power increases the water activity decreases and drying

bed thickness increases the water activity decreases. Similar trends were recorded for yogurt powder (Karabulut *et al.*, 2007). From Fig 4.25c, it was observed that the water activity was found minimum for artificial foaming agent as compared to natural foaming agent. This was found due to glycoprotein structure of guar gum, which resists the water transmission from pulp.

4.10.2 Acidity

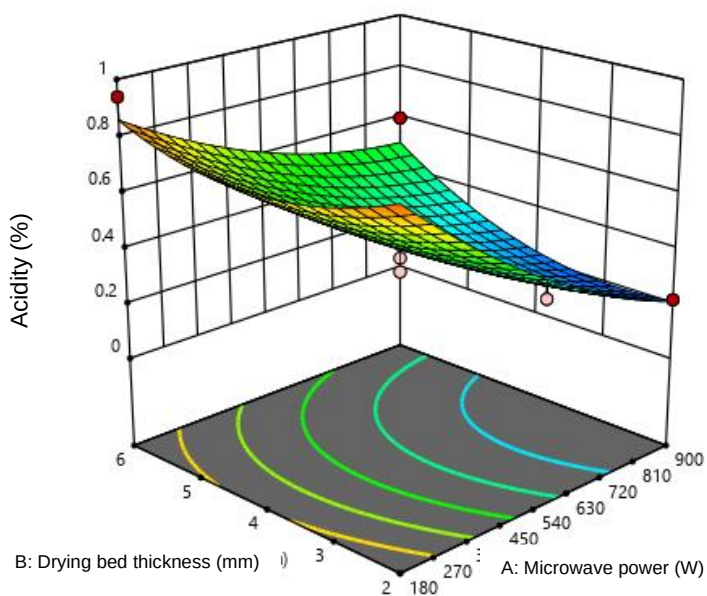
The observation for acidity of foamed Nagpur mandarin powder was found in the range of 0.14 to 0.86% at varying microwave power, foaming agent and drying bed thickness. The maximum acidity was found 0.86% at 180 W microwave power, 2 mm thickness for artificial foaming agent while minimum water activity was found 0.14% at 900 W microwave power, 4 mm thickness for natural foaming agent (Table 4.39). The most influencing factor was found microwave power on acidity and it was found due to heat liability to acidity. Various researchers for Alphonso mango (Rajkumar, 2007a), mango (Kadam *et al.*, 2010a), and tomato (Kadam *et al.*, 2012) reported similar results. The maximum acidity was found with artificial foaming agent as compared with natural foaming agent.

The ANOVA for acidity is presented in Table 4.41, it was found that the effect of microwave power and foaming agent were significant on acidity at 1% level of significance while drying bed thickness was found significant at 5%. The quadratic model was found best fitted to the experimental data and was found significant for linear, quadratic and interaction terms which was calculated for acidity and shown in Table 4.41. The R^2 value was determined by least square technique and found 0.9025 showing good fit of model with F value of 18.52 ($P < 0.01$). The P-values less than 0.05 indicate model terms are significant. In this case linear terms (A, B and C), interactive terms (AB and AC) and quadratic terms (A^2 and B^2) were significant model terms. The effect of the interactive term (BC) and quadratic term (C^2) was found non significant. The lack of fit F-value (3.24) implies that the lack of Fit was found not significant relative to the pure error. The predicted R^2 (0.6616) was in reasonable agreement with adjusted R^2 (0.8538).

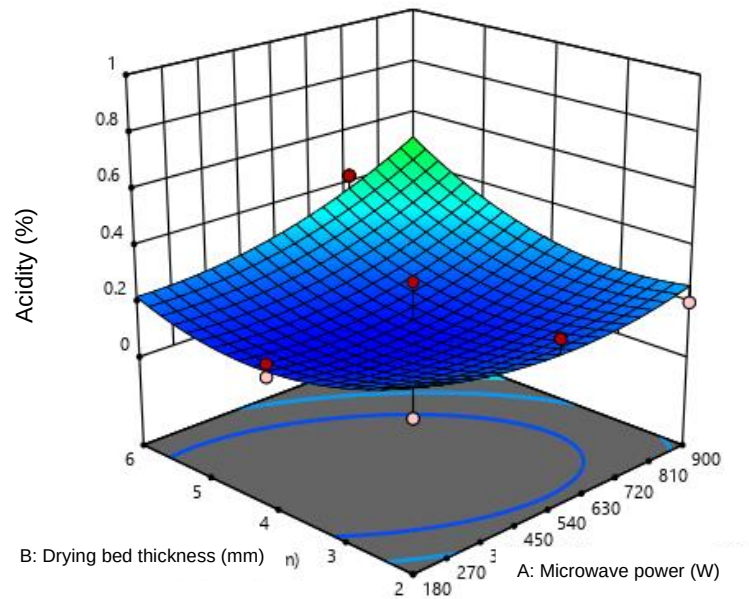
Table 4.41 ANOVA for effect of microwave power, foaming agents and drying bed thickness on acidity of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	0.90	7	0.13	18.52**
A-Microwave power, W	0.09	1	0.09	13.30**
B-Thickness of drying bed, mm	0.06	1	0.06	8.54*
C-Sample	0.44	1	0.44	63.00**
AB	0.04	1	0.04	5.49*
AC	0.25	1	0.25	35.97**
A ²	0.03	1	0.03	4.14*
B ²	0.07	1	0.07	9.65**
Residual	0.10	14	0.01	
Lack of Fit	0.07	7	0.01	3.24 ^{NS}
Pure Error	0.02	7	0.00	
Core Total	1.00	21		
SD	0.08			
CV	5.53			
R²	0.9025			
Adjusted R²	0.8538			
Predicted R²	0.6616			

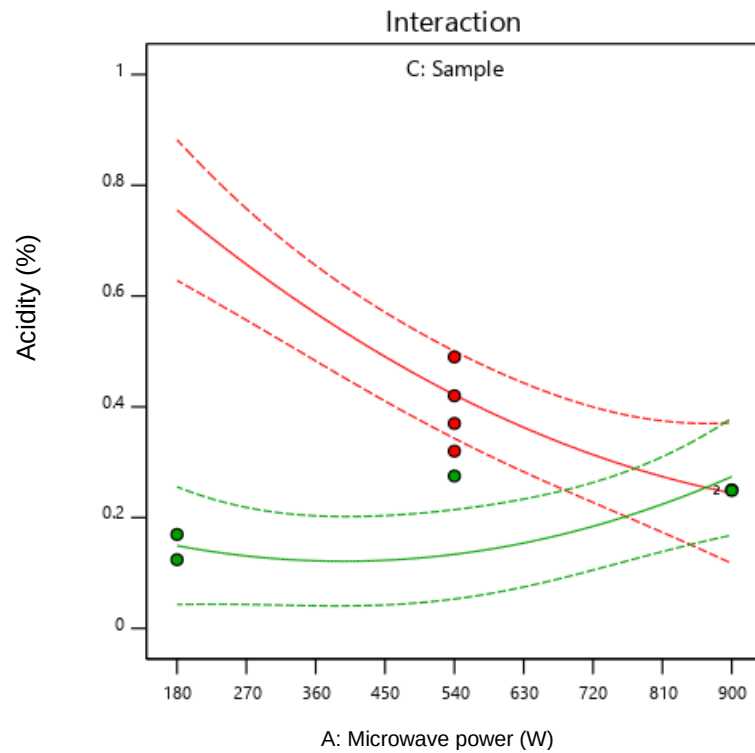
** is 1% level of significance * is 5% level of significance and NS is non significance



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig 4.26 Effect of foaming agents, microwave power and drying bed thickness on acidity (%)

The regression equation describing the effect of process variables (microwave power, drying bed thickness and foaming agent) on acidity in terms of coded values is given in the following equation.

$$\begin{aligned} \text{Acidity, \%} = & 0.28 - 0.10A + 0.07 B - 0.14C + 0.08AB + 0.16 AC + \\ & 0.08A^2 + 0.11B^2 \end{aligned}$$

$$(R^2 = 0.6616) \quad (4.17)$$

From the model fitted for acidity, linear effects of microwave power, drying bed thickness and foaming agent were found significant. The linear negative terms of Eqn. 4.17 indicated that acidity increases with decrease in microwave power and foaming agent. The positive linear term (drying bed thickness) in the equation shows that the acidity increases with increase in drying bed thickness. From Eqn 4.17, it shows that the most influencing factor on acidity was found foaming agent followed by microwave power and drying bed thickness.

To visualize the combined effect of three variables on the acidity, the response surface and contour plots (Fig. 4.26 a, b and c) were fitted as a function of two variables while keeping third variables at its central value. From Fig. 4.25 a b, it was found that the acidity increases with decrease in microwave power and acidity increase with increase in drying bed thickness. Also it was observed that the acidity continuously decreasing by increasing microwave power in artificial and natural foaming agent. Similar results were recorded by Mishra *et al.*(2002), Falade and Okocha (2010), Kadamet *al.*(2011a) with respect to microwave power(Karabulut *et al.*,2007).

4.10.3 Ascorbic acid

The ascorbic acid present in fresh juice was determined and was found 42.59 mg/100g. The ascorbic acid of powder was found in between 19.96 to 38.84 mg/100g. The losses of ascorbic acid in all combinations were recorded from 8.90 to 43.78% at varying microwave power from 180 to 900 W during microwave drying. According to Sokhansanj and Jayas (1996), the loss of ascorbic acid during drying was recorded between 10% and 50%.

The maximum ascorbic acid was found 38.84 mg/100g at 540 W microwave power, 6 mm thickness in artificial foaming agent while minimum ascorbic acid was found 19.96 mg/100g at 900 W microwave power, 4 mm thickness in natural foaming agent (Table 4.39). The samples with artificial foaming agent retained more ascorbic acid as compared to samples with

natural foaming agents. The increase in vitamin C content was due to the hydrocolloid activity of methyl cellulose on vitamin C during drying. For the presence of methyl cellulose in the aqueous medium, water activity of the medium decrease which reduces the extent of the hydration reaction and increase the stability of Vitamin C (Gogus *et al.*, 2000). As the microwave power increased, the vitamin C content of powder decreases and it was described due to heat liability of vitamin C similar finding was found by (Egerg *et al.*, 1977).

Table 4.42 ANOVA for effect of microwave power, foaming agents and drying bed thickness on ascorbic acid of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	846.65	5	169.33	57.90**
A-Microwave power, W	124.01	1	124.01	42.40**
C-Sample	273.05	1	273.05	93.36**
AC	14.41	1	14.41	4.93*
A ²	296.08	1	296.08	101.24**
B ²	17.42	1	17.42	5.96*
Residual	46.80	16	2.92	
Lack of Fit	35.72	9	3.97	2.51 ^{NS}
Pure Error	11.08	7	1.58	
Cor Total	893.45	21		
SD	1.71			
CV	6.04			
R²	0.9476			
Adjusted R²	0.9313			
Predicted R²	0.8939			

** is 1% level of significance * is 5% level of significance and NS is non significance

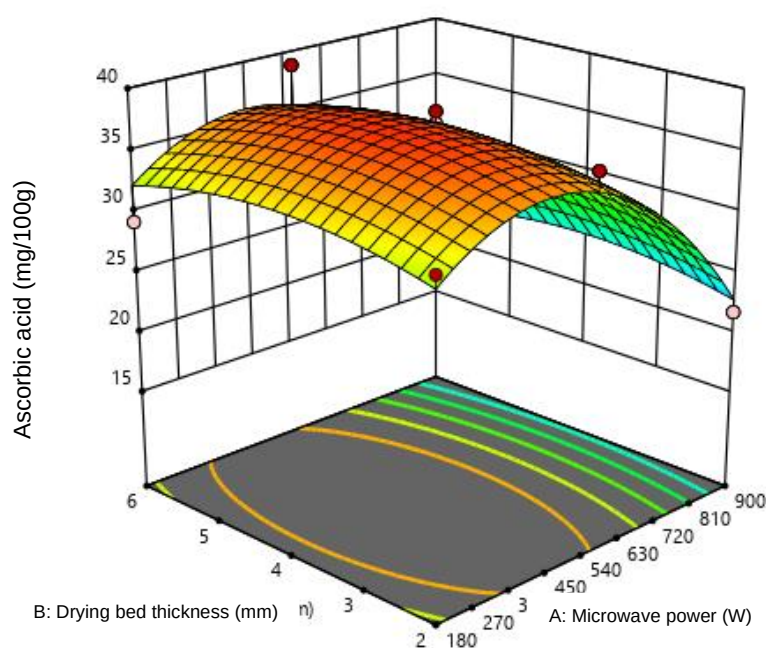
The ANOVA for ascorbic acid is presented in Table 4.42, it was found that the effect of microwave power and foaming agent were significant on ascorbic acid at 1% level of significance. The quadratic model was found best fitted to the experimental data which found significant for linear, quadratic and interaction terms (Table 4.40). The R² value was calculated by least square technique and found 0.9476 showing good fit of model with F value of 57.90 implies that the model is significant (P < 0.01). The linear terms (A

and C), interactive term (AC) and quadratic terms (A^2 and B^2) were significant while the linear term (B), interactive terms (AB and BC) and quadratic term (C^2) were found non significant. The lack of fit F value of 2.51 implies that the lack of fit was not significant relative to the pure error. Moreover the predicted R^2 (0.8939) was in reasonable agreement with adjusted R^2 (0.9313).

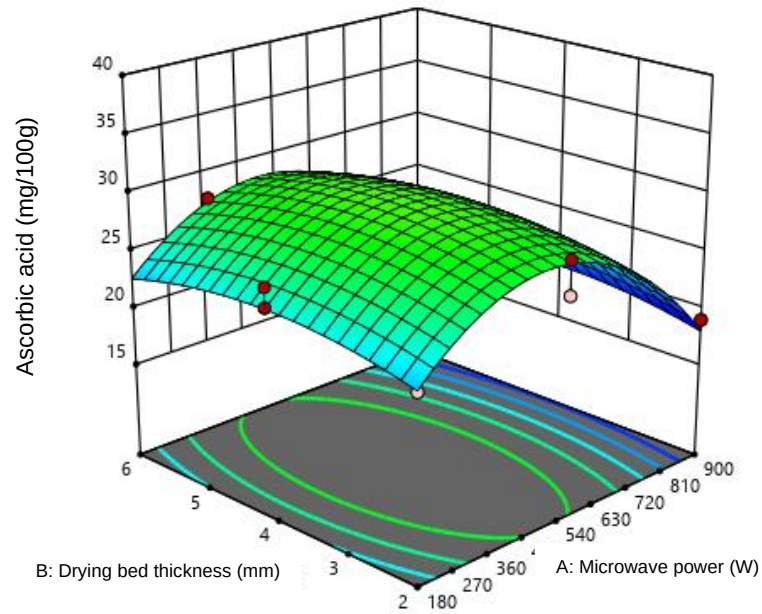
Second order regression model was best fitted to experimental data which shows the effect of foaming agents and microwave power on ascorbic acid in terms of coded equation is given in the following Eqn.

$$\begin{aligned} \text{Ascorbic acid, mg/100g} = & 33.62 - 3.52A - 3.60C + 1.20AC - 7.89A^2 \\ & - 1.82B^2 \end{aligned} \quad (R^2 = 0.8939) \quad (4.18)$$

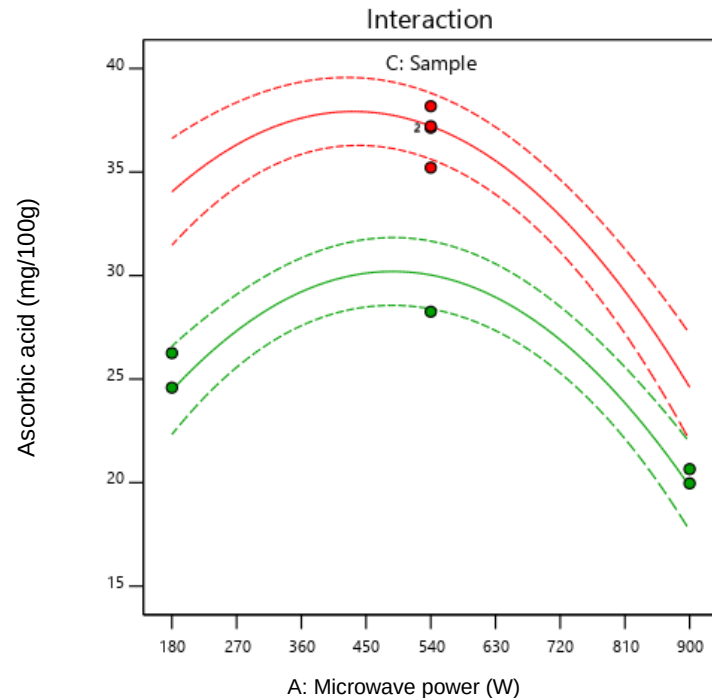
The model fitted on ascorbic acid was found significant on linear terms microwave power and foaming agent. The linear negative terms of Eqn. 4.18 indicated that ascorbic acid increases with decrease in microwave power and foaming agent. From Eqn. 4.18, it shows that the most influencing factor on ascorbic acid was found foaming agent followed by microwave power. Also the non significant effect of drying bed thickness was observed on ascorbic acid.



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig. 4.27 Effect of foaming agents, microwave power and drying bed thickness on ascorbic acid (mg/100g)

To visualize the combined effect of three variables on the ascorbic acid, the response surface and contour plots (Fig. 4.27 a, b and c) were fitted for two variables and third variable was at its central value. From Fig 4.27 (a and b), it shows that the ascorbic acid was increases with increase in

microwave power upto 540 W, afterwards the decreasing trends was observed. This result was due to destructive effect of prolong thermal treatment causing oxidation of ascorbic acid during drying. Similar findings were recorded by Mishra *et al.* (2002), Falade and Okocha (2010), Kadam *et al.* (2011a). From Fig. 4.27 c, it shows that the maximum ascorbic acid was found in artificial foaming agent as compared to natural foaming agent.

4.10.4 Colour (b-value)

Colour is often used as an indication of quality and freshness for food products. Hence, it has become important for food processors to evaluate and grade their products based on colour. The colour of mandarin powder was measured in terms of b-value (brightness / yellowness). The b value of mandarin powder was found in the range of 11.12 to 20.49 (Table 4.39). The maximum b value was found 20.49 at 540 W microwave power and 4 mm thickness while minimum b value was found 11.12 at 900 W microwave power and 6 mm thickness in artificial foaming agent. As the microwave power increased from 180 to 540 W, the b-value increased afterwards the b value decreases with increase in microwave power up to 900 W which may be due to discolouring the sample slightly because of elevated of microwave power.

The quadratic model was found best fitted to the experimental data which was significant for linear, quadratic and interaction terms as shown in Table 4.43. The R^2 value was calculated by least square technique and was found 0.8575 which shows good fit of model. The model F value was 15.05 which found significant ($P < 0.01$). The linear terms (A and C), interaction terms (AB and BC) and quadratic terms (A^2) was found significant and linear term (B), interactive term (AC) and quadratic term (B^2 and C^2) were found non significant. The lack of fit F value (2.03) was non significant. The predicted R^2 (0.648) was found reasonable agreement with adjusted R^2 (0.8005).

The second order polynomial equation was fitted with the experimental data. The Eqn 4.19 gives the predicted b value, as a function of

microwave power and foaming agent was expressed in coded form is given as

$$b \text{ value} = 18.47 - 0.85A - 0.56C - 1.7AB + 0.61BC - 2.92A^2$$

$$(R^2 = 0.6480) \quad (4.19)$$

In coded equation, the negative linear terms microwave power and foaming agent indicated that the b value increases with decrease in microwave power and foaming agent. From Eqn. 4.19, it shows that the most influencing factor on b value was found microwave power followed by foaming agent. Also the non significant effect of drying bed thickness was observed on b value.

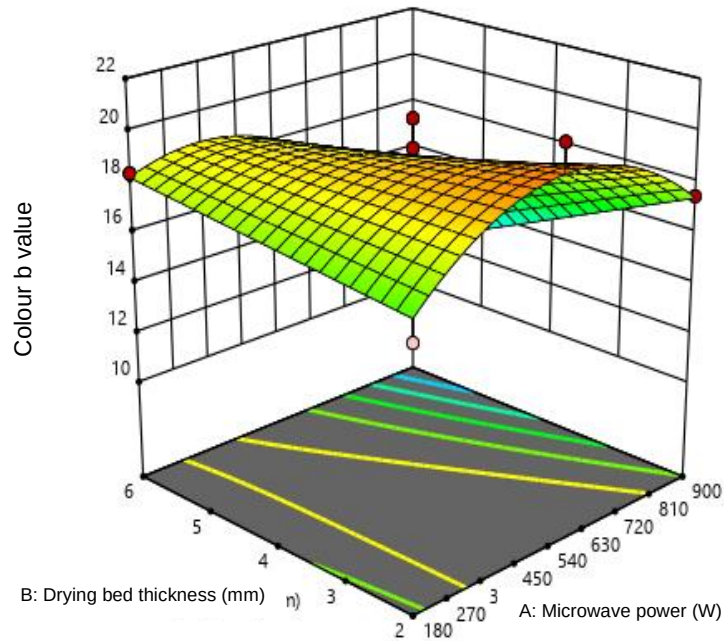
Table 4.43 ANOVA for effect of microwave power, foaming agents and drying bed thickness on b value of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	100.04	6	16.67	15.05**
A-Microwave power, W	7.06	1	7.06	6.37*
C-Sample	6.64	1	6.64	5.99*
AB	18.73	1	18.73	16.90**
BC	14.20	1	14.20	12.81**
A ²	40.61	1	40.61	36.65**
Residual	16.62	15	1.11	
Lack of Fit	11.62	8	1.45	2.03 ^{NS}
Pure Error	5.00	7	0.71	
Cor Total	116.66	21		
SD	1.05			
CV	6.23			
R²	0.8575			
Adjusted R²	0.8005			
Predicted R²	0.6480			

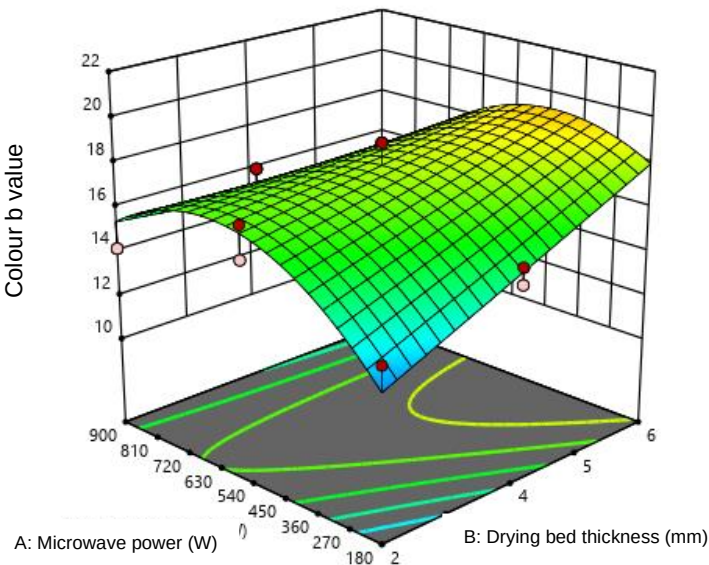
** is 1% level of significance * is 5% level of significance and NS is non significance

To visualize the combined effect of all variables on the b value, the response surface and contour plots (Fig. 4.28 a, b and c) were generated for the fitted model with function of two variables and keeping third variable at its

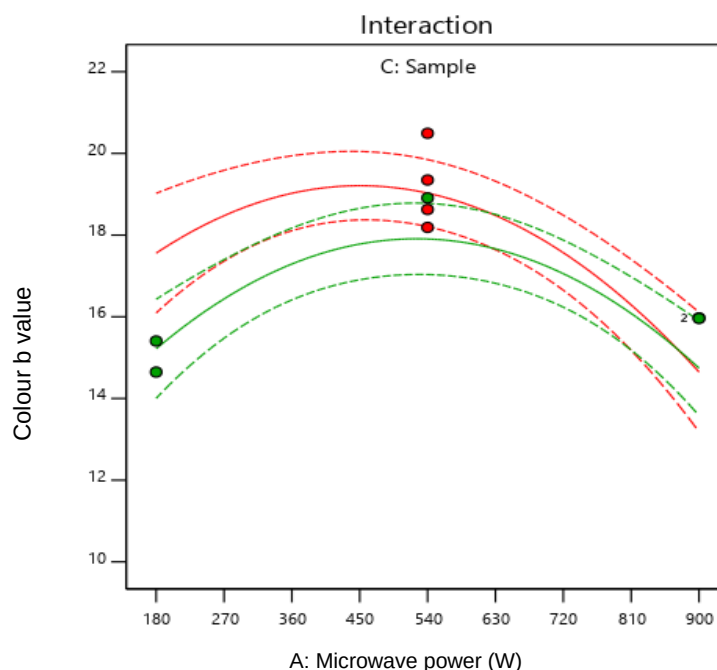
central value. From Fig 4.28 (a and b), it shows that the b value increases with increase in microwave power from 180 to 540 W afterwards the decreases while b value increases with increase in drying bed thickness. From Fig. 4.28 c, it shows that the b value was at par for artificial and natural foaming agent.



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig. 4.28 Effect of foaming agents, microwave power and drying bed thickness on b value

4.10.5 Colour (ΔE value)

The ΔE value represents the change in colour of the product which used as quality indication of the food products. Hence, it has become important for food processors to evaluate the change in colour. The change in colour of mandarin powder was measured in terms of ΔE value as shown in Table 4.39. The ΔE value of powder at various experimental conditions was found in the range of 3.90 to 13.01. The maximum ΔE value was found 13.01 at 180 W microwave power and 6 mm thickness with artificial foaming agent and minimum ΔE value was found 3.90 at 540 W microwave power, 6 mm thickness with artificial foaming agent.

The foamed juice dried at 540 W microwave power showed the least colour change as compared with the fresh samples. The microwave energy transfers liquid from the interior of the material to its surface, and this liquid are quickly converted into vapour. Therefore, the microwave drying process does not cause the phenomenon of surface overheating, resulting in less

change in the surface colour. Similar results were reported by Mana *et al.* (2012) and Alibas *et al.* (2007).

Table 4.44 ANOVA for effect of microwave power, foaming agents and drying bed thickness on ΔE value of powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	150.81	4	37.70	45.09**
A-Microwave power	5.22	1	5.22	6.24*
C-Sample	19.31	1	19.31	23.10**
AB	6.92	1	6.92	8.28*
A ²	130.15	1	130.15	155.65**
Residual	14.21	17	0.84	
Lack of Fit	9.77	10	0.98	1.54 ^{NS}
Pure Error	4.45	7	0.64	
Core Total	165.02	21		
SD	0.91			
CV	4.06			
R²	0.9139			
Adjusted R²	0.8936			
Predicted R²	0.8528			

** is 1% level of significance * is 5% level of significance and NS is non significance

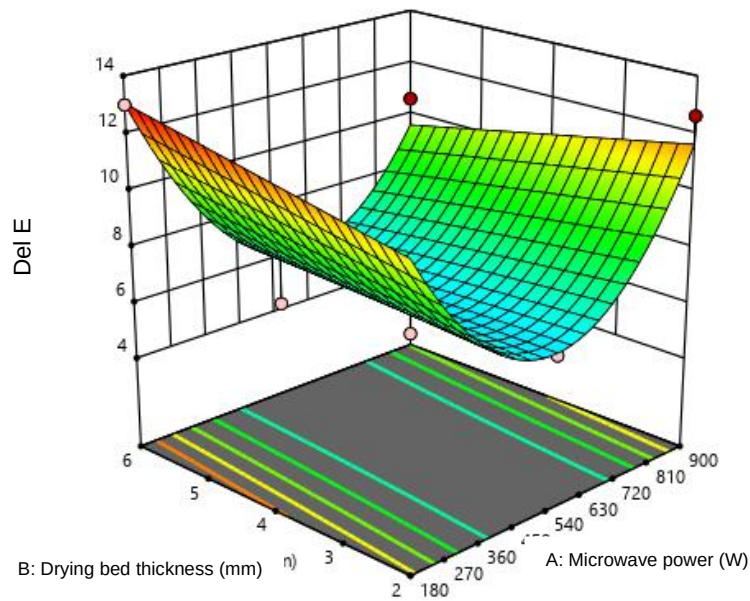
The quadratic model was found best fitted to the experimental data and found significant for linear, quadratic and interaction terms as shown in Table 4.44. The R² (0.9139) and F (45.09) value implies that the model was significant ($P < 0.01$). In this case linear terms (A and C), interaction terms (AB) and quadratic terms (A²) was found significant. The effect of the linear term (B), interactive terms (BC and AC) and quadratic terms (B² and C²) were found non significant.

The lack of fit F-value (1.54) implies the lack of fit was found not significant relative to the pure error. The lack of fit F value was non significant which indicates that the developed model was adequate for predicting the response. Moreover the predicted R² (0.8528) was in reasonable agreement with adjusted R² (0.8936).

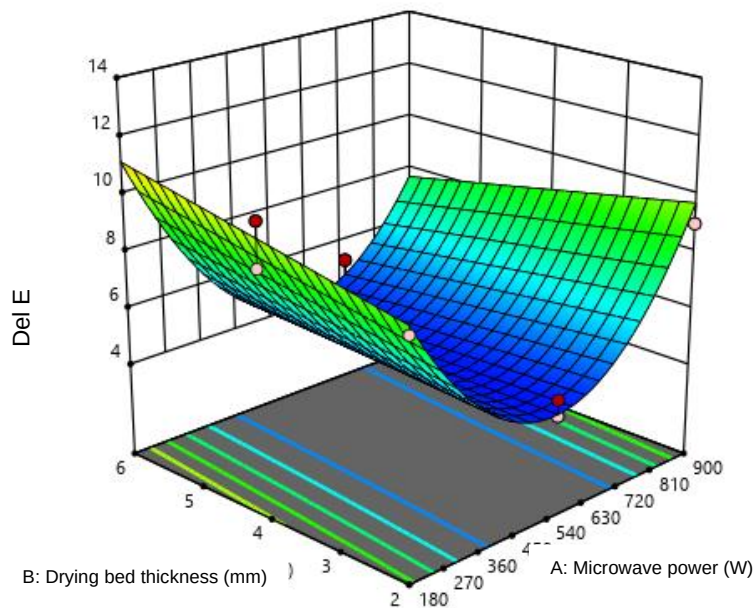
The regression equation describing the effects of process variables on change in colour in terms of coded values of variable is given as

$$\Delta E \text{ value} = 5.16 - 0.71A - 0.96C - 1.03AB + 5.22A^2 \quad (R^2 = 0.8528) \quad (4.20)$$

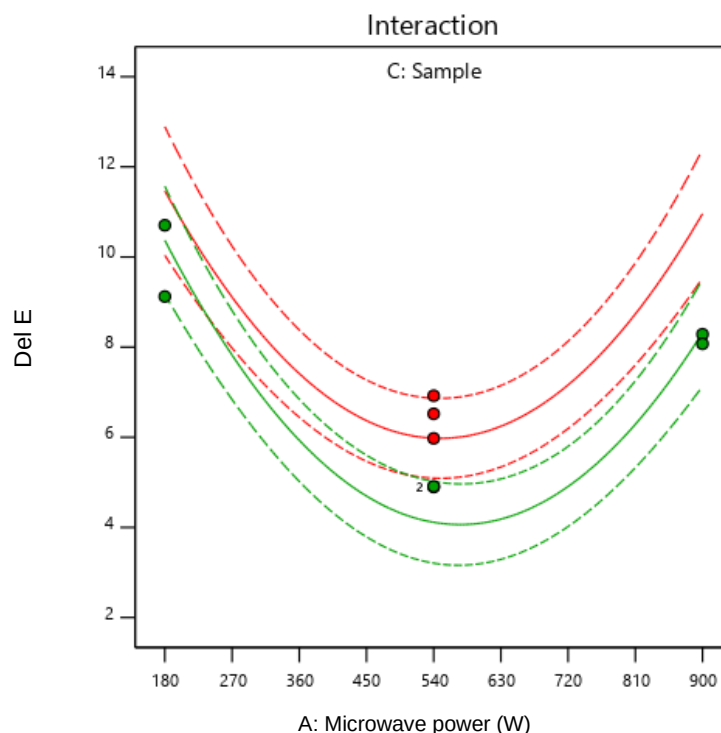
In coded equation, the negative linear terms indicates that the change in colour decreases with increase in microwave power and foaming agent. From Eqn. 4.20, it shows that the most influencing factor on ΔE value was found foaming agent followed by microwave power. Also the non significant effect of drying bed thickness was observed on ΔE value.



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig. 4.29 Effect of foaming agents, microwave power and drying bed thickness on ΔE value

To visualize the combined effect of all variables on the colour ΔE value, the response surface and contour plots (Fig. 4.29 a, b and c) were generated for the fitted model with function of two variables and keeping third variable at its central value. From Fig 4.29 (a and b), it shows that the colour ΔE value was decreases with increase in microwave power from 180 to 540 W afterwards increases and the non significant effect was found with drying bed thickness on colour ΔE value.

4.10.6 Overall acceptability

The overall acceptability of mandarin powder was found in the range of 4.20 to 8.30. The maximum overall acceptability (8.30) was found at 540 W microwave power and 2 mm thickness in artificial foaming agent. While minimum overall acceptability (4.20) was found at 900 W microwave power and 2 mm thickness in natural foaming agent (Table 4.39). The sample foamed using artificial foaming agent was having the highest overall acceptability as compared to natural foaming agent.

The ANOVA for overall acceptability was presented in Table 4.45. It was observed that the effect of microwave power was significant on overall acceptability at 1% level of significance and foaming agent was found significant at 5%. The quadratic model was found best fitted to the experimental data and found significant for linear, quadratic and interaction terms as shown in Table 4.45.

Table 4.45 ANOVA for effect of microwave power, foaming agents and drying bed thickness on overall acceptability of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	35.57	8	4.45	35.22**
A-Microwave power	1.13	1	1.13	8.96*
C-Sample	25.41	1	25.41	201.27**
AC	3.42	1	3.42	27.06**
A ²	0.51	1	0.51	4.04*
Residual	1.64	13	0.13	
Lack of Fit	0.72	6	0.12	0.93 ^{NS}
Pure Error	0.91	7	0.13	
Cor Total	37.21	21		
SD	0.36			
CV	5.61			
R²	0.9559			
Adjusted R²	0.9288			
Predicted R²	0.8710			

** is 1% level of significance * is 5% level of significance and NS is non significance

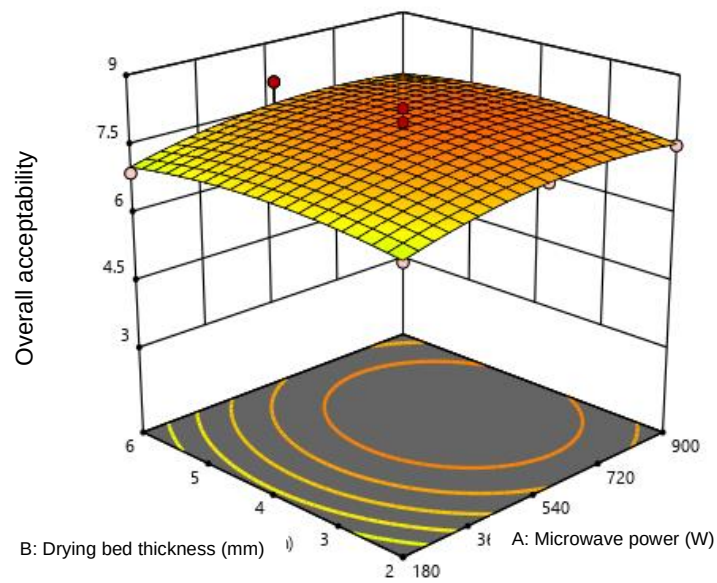
The R² value was calculated and found 0.9559 which shows good fit of model with F value of 35.22 which implies that the model was significant (P < 0.01). In this case linear terms (A and C), interactive term (AC) and quadratic term (A²) was found significant while linear term (B), interactive terms (AB and BC) and quadratic terms (B² and C²) was found non significant. The lack of fit F-value (0.93) was found not significant relative to the pure error which indicates that the developed model was adequate for predicting the response. The predicted R² (0.8710) was in reasonable agreement with adjusted R² (0.9288).

The second order regression model fitted to experimental data. This model shows the effect of foaming agents, microwave power and thickness of drying bed on overall acceptability.

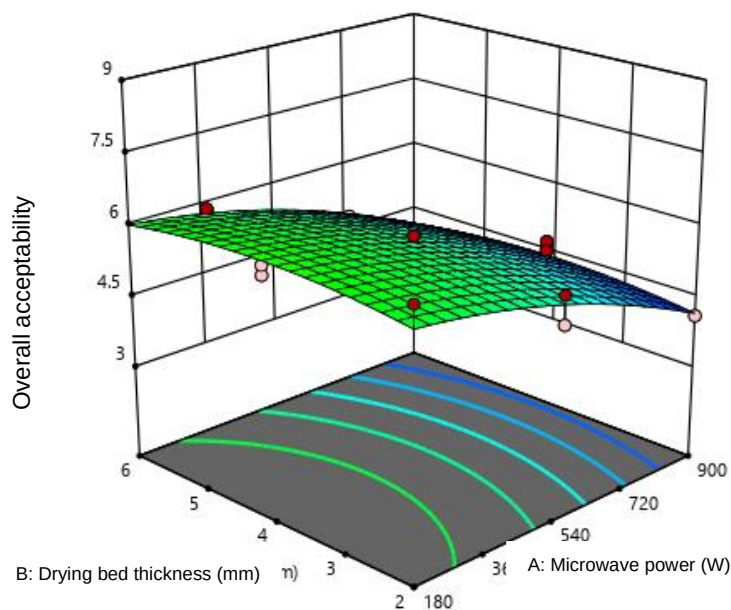
$$\text{Overall acceptability} = 6.76 - 0.35A - 1.10C - 0.60 AC - 0.32 A^2 - 0.25B^2$$

$$(R^2 = 0.8710) \quad (4.21)$$

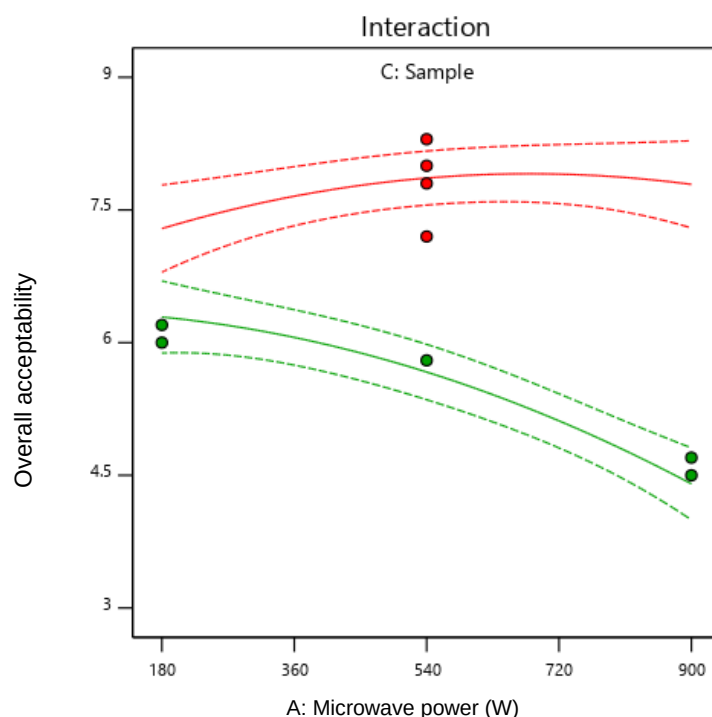
The linear negative terms of Eqn. 4.21 indicates that the overall acceptability increase with decrease in microwave power and foaming agent.



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig. 4.30 Effect of foaming agents, microwave power and drying bed thickness on overall acceptability

To visualize the combined effect of all variables on the overall acceptability, the response surface and contour plots (Fig. 4.30 a, b and c) were generated for the fitted model with function of two variables and keeping third variable at its central value. From Fig 4.30 (a and b), it shows that the overall acceptability of powder was increases with increase in microwave power from 180 to 540 W, afterwards the trend was found decreasing with increase in microwave power (540 to 900W). This was found due to the loss of volatiles during drying process. Similar trend was reported by Hassan and Ahmed (1998) for foamat dried pineapple powder, Kandasamy *et al.* (2014) for papaya pulp and Falade and Okocha (2012) for foamat dried banana.

From Fig. 4.30 c, it was observed that the powder prepared with artificial foaming agent was found more acceptable than that of natural foaming agent. This was found due to higher drying time in natural foaming agent, as higher drying time leads to more denaturation of nutrients hence the overall sensory score was less.

4.10.7 Drying time

The initial moisture content of foamed Nagpur mandarin juice was found 89.35% and 87.59% (wb) with artificial and natural foaming agent and the final moisture content was found 1.40 to 4.70% (wb). The drying time of mandarin powder was found from 18.00 to 81.00 min at varying microwave power 180 to 900 W (Table 4.39). From Table 4.39, it was observed that the drying time was increases with decrease in microwave power and increasing drying bed thickness. Similar results were reported by Balbay *et al.* (2012) for black cumin and Kudra and Ratti (2006) for tomato paste. The lowest drying time was observed in artificial foaming agent.

The ANOVA was carried out to study the effect of process variables i.e. microwave power, foaming agent and drying bed thickness on drying of foamed Nagpur mandarin juice and the results presented in Table 4.46. It was observed that the effect of microwave power, drying bed thickness and foaming agent were significant on drying time at 1% level of significance. The R^2 value was calculated and found 0.9925 which shows good fit of model with F value of 214.81 which implies that the model was significant ($P < 0.01$). It reveals that linear terms (A, B and C), interactive term (AC) and quadratic term (A^2) were significant. The interactive term (AB and BC) and quadratic term (B^2 and C^2) were found non significant. The lack of fit F-value (3.48) was found not significant. Moreover the predicted R^2 (0.9625) was in reasonable agreement with adjusted R^2 (0.9879) reveals that the non-significant terms were not included in the model. Therefore, this model was used to navigate the design space. The second order regression model fitted to the experimental as shown in Eqn. (4.22). This model shows the effect of foaming agents, microwave power and thickness of drying bed on drying time.

$$\text{Drying time} = 30.88 - 14.90 A + 4.93B + 1.76C - 2.47 AB + 6.22 A^2$$
$$(R^2= 0.9625) \quad (4.22)$$

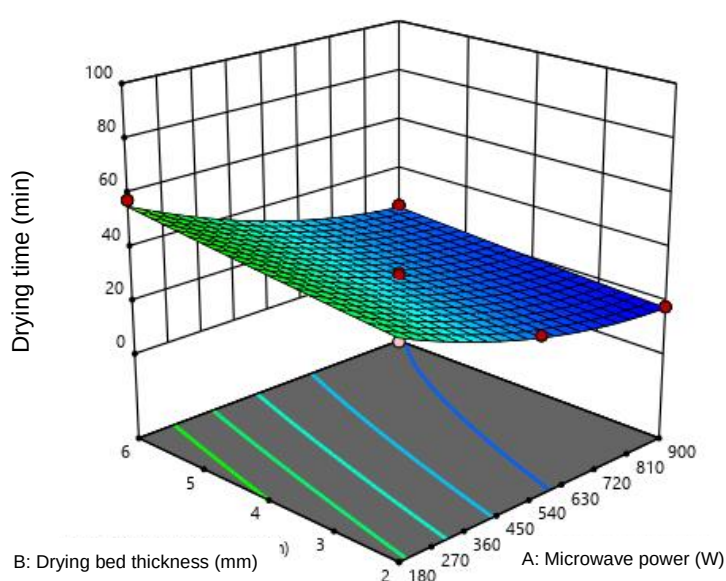
In coded equation, the negative linear terms indicates that the drying time decreases with increase in microwave power and positive terms indicates that the drying time increases with increase in drying bed

thickness and foaming agent. From Eqn. 4.22, it shows that the most influencing factor on drying time was found microwave power followed by drying bed thickness and foaming agent.

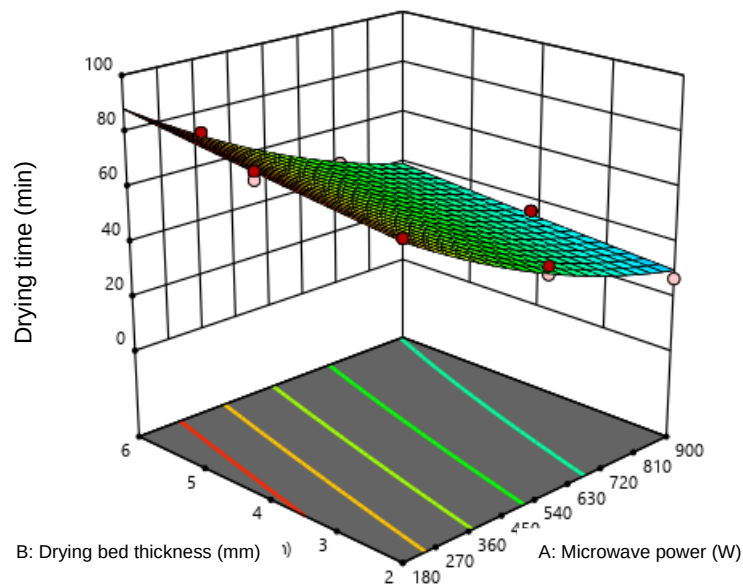
Table 4.46 ANOVA for effect of microwave power, foaming agents and drying bed thickness on drying time of Nagpur mandarin powder

Source	Sum of Squares	Df	Mean Square	F-value
Model	7372.05	8	921.51	214.81**
A-Microwave power	3480.21	1	3480.21	811.25**
B-Thickness of drying bed	345.08	1	345.08	80.44**
C-Sample	2679.06	1	2679.06	624.50**
AC	181.78	1	181.78	42.37**
A ²	153.41	1	153.41	35.76**
Residual	23.76	16	1.48	
Lack of Fit	41.77	6	6.96	3.48 ^{NS}
Pure Error	14	7	2	
Cor Total	7427.82	21		
SD	2.07			
CV	4.72			
R²	0.9925			
Adjusted R²	0.9879			
Predicted R²	0.9625			

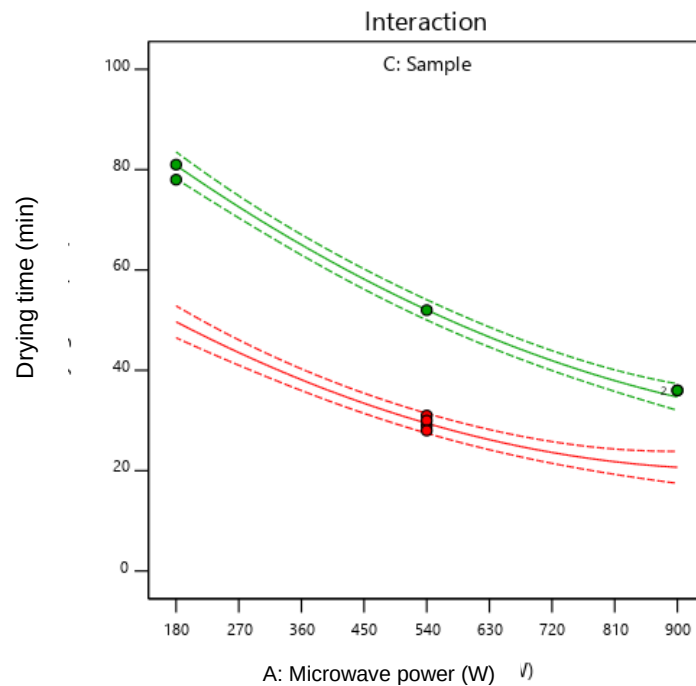
** is 1% level of significance * is 5% level of significance and NS is non significance



a) Foamed with artificial foaming agent



b) Foamed with natural foaming agent



c) At constant drying bed thickness 4 mm

Fig. 4.31 Effect of foaming agents, microwave power and drying bed thickness on drying time (min)

To visualize the combined effect of three variables on the drying time, the response surface and contour plots (Fig. 4.31 a, b and c) were generated for the fitted model as a function of two variables while keeping third variables at its central value.

From Fig. 4.31 (a, b and c), it reveals that microwave power is most predominant factor on drying time. As microwave power increases the drying time decreases. It also observed that the drying time increase with increasing drying bed thickness. Similar drying trends were observed by various researchers for fruits and vegetable dried in microwave drying (Darvishi and Hazbavi (2012) for date plum, Aral *et al.* (2016) for radix eremut, Rajkumaret *al.* (2007a) for alfanso mango, Alibas (2014) for celery leaves). From Fig. 4.31 c, it was found that the drying time was more in natural foaming agent than artificial foaming agent. This was due to changes occurred during the cell structure of foam and rupture of air bubbles during drying in natural foaming agent.

4.11 Optimization of microwave power, drying bed thickness and foaming agent for drying of foamed Nagpur mandarin juice

The optimum range of process parameters was presented in Table 4.47 with their levels of importance.

Table 4.47 Constraints for optimization of microwave power, foaming agent and drying bed thickness of Nagpur mandarin juice

Name	Goal	Lower Limit	Upper Limit	Importance
A: Microwave power, W	is in range	180	900	3
B: Thickness of drying bed, mm	is in range	2.00	6.00	3
C: Sample	is in range	AFA	NFA	3
Water activity	Minimize	0.24	0.77	3
Acidity, %	is in range	0.12	0.89	3
Ascorbic acid, mg/100g	Maximize	18.99	38.84	3
colour b value	Maximize	11.12	21.25	3
change in colour (ΔE)	Minimize	4.025	13.01	3
Overall acceptability	Maximize	4.10	8.30	3
Drying time, min	Minimize	18.00	81.00	3

AFA is artificial foaming agent and NFA is natural foaming agent

In order to optimize the process parameters for preparation of powder by categorical factor optimization; which finds a point with maximization of desirability function. The optimum operating conditions for drying of foamed juice in microwave drying (microwave power, drying bed thickness and foaming agent) is presented in Table 4.47.

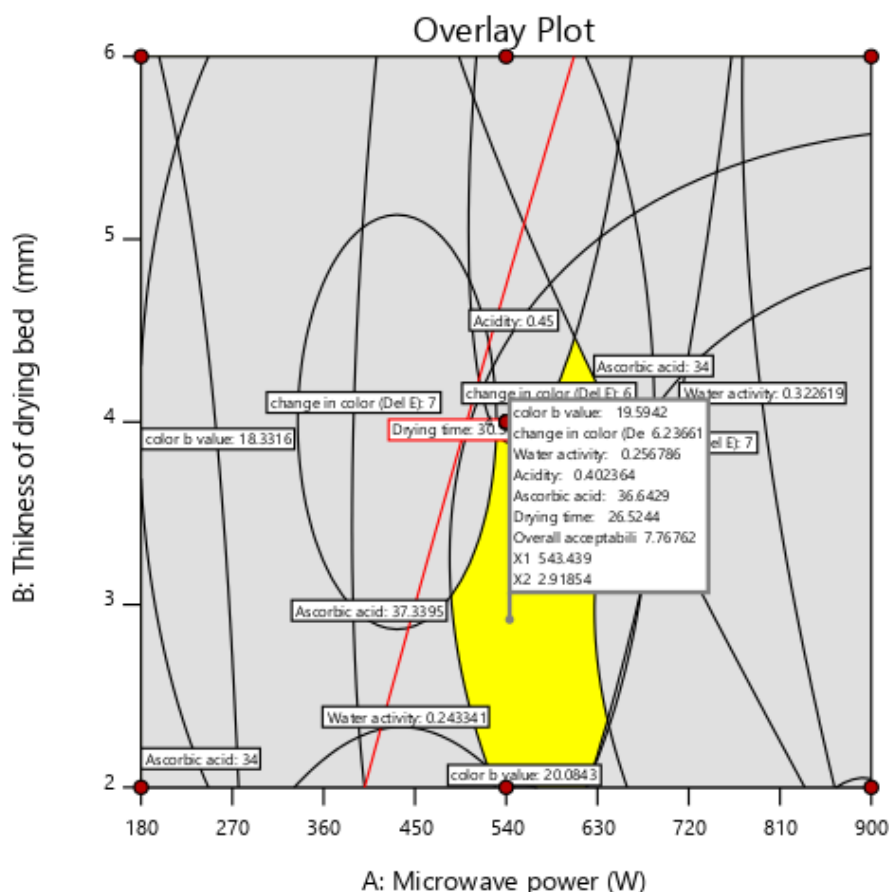


Fig. 4.32 Superimposed contour plots for optimization of microwave power, drying bed thickness and foaming agent for development of powder.

Graphical multi-response optimization technique was adopted to determine the workable optimum conditions for development of Nagpur mandarin powder. The contour plots for all responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions. These constraints resulted in 'feasible zone' of the optimum conditions (shaded area in the superimposed contour plots). The superimposed contour plots having common superimposed area for all responses were shown in Fig. 4.32.

Based on criteria as given in Table 4.47, the optimization was carried out. During optimization the solutions were obtained, out of which one best suited solution was selected and as shown in Table 4.48.

Table 4.48 Solution for optimization of microwave power, drying bed thickness and foaming agent for development of powder

MP, W	DBT, mm	S	WA	Acidity, %	AA, mg/100g	color b value	ΔE	OA	DT, min	D
543.44	2.92	AFA	0.26	0.40	36.64	19.59	6.24	7.77	26.52	0.84

MP is microwave power, DBT is drying bed thickness, S is sample, WA is water activity, AA is water activity, ΔE is change in colour, OA is overall acceptability, DT is drying time, D is desirability and AFA is artificial foaming agent

The optimum values of process variables obtained by categorical optimization as follows:

Foaming agent (F)	: Artificial
Microwave power (MP)	: 543W ~ 540 W
Thickness of drying bed (Td)	: 2.92 mm ~ 3 mm

The optimum condition for development of powder was found 540 W microwave power for drying with drying bed thickness of 3 mm using artificial foaming agent. The quality parameters at optimized condition viz. colour b value, ΔE , acidity, ascorbic acid, water activity, drying time and overall acceptability were found as 19.59, 6.24, 0.40%, 36.64 mg/100 g, 0.26, 26.52 min and 7.77, respectively. The desirability of optimized solution was found 0.84.

4.12 Verification of the model for development of Nagpur mandarin powder

The experiment was performed in order to check the adequacy of model for predicting the response value in the optimum process conditions. Table 4.49 summarizes the experimental values and predicted values (meaning 3 experiments). It was observed that the experimental values were very similar to the predicted values. Therefore, it was concluded that the model are quite adequate to assess the drying behaviour.

Table 4.49 Predicted and experimental values of response at optimum process conditions for drying of Nagpur mandarin juice.

Response	Predicted mean	Experimental mean Value $\pm$ SD	SE	% Variation	Mean difference
Water activity	0.26	0.26 $\pm$ 0.02	0.01	0.05	0.01
Acidity, %	0.40	0.412 $\pm$ 0.08	0.04	0.16	0.01
Ascorbic acid, mg/100g	36.64	32.14 $\pm$ 1.71	0.66	2.79	4.50
Colour b value	19.59	18.38 $\pm$ 1.05	0.41	1.75	1.21
Del E	6.24	5.69 $\pm$ 0.93	0.41	1.78	0.55
Overall acceptability	7.77	7.49 $\pm$ 0.36	0.16	0.68	0.28
Drying time, min	26.52	28.00 $\pm$ 1.21	0.54	2.32	1.48

4.13 Bio-chemical composition of Nagpur mandarin powder and juice

The biochemical composition of Nagpur mandarin powder and juice was determined on dry basis. The major compositions, vitamins and minerals were determined as per the procedure given in the section 3.24 and 3.25 and the values are presented in Table 4.50.

From Table 4.50, it reveals that the energy was found 536.81 Kcal/100g in juice and 418.53 in powder on dry basis. The total sugar, reducing sugar and non-reducing sugar were found 46.16, 36.4. 9.76%, respectively in powder and in juice were observed as 43.50, 32.94 and 11.55%, respectively. The sugar content was found maximum in foamed juice powder. This increase was attributed to the inherent sugar content offoaming agents that also contributed towards the totalsugar content of the sample. Similar finding was observed by Kadamet *al.* (2011a), Chaves *et al.* (2013),Kadamet *al.* (2010b).The carbohydrate, dietary fibers and acidity were found higher i.e. 105.73, 8.18 and 0.67% respectively in juice as compared to powder i.e. 63.07, 0.44 and 0.412%, respectively. The protein was found more in developed powder (14.88%) as compared to juice (8.28%). This was due found due to the SPI in developed powder. Due to evaporation during

drying, a significant reduction in acidity was observed, Askaret *al.* (1992) also reported a noticeable loss in the acidity of guava powder.

The Thiamine, Niacin, Vitamin B₆ and vitamin C were determined and data presented in Table 4.50. The values of Thiamine, Niacin, Vitamin B₆ and vitamin C were recorded as 0.59, 3.84, 0.80 and 46.37 mg/100g, respectively in fresh juice and 2.90, 5.13, 0.06 and 36.5 mg/100g, respectively in powder. The decreasing trend was observed in dried powder as compared with juice, this decrease was due to creation of increase air to liquid surface area in foamed sample. Therefore the oxidative reaction was accelerated. Similar finding were observed in foam-dried mandarin (Kadamet *al.*, 2011b), pineapple (Kadamet *al.*, 2012b), tomato (Kadamet *al.*, 2012a), grape leather (Gupta and Alam, 2014) and papaya (Kandasamyet *al.*, 2012b). It was considered that the product with 45% of vitamin C retention will provide the recommended daily intake of vitamin C (Breda *et al.*, 2012).

The calcium, iron, magnesium, manganese, phosphorus, potassium and zinc were predominant mineral elements in Nagpur mandarin, which were determined and presented in Table 4.50. The calcium, iron, magnesium, manganese, phosphorus, potassium and zinc were found 185.82 mg/100g dm, 6.64 mg/100g dm, 12 mg/100g dm, 0.039 ppm, 20 mg/100g dm, 654.39 mg/100g dm and 0.63 ppm respectively in juice and the same minerals in powder were found 178.72 mg/100 g dm, 8.58 mg/100 g dm, 61.48 mg/100 g dm, 5.38 ppm, 16.31 mg/100 g dm, 327.54 mg/100 g dm and 0.565 ppm respectively. However Nagpur mandarin powder showed considerable decrease in mineral content against the fresh juice which was due to leaching of inorganic compounds (Sablani, 2006). Among the minerals studied, the level of Calcium was found (78.72 mg/100 g dm) in powder. Calcium plays important role in bone and tooth development (Ozcan and Haciseferogullari, 2007).

Furthermore, Ca may be used for the prevention and treatment of hypertension, since it stabilize vascular membranes, blocks its own entry into cells and reduces vasoconstriction. The P content in powder was found 16.31 mg/100 g dm. Phosphorus is the second most abundant mineral of the human body. Together with Ca, P constitutes the part of inorganic structure

of bones. Phosphorus also contributes to the maintenance of acid base equilibrium in the blood (Martinez and Garcia, 2001).

Table 4.50 Composition of fresh and developed Nagpur mandarin powder

Parameters	Values of Nagpur mandarin juice on db	Values of Nagpur mandarin powder
Energy, Kcal/100g	536.81	418.53
Sugar, %	43.50	46.16
Reducing sugar, %	32.94	36.4
Non reducing sugar, %	11.55	9.76
Carbohydrates, %	105.73	63.07
Dietary fibers, %	8.18	0.44
Protein, %	8.28	14.88
Fat, %	3.17	10.97
Acidity, %	0.67	0.412
Vitamins		
Thiamine B ₁ , mg/100g	0.59	2.90
Niacin B ₃ , mg/100g	3.84	5.13
Vitamin B ₆ , mg/100g	0.80	0.06
Vitamin C, mg/100g	46.37	36.5
Minerals		
Calcium, mg/100g	185.82	178.72
Iron, mg/100g	6.64	8.58
Magnesium, mg/100g	12	61.48
Manganese, ppm	0.039	5.38
Phosphorus, mg/100g	20	16.31
Potassium, mg/100g	654.39	327.54
Zink, ppm	0.63	0.565

4.14 Sensory Evaluation of Cookies

The fuzzy logic was applied to treat uncertain phenomena mathematically, i.e., expressing the degree of ambiguity in human thinking and relating it to a real number (Jaya and Das, 2003). The fuzzy logic technique converts the linguistic sensory responses obtained from the judges into numerical values which applied for comparison of similar products. Table 4.51 shows the sum of the number of judges with different preference levels for different quality attributes of samples with the triplets associated with sensory scales and the sensory scores given by judges, using the Eqn3.83.

Table 4.51 Sensory scores in terms of preference given by judges and corresponding triplets for sensory quality of cookies

SQA	NS	F	M	G	E	Triplets for Sensory Quality of Samples
Colour						
S ₁	0	3	7	10	2	CS ₁ = (63.5025.00 22.73)
S ₂	0	3	8	8	3	CS ₂ = (72.5025.00 21.59)
S ₃	0	4	7	9	2	CS ₃ = (60.23 25.00 22.73)
Flavour						
S ₁	0	1	2	11	8	FS ₁ =(79.55 25.00 15.91)
S ₂	0	2	5	9	6	FS ₂ =(71.59 25.00 18.18)
S ₃	0	3	3	10	6	FS ₃ =(71.59 25.00 18.18)
Texture						
S ₁	0	0	5	12	5	TS ₁ = (75.00 25.00 19.32)
S ₂	1	2	8	8	3	TS ₂ =(61.36 23.86 21.59)
S ₃	1	3	9	8	1	TS ₃ =(55.68 23.86 23.86)
OAA						
S ₁	0	2	5	10	5	OS ₁ =(70.45 25.00 19.32)
S ₂	1	3	6	8	4	OS ₂ = (62.50 23.86 20.45)
S ₃	0	2	9	9	2	OS ₃ =(62.50 25.00 22.73)

SQA is sensory quality attributes, NS is not satisfactory, F is Fair, M is Medium, G is Good, E is Excellent

Three types of cookies were prepared and sensory evaluation were done by twenty two judges for overall acceptability from Nagpur mandarin powder and to find the ratings scores given by the judges. The sensory evaluation of the cookies was analysed by the method as described in the section 3.26. Three samples (S₁, S₂ and S₃) were taken like Marry orange

cookies S_1 , local orange cookies S_2 , cookies prepared using Nagpur mandarin powder S_3 .

The triplets associated with the sensory scores of each sample were calculated by the method described in section 3.26.1. The sensory scores considered for quality attributes in general were not at all important (NI), somewhat important (SI), important (I), highly important (HI) and extremely important (EI). Triplets for sensory scores of quality attributes viz., colour, flavour, texture and overall acceptability of cookies in general were calculated by same procedure followed for the sensory scores of prepared cookies. Table 4.52 shows the sensory preferences given by the judges for the commercial cookies and prepared cookies using Nagpur mandarin powder. Sensory scores and the triplets associated with quality attributes of cookies in general and the relative weightages are presented in Table 4.52 and for determination of overall sensory scores of each sample, Eqn 3.84 was used.

Table 4.52 Sensory scores in terms of preference given by number of judges, triplets and relative weightage for quality attributes of cookies

Quality attributes	Sensory scale factors					Triplets for quality attributes	Triplets for relative weightage	
	NI	SI	I	HI	EI			
Colour	0	2	9	9	2	QC =(68.75 27.50 25.00)	(0.2099 0.0763)	0.0840
Flavour	0	0	2	11	9	QF =(91.25 27.50 16.25)	(0.2786 0.0496)	0.0840
Texture	0	0	2	17	3	QT =(83.75 27.50 23.75)	(0.2557 0.0725)	0.0840
OAA	0	0	5	11	6	QO =(73.75 27.50 20.00)	(0.2557 0.0611)	0.0840

NI – Not at all Important, SI – Somewhat Important, I – Important, HI – Highly Important, EI – Extremely Important

The values of triplets for sensory scores of prepared samples and relative weightages of the quality attributes were multiplied following the rule of multiplication of triplets mentioned in Eqn 3.85. The calculated values of triplets for overall sensory scores of Sample S_1 (SOS_1), S_2 (SOS_2) and S_3 (SOS_3) are as follows:

$$SOS_1 = (72.48005 \quad 49.14122 \quad 37.5434)$$

$$SOS_2 = (64.74237 \quad 46.07911 \quad 36.9405)$$

$$SOS_3 = (62.81228 \quad 45.70177 \quad 37.7559)$$

4.14.1 Overall membership functions of sensory scores on standard fuzzy scale

Six point sensory scale viz., poor/not at all necessary, fair/somewhat necessary, medium/necessary, good/important, very good/highly important, excellent /extremely important referred to as 'standard fuzzy scale' and designated as F_1 , F_2 , F_3 , F_4 , F_5 and F_6 , respectively were used in the evaluation of sensory scores. Membership function values for the standard fuzzy scale have been presented in Eqn 3.86. Values of overall membership function of sensory scores of the samples on standard fuzzy scale, B_x were calculated using Eqn 3.87.

Overall membership functions of Sample S_1 , S_2 and S_3 were calculated by using the values in Eqn 3.87 and the triplets obtained are given in Eqn 4.23.

$$BS1 = (0 \quad 0 \quad 0.136 \quad 0.340 \quad 0.543 \quad 0.746 \quad 0.950 \quad 1 \quad 0.800 \quad 0.533)$$

$$BS2 = (0 \quad 0.029 \quad 0.246 \quad 0.463 \quad 0.680 \quad 0.897 \quad 1 \quad 0.848 \quad 0.587 \quad 0.316)$$

$$BS3 = (0 \quad 0.063 \quad 0.282 \quad 0.501 \quad 0.720 \quad 1 \quad 0.939 \quad 0.910 \quad 0.5448 \quad 0.280)$$

(4.23)

4.14.2 Cookiesvales and their ranking

Similar values for cookies were calculated using the values of membership functions of standard fuzzy scale and overall membership function values of sensory scores (Eqn 3.88) by applying rules of matrix multiplication (Das, 2005; Sinija and Mishra, 2011). The ranking of samples was done on the basis of obtained similarity values under Poor (F_1), Fair (F_2), Medium (F_3), Good (F_4), Very good (F_5) and Excellent (F_6) categories. The

similarity values for all the four samples under different scale factors are presented in Table 4.53.

From the Table 4.53, it shows that, for sample S₁ having highest value obtained in the category “very good” is 0.667 and S₂ and S₃ having similarity value lies in the category “good” i.e. 0.718 and 0.716. On comparison of highest similarity values, their ranking was done as sample S₁ and S₃ > S₂. Thus, it indicates that all three samples were preferred by judges. Also, the score of sample S₃ and S₂ was very close under the category of “good”. Therefore, present method of fortification by Nagpur mandarin powder cookies are similar to the commercial cookies and improve the sensorial and nutrition property of cookies. Similar ranking under the category “very good” was obtained by Rezagholi and Hesarinejad (2017) for gluten free cake, Shindeet *al.* (2016) and Deshmukhet *al.* (2018) for RTE snack food, Solankeet *al.* (2018) for “Kharodi”.

Table 4.53 Cookies and their ranking

Sensory scale	Sample 1 (Marry Cookies)	Sample 2 (Locally manufactured Cookies)	Sample 3 (Cookies with Nagpur mandarin powder)
Poor	0	0.004	0.008
Fair	0.080	0.136	0.158
Medium	0.347	0.461	0.486
Good	0.647	0.716	0.718
Very good	0.667	0.565	0.530
Excellent	0.245	0.164	0.147
Ranking	I	III	II

4.14.3 Quality ranking of cookies

The quality attributes of cookies and other commercial sample in general were ranked by calculating similarity values under various scale factors. Values of membership functions of F₁, F₂, F₃, F₄, F₅ and F₆ as given in Eqn 3.85 were used in the calculation of similarity values. The values of overall membership functions for sensory scores of the quality attributes viz., colour, flavour, texture and overall acceptability were calculated using the same procedure as described above. The similarity values of all the quality attributes are given in Table 4.54.

The results from Table 4.54 show that all quality attributes viz. colour, flavour, texture and overall acceptability were considered as highly important for cookies in general. The overall acceptability (0.983) has highest quality attributes value followed by texture (0.971), flavour (0.864) and colour (0.829). The order of preference given by judges for quality attributes of cookies in general was overall acceptability (highly important) > texture (highly important) > colour (highly important) > colour (highly important).

Table 4.54 Quality attributes of cookies in general

Sensory scale	Colour	Flavour	Texture	Overall Acceptability
Not at all Important	0	0	0	0
Somewhat Important	0	0	0	0
Important	0.236	0	0.027	0.027
Very Important	0.829	0.209	0.418	0.427
Highly Important	0.743	0.864	0.971	0.983
Extremely Important	0.152	0.639	0.484	0.477
Ranking	IV	III	II	I

Davidson *et al.* (2001) stated that in the quality attributes, texture was the strongest quality attribute for cookies or biscuits. The close tie in the quality attribute of cookies well-established consumer choice and products. Thus, it's found that for cookies, all quality parameters are highly important as per the preferences of judges in this evaluation. The opinion of judges regarding the general quality attributes and the results of fuzzy logic analysis indicate that the present technology is suitable for the preparation of cookies.

4.15 Storage Studies of the Final Product (Nagpur mandarin powder)

This section deals with the changes observed in the product during the accelerated storage study under relative humidity, 95% at 40°C temperature. As already discussed in the section 3.27, the product was stored in three types of packaging material (HDPE, MP and PP) for above condition during storage study.

4.15.1 Properties of packaging materials

The cumulative moisture gain with time by silica gel kept in three pouches (HDPE, MP and PP) at 40 ± 2°C temperature and 95 ± 1% relative

humidity were measured as discussed in section 3.27.2. From the slope of respective curves, the WVTR were determined and it is given in Table 4.55.

Table 4.55 Specifications of packaging materials used in the storage study

Sr. No.	Packaging Material	Thickness (microns)	WVTR (kg water/day m ²)	Permeability x 10 ⁻⁶ (kg water/day m ² Pa)
1	HDPE	75	0.0026	4.65
2	MP	50	0.0012	3.35
3	PP	50	0.0027	7.33

4.15.2 Sorption isotherm of the final products (Nagpur mandarin powder)

Sorption isotherms of powder stored at 38 ± 2 °C temperature and 95 % RH, showing the variation of moisture content of the products with water activity (a_w) are as shown in Fig. 4.33. The values of water activity of finished products with 0.068 kg/kg dm moisture content for powder was found 0.521 at the said temperature. Moisture content increased slowly with increase in water activity until the water activity values of about 0.542, after which rapid increase in moisture content was observed. Thus it was concluded from the Fig. 4.33 that the water activity values of about 0.521 was taken as the critical water activity values of Nagpur mandarin powder, beyond which the products would loose the flowability and increased degree of caking. Similar phenomenon was observed by Huaning (2013) that the water activity values for bovine colostrum powder ranged between 0.11 - 0.86. Breda *et al.* (2012) found the water activity increased in storage, being greater under accelerated conditions (0.680). The a_w values for the papaya powders were less than 0.6 and can thus be considered to be quite stable against microbial, browning, hydrolytic reaction, lipid oxidation, auto-oxidation and enzymatic activity (Caliskan and Dirim, 2013). According to Queket *al.* (2007), high water activity in products leads to shorter shelf life due to high free water for biochemical degradations. The initial moisture content of optimum Nagpur mandarin powder was found to 0.0031 kg/kg dm. The

variation of moisture content with time indicates that the moisture content increased with time.

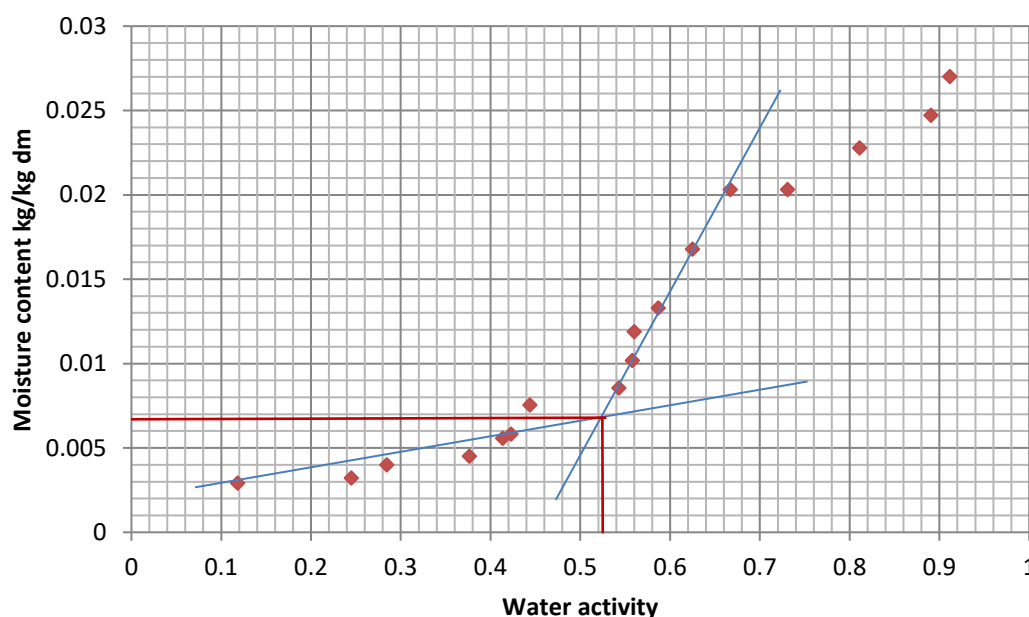


Fig. 4.33 Water activity of Nagpur mandarin stored powder

4.15.3 Moisture content of Nagpur mandarin powder during storage

Variation in moisture content of the powder stored under accelerated storage conditions is presented graphically represented in Fig. 4.34. Moisture content was found to increase rapidly with time at 40 °C with 95% RH. The variation of moisture content in the product was higher in case of those packed in high density poly ethylene (HDPE) and polypropylene (PP) and lower in case of metalised polyester (MP).

This was obvious as the water vapour transmission rate was higher in case of HDPE and PP whereas lower in case of MP. For all packaging materials (HDPE, PP and MP), the maximum moisture uptake was observed for the product at RH (95 %), which may be because of the highest vapour pressure difference under accelerated condition, which acted as the driving force for the moisture transfer. It was found that the moisture content increased with 40 °C temperature for any particular storage period. This indicated that moisture transfer is a function of temperature during period of storage, under consideration.

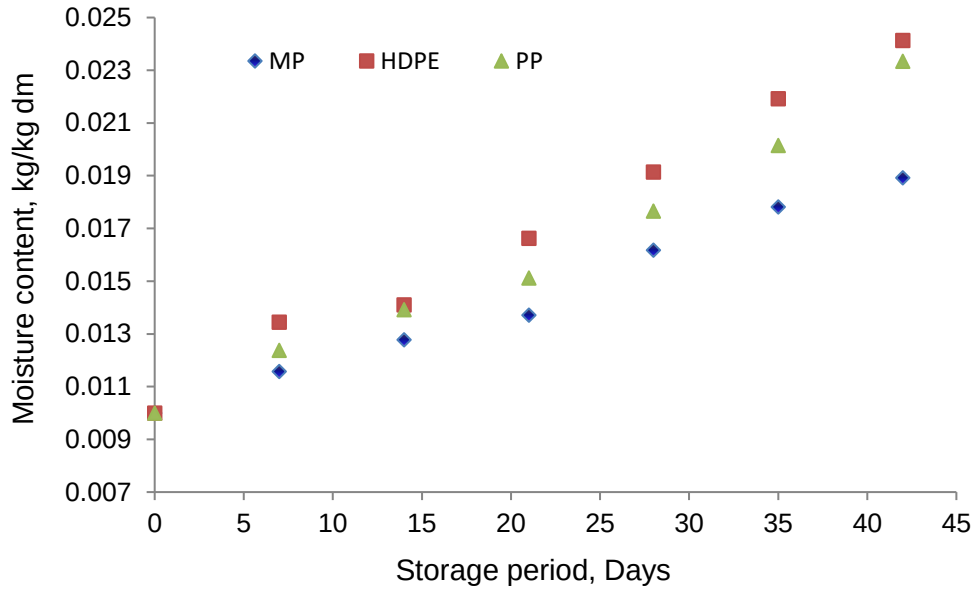


Fig. 4.34 Moisture content of Nagpur mandarin powder with storage period

Similarly Kumar and Mishra (2004) reported that the moisture content of mango soy fortified yoghurt powder during accelerated storage ($38 \pm 1^\circ\text{C}$, $90 \pm 1\%$ RH) was gradually increased when packaged in high-density polypropylene (HDPP) and ALP. Puaet *al.* (2008) suggested that the increased of moisture content for drum dried jackfruit powders packaged in both ALP and metallized co-extruded biaxially oriented polypropylene (BOPP/MCPP) over 12 weeks accelerated storage (38°C ; 50%, 75% and 90% RH) was due to the migration of water vapour from storage environment into the packaging material. According to Puaet *al.* (2008), the water vapour transmission rate of ALP packaging material which was laminated with $7\ \mu\text{m}$ of aluminium was $1.21 \times 10^{-6}\ \text{kg/m}^2/\text{day}$, whereas the water vapour transmission rate of PET packaging material of $17\ \mu\text{m}$ was approximately $2.0 \times 10^{-6}\ \text{kg/m}^2/\text{day}$ at 38°C and 90% RH. A higher value of water vapour transmission rate of PET packaging showed that it had a greater permeability towards moisture gained during the storage of the foam-dried papaya powder.

4.15.5 Flowability

For determination of flowability the accelerated storage condition was at $38 \pm 2^\circ\text{C}$ and 90% RH. Flowability is the ability of powder to flow freely

which is measured as the angle of repose. From Table 4.56, the angles of repose for Nagpur mandarin powder were increased significantly for all packaging materials with storage time from 41.92 to 77.91^o for 0 to 42 days in accelerated storage condition (95% RH and 38 ± 2 °C). From Table 4.56, it shows that the flowability was found at par from 0 day of storage to 14th day of storage in accelerated storage condition. In MP packaging the flowability was found more as compared to HDPE and PP. This might be due to highest resistance to moisture. These results were consistent with those reported by Chauhan and Patil (2013) for mango milk powder. The reduction in flowability during storage of powders could have been caused by the low molecular weight of sugar found in fruits, which tends to have high molecular mobility which could easily lose its free flowing (Jaya and Das, 2004).

Table 4.56 Degree of caking and flowability of Nagpur mandarin powder

Storage period, days	Flowability (°)			Degree of caking (%)		
	HDPE	MP	PP	HDPE	MP	PP
0	41.92 ^a	41.92 ^a	41.92 ^a	10.35 ^a	10.35 ^a	10.35 ^a
7	45.00 ^{abc}	43.01 ^{ab}	45.00 ^{abc}	11.78 ^a	13.36 ^a	14.74 ^a
14	50.52 ^{abcde}	45.00 ^{abc}	47.98 ^{abc}	24.73 ^{ab}	16.38 ^{ab}	22.73 ^{ab}
21	55.50 ^{cdefgh}	49.77 ^{abcd}	53.83 ^{bcdefg}	68.73 ^{cde}	46.71 ^{bc}	59.42 ^{cd}
28	63.43 ^{fghi}	52.13 ^{abcef}	61.39 ^{efghi}	97.71 ^e	63.61 ^{cde}	72.85 ^{cde}
35	67.38 ^{ij}	60.65 ^{deghe}	65.75 ^{hij}		79.60 ^{de}	82.44 ^{de}
42	77.91 ^j	63.44 ^{ghj}	74.50 ^j			

SD = 11.07 and CV = 0.22 at 5%

SD = 31.04 and CV = 1.26 at 5%

4.15.4 Degree of caking

According to Table 4.56, the degree of caking for Nagpur mandarin powder packed in high density poly ethylene (HDPE), polypropylene (PP) and metalised polyester (MP) was found 97.71, 82.44 and 79.60 % by the end of 35 days, 42 and 42 accelerated storage days, respectively. The powder with high hygroscopicity will have the tendency to absorb moisture from the surrounding easily, which resulted in stickiness of powder and eventually causing caking of powder. Similar observation was obtained by Huaning *et al.* (2013), for bovine colostrums powder. Liu *et al.* (2010), Ramachandran *et al.* (2014) and Wong and Lim (2016) also reported the

increased of in degree of caking during their storage studies for tomato powder and papaya powder. The value of degree of caking $<30^\circ$ indicates excellent flow whereas $>56^\circ$ indicates very poor flow. The intermediate scale indicates 'good' (θ between $31-35^\circ$), fair (θ between $36-40^\circ$), passable which may hang up (θ between $41-45^\circ$), and poor which must be agitated or vibrated' (θ between $46-55^\circ$) (Rakhiet *al.*, 2008). Form Table 4.56, it shows that the limit of flowability was found from 10.35 to 24.73) for 14 days accelerated storage.

4.15.6 Shelf life of Nagpur mandarin powder

Water activity generally varied with the moisture content following sorption isotherm (Fig. 4.35). The quality of the product was better maintained at storage condition of 30°C , 65 % RH; followed by 30°C , 95 % RH, 40°C , 65 % RH and 40°C , 95 % RH. At very high humidity (95 %) the Nagpur mandarin powder lost its shelf life within 35 days in MP, 21 days in HDPE and 14 days in PP. Thus it could be concluded that the product if stored in MP package at moderate RH (65 %) and ambient temperature of 30°C , considerably long shelf life of 120 days was achieved.

Table 4.57 Predicted shelf life of Nagpur mandarin fruit powder

Storage condition		MP		HDPE		PP	
T $^\circ\text{C}$	RH (%)	OSL (days)	PSL (days)	OSL (days)	PSL (days)	OSL (days)	PSL (days)
40*	95	35	47	21	33	14	22
40	65	—	68	—	49	—	32
30	95	—	82	—	58	—	38
30	65	—	120	—	85	—	55

* is experiment conducted, T is temperature, RH is relative humidity, OSL is observed shelf life and PSL is predicted shelf life

From Table 4.57, it is seen that 50 microns of PP could give the shelf life of 55 days at 30°C and 65 % RH and for 32 days at 40°C and 95 % RH. 75 micron HDPE could protect the developed powder for about 85 days at 30°C and 65 % RH and for 49 days at 40°C and 65 % RH respectively. Whereas, It was found that 50 micron MP could protect the developed

Nagpur mandarin powder for about 120 days at 30 °C and 65 % RH and 68 days at 40 °C and 65% RH. This was because HDPE and PP being less moisture resisting film allowed the product to attain moisture equilibrium faster as compared to metallized polyester film

Similar findings were reported as 2 months storage for honey powder and 105 days for watermelon and mango juice powder (Jaya and Das 2005 and Arya *et al.*, 1986), 44 days for inapple and Lassi powder in MPpouches (Shibyet *al.*, 2017), 3 months in aluminium foil laminated pouch for banana Evelin *et al.* (2007).



Plate 4.1 Final product before grinding and after grinding

CHAPTER V

SUMMARY AND CONCLUSIONS

Mandarin orange (*Citrus reticulata*) is easily peelable and commonly grown citrus fruit in India. Mandarin is a name of cluster for a group of oranges with thin and slack peel. Citrus is most commonly used as a good source of vitamin C. However, fruits also contain an impressive list of other essential nutrients, including both glycaemic and non-glycaemic carbohydrate (sugars and fiber), potassium, calcium, thiamine, niacin, vitamin B₆, phosphorus, magnesium, copper, riboflavin, pantothenic acid and a variety of phyto chemicals (Whitney and Rolfes, 1999).

Removing most of the moisture from food will control the growth of microorganisms and increase the shelf life of product. Fruits and vegetables are dried to enhance storage stability, minimize packaging requirement and reduce transportation weight. But drying of sugar rich foods such as fruit pulp and juices to powder is difficult, mainly due to low molecular weight sugars, such as fructose, glucose, sucrose and acids such as citric acid present in ripe fruits (Jaya and Das, 2003). The foam mat drying is one of the promising new innovations in the field of aqueous foodstuffs. The foam mat drying method is a mechanism by which liquid or semi-liquid turns its shape into solid foam and is eventually dehydrated with fast cycle. Reduced the drying time due to porous structure of foamed juice/ pulp, also the quality in terms of texture and rehydration improves (Foegeding *et al.*, 2006). In foam mat drying, foam layer dries quicker than fluid layer at the same ambient conditions as vapour travels better through a thin foamed structure than through a thick layer of the same substance. Other advantage of foam-mat drying includes faster drying and better quality of final product as the drying temperature is less than the conventional drying methods. Foam mat drying happens at low temperature; therefore retain maximum nutrients in the food. This process offers a wide range of applications in the fruit processing industry so it allows fruit dehydration which are difficult to dry under mild (viscous and sticky) conditions (Khamjae and Rojanakorn, 2018). This process offers the wide range of applications in fruit industry because it

allows dehydration of fruits, difficult to dry under mild conditions (viscous and sticky) such as at lower temperature without having any impact on the product quality.

Some investigation carried out on foam mat drying by various researchers on mango (Sankat & Castaigne, 2004), guava (Qadri & Srivastava, 2015), muskmelon (Sangamithra, *et al.* 2015), tomato juice (Kadam & Balasubramanian, 2011), bael fruit pulp (Bag, Srivastav & Mishra 2009), apple juice (Raharitsifa, Genovese, & Ratti, 2006), banana (Thuwapanichayanan, Prachayawarakorn, & Soponronnarit, 2008) and kinnow mandarin (Kadam *et al.* 2011).

Nagpur mandarin is seasonal fruit crop and most of the product is therefore used for the table purpose. Post harvest losses of citrus fruits in developed countries ranges from 5 to 10 per cent while in developing countries ranges from 30 to 35 per cent. The processing on Nagpur mandarin fruit is limited due to limonin and nomilin present in fruit/ juice, which gives bitterness to juice cause off flavor. Freeze drying process is commonly known and produces products of better quality but this is a very costly technique. The cost of the product is also affected by the other drying methods like drums and spray drying. Thus, a microwave drying method in combination with foam mat drying, in which foam is developed by adding foaming agent that influenced the drying time. Sugar having anti bittering properties, hence sugar also incorporated in the present study. Therefore, the present study was conducted with objective to optimize proportions of foaming agent, sugar and whipping time. After optimization the microwave power and drying bed thickness was optimized to develop the Nagpur mandarin powder from juice.

1.3 Objective

1. To optimize proportion of artificial foaming agent and its concentration on foaming properties of Nagpur mandarin juice.
2. To optimize proportion of natural foaming agent and its concentration on foaming properties of Nagpur mandarin juice.

3. Optimization of microwave power, foaming agent and drying bed thickness during drying of Nagpur mandarin juice.
4. To study the drying characteristics of foamed juice during microwave drying.
5. To evaluate the quality parameters of developed Nagpur mandarin powder.
6. To study the storage period of developed Nagpur mandarin powder.

For study, fully ripe Nagpur mandarin fruit was selected then peeled. The peeled fruit was used for juice extraction. The juice was squeezed with a juicer (Bajaj JEX 16 800-Watt Juicer). To inactivate the enzyme the fresh juice was blanched for 1 min at 95 °C (Shaari, *et al.* 2017). The juice was used for further processing after fast cooling. The 100 g of Nagpur mandarin juice was taken in a 200 ml beaker. The artificial foaming agents were soy protein isolate (3 to 9%), glycerol mono stearate (2 to 5%), carboxyl methyl cellulose (1 to 3%) and sugar content (5 to 15%) while the natural foaming agents were protein isolates (3 to 9%), guar gum (0.3 to 0.9%) and sugar (5 to 15%) were added with whipping time (3 to 9 min). The hand blender (ORPAT model: HHB 100E, Ajanta, Limited, Morbi, India) was used for mixing and whipping the juice which was operated for 3, 6 and 9 min for foam generation (1,400 rpm).

Numerical and graphical multiresponse optimization technique was adopted for the process parameters of the foam mat drying. For the optimization of input parameters, the CCD architecture of 28 experiments made up of five main points was used. The dimensional, quadratic and interactive results were examined in relation to foam growth, foam density and mould stability. For each response, multiple regression analysis used to construct polynomial models of the second order. Variance analysis (ANOVA) was conducted to validate the adequacy and precision of the versions installed. Reaction surfaces and contour maps have been developed for demonstrating the relationship of the method variables. The F values indicated that the foaming agent concentration and whipping time were the most important element.

After optimization the samples were dried in microwave drying at various microwave power (180 to 900 W) at different drying bed thickness (2 to 6 mm) up to desired moisture content. The optimization of microwave power and drying bed thickness was done using different responses. Then powder was prepared. The powder was packed in polyethylene bag for further analysis and storage study.

For optimization of microwave power, foaming agent and drying bed thickness, the quality parameters viz. colour, water activity, ascorbic acid, acidity, colour b value, change in colour, drying time and overall acceptability were determined. The drying behaviour was investigated for foamed Nagpur mandarin juice at varying microwave power and drying bed thickness. The moisture content of the substance was observed with drying time and no constant rate cycle was observed exponentially. This shows that the overall mass transmission resistance was primarily attributed to the diffusion of internal moisture in the sample. The moisture ratio data for foamed Nagpur mandarin juice with different microwave power have been fitted into 18 thin-layer drying models in order to establish the most suitable drying equation

On the basis of the outcome of the investigation, the following findings were reported:

1. The mean values for length, width and thickness of Nagpur mandarin fruit was found 70.56, 68.05 and 67.11 mm, respectively and the average geometric mean diameter and sphericity of fruit was found 65.72 mm and 0.932.
2. The one dimensional mass model (mass vs length) gives R^2 (0.969) with RSE (0.239) value and predicted best relationship with mass.
3. The initial moisture content (wb) of juice, foamed with artificial and natural foaming agent were found 90.46%, 89.35% and 87.59% (wb), respectively.
4. The optimum operating conditions was found that the soy protein isolate 2.10%, sugar content 5.50% GMS concentration 2.75%, CMC 1.75% and whipping time 8 min in artificial foaming agent with foam

expansion 36.25%, foam density 0.65 g/cm³, foam stability 84.03% and overall desirability 0.75.

5. The optimum operating conditions was found that the guar gum 0.45%, soy protein isolate 3.30%, sugar content 10% and whipping time 6 min in natural foaming agent with foam expansion 25.76%, foam density 0.71 g/cm³, foam stability 83.04% and overall desirability 0.63.
6. For development of Nagpur mandarin powder, optimized drying condition was found with microwave power 540 W and drying bed thickness 3 mm in artificial foaming agent. Values of quality parameters viz. colour b value, ΔE , acidity, ascorbic acid, water activity, drying time and overall acceptability were found in the range of 19.59, 6.24, 0.40%, 36.64 mg/100 g, 0.26, 26.52 min and 7.77, respectively and 0.84 was desirability.
7. The drying time was found maximum in natural foaming agent at 180 W microwave power (80 min) and minimum in artificial foaming agent at 900 W microwave power (18 min).
8. The effective moisture diffusivity (D_{eff})_{avg} values of Nagpur mandarin foamed juice at different microwave power varied with moisture content from 0.041×10^{-9} to 14.61×10^{-9} m²/s for 2, 4 and 6 mm drying bed thickness. The activation energy for moisture diffusion process was 17.48 to 19.68 W/g for 2, 4 and 6 mm drying bed thickness.
9. The total sugar, reducing sugar and non reducing sugar were found 46.16, 36.4. 9.76%, respectively in powder while the same were 43.50, 32.94 and 11.55%, respectively in Nagpur mandarin juice on dry basis. The protein was increased in powder i.e. 14.88% as compared to juice i.e. 8.28%.
10. The values of vitamins viz. Thiamine, Niacin, Vitamin B₆ and vitamin C were found 0.59, 3.84, 0.80 and 46.37 mg/100g, respectively in fresh juice and 2.90, 5.13, 0.06 and 36.5 mg/100g, respectively in powder.

11. The minerals viz. Ca, iron, magnesium, manganese, phosphorus, potassium and zinc were found 78.72 mg/100 g dm, 4.58 mg/100 g dm, 61.48 mg/100 g dm, 5.38ppm, 16.31 mg/100 g dm, 327.54 mg/100 g dm, and 0.565ppm, respectively in the powder.
12. Cookies prepared with developed Nagpur mandarin powder obtained overall sensory score (0.718) was in “good” category.
13. The developed powder stored in Metallised Polyester (50 microns) package at moderate RH (65%) and ambient temperature of 30 °C for considerably long shelf life i. e. 120 days.

From the study, it is concluded that the Nagpur mandarin powder developed by foam mat drying technology using soy protein isolate 2.10%, sugar content 5.50%, GMS concentration 2.75%, CMC 1.75% and 8 min whipping time, dried at 540 W microwave power with 3 mm drying bed thickness gives good quality product in respect with nutritional and sensory parameters with having good shelf life.

CHAPTER VI

IMPLICATIONS

On the basis of the study undertaken the following implications can be suggested

1. The foam mat drying will be useful for developing export quality product of Nagpur mandarin.
2. Using this technology cottage level fruit processing industry can be promoted for employment generation.
3. Development of value added products using Nagpur mandarin powder.
4. Rehydration properties of the Nagpur mandarin powder are necessary to determine its market approach and applications in the food industry.
5. Process automation may be developed for the processing operations involved in present study.
6. Conduct the experimentation on microwave drying at 915 Hz frequency microwave dryer.

CHAPTER VII

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APPENDIX – A
Physical Properties of Nagpur Mondrian fruit

Sr. No.	Length, mm	Width, mm	Thickness, mm	Geometric Dia. mm	Sphericity	Weight, g	Actual Volume, cm ³	Oblate Spheroid Volume, cm ³	Ellipsoid Volume, cm ³	Surface area, cm ²	projected area, cm ²	Fruit Sp. Gravity, kg/cm ³	Juice Sp. Gravity, kg/cm ³
1	65.680	63.890	63.020	64.187	0.977	148.540	145.940	140.306	138.396	129.368	90.340	1.018	0.945
2	69.750	66.890	66.100	67.562	0.969	159.750	152.450	163.322	161.393	143.329	94.370	1.048	0.949
3	70.250	66.980	65.980	67.712	0.964	163.850	157.010	164.936	162.473	143.968	96.340	1.044	0.953
4	65.570	63.480	62.180	63.728	0.972	146.780	145.650	138.279	135.448	127.524	91.305	1.008	0.940
5	68.290	67.100	66.578	67.319	0.986	155.100	146.650	160.909	159.657	142.299	91.350	1.058	0.949
6	69.580	67.980	66.780	68.104	0.979	158.960	153.410	168.277	165.307	145.637	94.370	1.036	0.952
7	71.360	69.870	68.010	69.733	0.977	165.580	157.540	182.312	177.458	152.689	96.470	1.051	0.955
8	74.450	72.450	71.540	72.803	0.978	173.950	165.940	204.513	201.944	166.430	98.370	1.048	0.958
9	72.360	70.980	69.980	71.100	0.983	169.250	160.350	190.787	188.099	158.734	96.860	1.056	0.960
10	69.650	67.590	66.980	68.064	0.977	159.890	153.010	166.519	165.016	145.466	92.380	1.045	0.951
11	68.680	65.650	65.100	66.458	0.968	158.470	148.640	154.910	153.612	138.684	93.340	1.066	0.947
12	71.860	68.540	67.580	69.303	0.964	166.260	159.480	176.666	174.192	150.810	95.960	1.043	0.958
13	74.540	70.650	68.980	71.352	0.957	173.890	167.250	194.712	190.109	159.862	99.375	1.040	0.961
14	71.540	68.547	66.574	68.857	0.962	166.250	159.240	175.916	170.852	148.876	96.370	1.044	0.955
15	71.320	69.890	68.840	70.009	0.982	165.890	157.140	182.314	179.575	153.901	94.340	1.056	0.955
16	69.570	66.580	65.547	67.211	0.966	158.240	151.580	161.394	158.890	141.843	93.570	1.044	0.946
17	64.580	62.470	61.580	62.864	0.973	143.540	144.360	131.892	130.013	124.090	89.350	0.994	0.937
18	68.620	66.257	64.987	66.604	0.971	156.010	147.580	157.650	154.628	139.295	90.370	1.057	0.947
19	72.680	71.890	70.450	71.667	0.986	169.900	161.870	196.576	192.638	161.277	97.340	1.050	0.959
20	69.980	65.980	62.578	66.110	0.945	161.540	155.450	159.433	151.212	137.236	96.860	1.039	0.953
21	72.680	71.350	70.980	71.666	0.986	170.540	165.870	193.634	192.630	161.272	98.720	1.028	0.959
22	70.260	69.210	67.960	69.137	0.984	164.010	157.960	176.126	172.945	150.089	94.070	1.038	0.954
23	75.690	72.140	72.570	73.450	0.970	174.350	167.980	206.143	207.372	169.399	99.348	1.038	0.962
24	69.890	67.980	67.010	68.283	0.977	160.750	153.870	169.027	166.615	146.404	91.860	1.045	0.949
25	70.650	68.890	68.010	69.175	0.979	164.580	158.210	175.470	173.229	150.253	96.750	1.040	0.955
26	68.350	66.250	65.580	66.716	0.976	155.450	146.980	156.996	155.408	139.763	92.370	1.058	0.948
27	71.260	68.680	66.890	68.920	0.967	166.540	159.040	175.908	171.323	149.149	96.072	1.047	0.955
28	69.980	67.890	66.870	68.234	0.975	160.870	154.980	168.797	166.261	146.197	94.050	1.038	0.949
29	70.390	68.690	67.100	68.714	0.976	164.890	158.140	173.811	169.787	148.257	97.348	1.043	0.955
30	70.650	68.470	67.140	68.738	0.973	163.580	157.450	173.337	169.970	148.363	95.340	1.039	0.955
Avg.	70.337	68.107	66.982	68.459	0.973	162.240	155.701	171.362	168.548	147.349	94.832	1.042	0.953

APPENDIX – A
Physical Properties of Nagpur Mondrian fruit and Segments

Sr. No.	Peel Weight, g	Peel Thickness, mm	Pulp Weight, g	pomace weight, g	No. of Seed	Weight of seed, g	Juice Content, %	Juice to Pomace Ratio	Peel to Pomace ratio	Number of Segment	Weight of Each Segment, g	segment length, mm	Width, mm	Thickness, mm	Geometric mean dia, mm	Sphericity
1	28.970	2.970	139.240	48.690	7.000	2.147	25.720	0.528	0.595	11.000	12.140	44.540	21.900	10.870	21.969	0.493
2	31.540	3.240	134.540	56.720	4.000	0.795	28.127	0.496	0.556	7.000	14.250	45.780	20.810	9.260	20.663	0.451
3	32.210	2.470	129.450	54.987	6.000	0.987	30.468	0.554	0.586	9.000	10.270	47.800	25.050	14.300	25.775	0.539
4	28.240	2.680	124.550	50.390	9.000	3.258	23.468	0.466	0.560	12.000	10.280	50.140	22.870	16.190	26.479	0.528
5	28.870	3.470	110.250	47.650	8.000	1.986	27.771	0.583	0.606	12.000	11.010	47.690	18.470	9.330	20.180	0.423
6	29.700	2.510	112.780	50.100	7.000	1.387	29.511	0.589	0.593	9.000	10.280	42.410	17.750	10.510	19.926	0.470
7	29.870	3.140	129.870	48.340	4.000	0.891	29.280	0.655	0.618	14.000	10.170	45.065	18.550	11.530	21.282	0.472
8	38.570	3.240	104.250	47.360	5.000	0.873	34.400	0.726	0.814	12.000	10.140	43.700	18.190	11.380	20.836	0.477
9	29.570	4.240	128.640	51.760	4.000	0.758	32.540	0.699	0.571	13.000	12.840	47.630	22.300	16.020	25.721	0.540
10	32.680	3.240	129.280	46.790	4.000	0.816	28.993	0.620	0.698	14.000	11.350	48.800	20.300	9.300	20.964	0.430
11	30.950	4.050	124.680	50.410	3.000	0.610	26.661	0.529	0.614	10.000	12.140	44.440	21.430	11.340	22.104	0.497
12	31.470	2.810	140.850	54.290	5.000	0.891	33.980	0.626	0.580	11.000	11.270	42.080	16.660	9.000	18.478	0.439
13	38.290	2.570	115.580	47.650	7.000	1.278	34.250	0.775	0.804	8.000	13.510	43.500	17.830	10.410	20.062	0.461
14	30.570	4.010	120.450	49.840	6.000	1.987	31.572	0.633	0.613	12.000	9.240	46.010	21.120	11.580	22.409	0.487
15	36.590	2.340	134.580	49.570	8.000	1.985	31.978	0.645	0.738	10.000	10.240	43.040	16.420	11.410	20.053	0.466
16	37.420	3.170	127.340	45.280	5.000	0.987	26.351	0.582	0.826	12.000	11.100	44.710	19.930	10.950	21.369	0.478
17	35.650	3.580	122.480	49.820	7.000	1.478	22.328	0.448	0.716	14.000	11.240	45.065	18.550	11.530	21.282	0.472
18	26.470	2.470	134.280	53.970	6.000	1.104	26.969	0.500	0.490	8.000	14.100	42.340	18.020	11.130	20.402	0.482
19	27.570	2.310	137.390	51.270	7.000	1.189	31.980	0.691	0.538	13.000	10.270	47.960	22.340	16.110	25.844	0.539
20	33.570	2.980	140.480	57.640	4.000	0.789	30.453	0.528	0.582	11.000	12.140	48.800	20.300	12.250	22.980	0.471
21	35.900	3.240	134.280	54.325	8.000	1.587	35.183	0.648	0.661	10.000	11.900	44.440	21.430	11.340	22.104	0.497
22	27.240	2.390	135.470	54.350	5.000	0.954	31.285	0.576	0.501	10.000	11.240	42.080	15.240	9.240	18.096	0.430
23	31.650	3.100	141.640	52.365	7.000	1.354	31.540	0.734	0.604	10.000	9.540	43.500	17.830	10.410	20.062	0.461
24	27.870	2.670	120.250	49.350	8.000	2.254	28.035	0.568	0.565	9.000	14.240	45.890	20.680	11.240	22.013	0.480
25	30.650	2.900	130.180	50.730	4.000	0.798	32.078	0.632	0.604	12.000	12.010	44.210	16.510	11.240	20.169	0.456
26	27.270	3.280	149.250	53.710	4.000	0.871	27.135	0.505	0.508	9.000	13.100	44.010	19.380	10.590	20.826	0.473
27	28.470	2.970	121.250	41.810	5.000	1.014	32.006	0.766	0.681	8.000	13.140	45.620	18.950	11.560	21.540	0.472
28	30.800	2.570	129.370	47.280	6.000	1.214	27.920	0.591	0.651	12.000	10.270	43.100	18.320	11.240	20.704	0.480
29	29.540	3.470	124.280	41.950	6.000	1.369	31.473	0.750	0.704	14.000	10.240	44.390	18.340	11.650	21.168	0.477
30	22.980	2.580	129.250	47.430	7.000	2.475	30.240	0.678	0.485	10.000	12.140	42.690	15.680	10.210	18.977	0.445
Avg.	31.038	3.022	128.539	50.194	5.867	1.336	29.790	0.611	0.622	10.867	11.527	45.048	19.372	11.437	21.481	0.476

APPENDIX – B

Data on Microwave Drying of Artificial Foamed Nagpur Mandarin Juice

Microwave power 180 W

Thickness of drying bed 2 mm

Initial moisture content of foamed juice is 79.94% (wb)

BDM = 20.06 g/100g

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) db	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0	100.750	0.000	80.450	411.509	1.000	0.000	0.000	-0.085	0.000
1	98.611	2.139	78.311	361.063	0.973	10.663	-0.027	-0.074	-0.296
2	96.352	4.398	76.052	317.569	0.945	10.962	-0.056	-0.062	-0.124
3	93.605	7.146	73.305	274.595	0.911	11.874	-0.093	-0.047	-0.063
4	89.315	11.435	69.015	222.736	0.858	14.251	-0.153	-0.023	-0.023
5	87.149	13.601	66.849	201.648	0.831	13.561	-0.185	-0.010	-0.008
6	84.475	16.275	64.175	179.135	0.798	13.522	-0.226	0.006	0.004
7	88.350	12.400	68.050	212.989	0.846	8.831	-0.167	-0.017	-0.009
8	82.150	18.600	61.850	162.123	0.769	11.590	-0.263	0.021	0.010
9	79.050	21.700	58.750	142.424	0.730	12.019	-0.314	0.042	0.018
10	76.915	23.835	56.615	130.494	0.704	11.882	-0.351	0.057	0.022
11	74.754	25.996	54.454	119.559	0.677	11.781	-0.390	0.073	0.026
12	72.439	28.311	52.139	108.939	0.648	11.761	-0.434	0.091	0.030
13	71.261	29.489	50.961	103.920	0.633	11.308	-0.457	0.100	0.030
14	67.699	33.051	47.399	90.112	0.589	11.768	-0.529	0.129	0.036
15	64.325	36.425	44.025	78.651	0.547	12.105	-0.603	0.159	0.042
16	62.000	38.750	41.700	71.527	0.518	12.073	-0.657	0.181	0.045
17	59.949	40.801	39.649	65.698	0.493	11.964	-0.708	0.202	0.047
18	57.769	42.982	37.469	59.919	0.466	11.904	-0.764	0.225	0.049
19	55.785	44.966	35.485	55.002	0.441	11.798	-0.819	0.247	0.051
20	53.359	47.391	33.059	49.385	0.411	11.812	-0.889	0.275	0.055
21	51.026	49.724	30.726	44.354	0.382	11.804	-0.963	0.305	0.058
22	48.404	52.346	28.104	39.090	0.349	11.861	-1.052	0.341	0.062
23	46.500	54.250	26.200	35.501	0.326	11.758	-1.122	0.370	0.064
24	45.310	55.440	25.010	33.352	0.311	11.515	-1.168	0.388	0.064
25	43.509	57.242	23.209	30.223	0.288	11.414	-1.243	0.419	0.067
26	42.256	58.494	21.956	28.133	0.273	11.215	-1.299	0.441	0.067
27	40.300	60.450	20.000	25.000	0.249	11.161	-1.392	0.479	0.071
28	38.556	62.194	18.256	22.334	0.227	11.073	-1.483	0.516	0.073
29	37.526	63.225	17.226	20.810	0.214	10.868	-1.541	0.540	0.074
30	35.635	65.116	15.335	18.112	0.191	10.820	-1.658	0.587	0.078
31	34.875	65.875	14.575	17.062	0.181	10.593	-1.708	0.607	0.078
32	31.000	69.750	10.700	11.982	0.133	10.866	-2.017	0.733	0.091
33	29.450	71.300	9.150	10.072	0.114	10.771	-2.174	0.796	0.096
34	27.900	72.850	7.600	8.225	0.094	10.681	-2.359	0.871	0.102
35	27.474	73.276	7.174	7.728	0.089	10.437	-2.417	0.895	0.102
36	26.431	74.319	6.131	6.531	0.076	10.291	-2.574	0.958	0.106
37	25.505	75.245	5.205	5.491	0.065	10.138	-2.738	1.025	0.110
38	24.676	76.074	4.376	4.576	0.054	9.980	-2.912	1.095	0.115
39	23.622	77.128	3.322	3.436	0.041	9.859	-3.187	1.207	0.123
40	22.894	77.857	2.594	2.663	0.032	9.703	-3.435	1.307	0.130
41	22.452	78.298	2.152	2.199	0.027	9.520	-3.621	1.383	0.134
42	21.832	78.918	1.532	1.556	0.019	9.367	-3.961	1.520	0.144
43	21.685	79.066	1.385	1.404	0.017	9.166	-4.062	1.561	0.145

Data on Microwave Drying of Artificial Foamed Nagpur Mandarin Juice

Microwave power 180 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	100.067	0.000	79.940	398.504	1.000	0.000	0.000	-0.085	
1	98.895	1.172	78.768	370.987	0.985	5.842	-0.015	-0.079	-1.2661
2	97.166	2.901	77.039	335.521	0.964	7.231	-0.037	-0.070	-0.5611
3	95.342	4.725	75.215	303.470	0.941	7.851	-0.061	-0.060	-0.3223
4	93.322	6.745	73.195	273.060	0.916	8.406	-0.088	-0.049	-0.1976
5	91.833	8.234	71.706	253.436	0.897	8.209	-0.109	-0.041	-0.1314
6	90.567	9.500	70.440	238.291	0.881	7.893	-0.127	-0.034	-0.0902
7	88.825	11.242	68.698	219.468	0.859	8.006	-0.152	-0.024	-0.0542
8	87.121	12.946	66.994	202.978	0.838	8.067	-0.177	-0.014	-0.0270
9	84.518	15.549	64.391	180.831	0.805	8.612	-0.216	0.003	0.0045
10	82.422	17.645	62.295	165.217	0.779	8.796	-0.249	0.016	0.0255
11	81.067	19.000	60.940	156.014	0.762	8.611	-0.271	0.025	0.0362
12	79.129	20.938	59.002	143.912	0.738	8.698	-0.304	0.038	0.0506
13	76.994	23.073	56.867	131.843	0.711	8.848	-0.341	0.053	0.0651
14	74.702	25.365	54.575	120.141	0.683	9.032	-0.382	0.070	0.0795
15	72.118	27.949	51.991	108.293	0.650	9.289	-0.430	0.089	0.0952
16	70.306	29.761	50.179	100.720	0.628	9.272	-0.466	0.104	0.1036
17	68.400	31.667	48.273	93.323	0.604	9.286	-0.504	0.119	0.1123
18	66.500	33.567	46.373	86.473	0.580	9.296	-0.545	0.136	0.1205
19	63.967	36.100	43.840	78.062	0.548	9.472	-0.601	0.158	0.1333
20	62.067	38.000	41.940	72.235	0.525	9.472	-0.645	0.176	0.1410
21	60.452	39.615	40.325	67.573	0.504	9.404	-0.684	0.192	0.1465
22	59.061	41.006	38.934	63.757	0.487	9.292	-0.719	0.206	0.1501
23	57.633	42.434	37.506	60.016	0.469	9.197	-0.757	0.222	0.1541
24	55.889	44.179	35.762	55.670	0.447	9.176	-0.804	0.241	0.1606
25	54.628	45.439	34.501	52.673	0.432	9.061	-0.840	0.255	0.1635
26	53.361	46.706	33.234	49.777	0.416	8.955	-0.878	0.271	0.1665
27	52.280	47.787	32.153	47.390	0.402	8.823	-0.911	0.284	0.1683
28	50.394	49.673	30.267	43.405	0.379	8.844	-0.971	0.308	0.1763
29	48.767	51.300	28.640	40.134	0.358	8.818	-1.026	0.331	0.1826
30	47.487	52.580	27.360	37.666	0.342	8.737	-1.072	0.349	0.1864
31	45.651	54.416	25.524	34.271	0.319	8.751	-1.142	0.378	0.1949
32	44.061	56.006	23.934	31.465	0.299	8.725	-1.206	0.404	0.2018
33	42.174	57.893	22.047	28.282	0.276	8.745	-1.288	0.437	0.2118
34	39.900	60.167	19.773	24.646	0.247	8.822	-1.397	0.481	0.2264
35	38.000	62.067	17.873	21.763	0.224	8.840	-1.498	0.522	0.2386
36	36.733	63.334	16.606	19.913	0.208	8.770	-1.571	0.552	0.2452
37	35.467	64.600	15.340	18.119	0.192	8.704	-1.651	0.584	0.2525
38	34.200	65.867	14.073	16.378	0.176	8.641	-1.737	0.619	0.2606
39	32.933	67.134	12.806	14.687	0.160	8.581	-1.831	0.657	0.2696
40	31.667	68.400	11.540	13.045	0.144	8.524	-1.935	0.699	0.2797
41	30.400	69.667	10.273	11.449	0.129	8.471	-2.052	0.746	0.2913
42	29.767	70.300	9.640	10.668	0.121	8.344	-2.115	0.772	0.2942
43	28.500	71.567	8.373	9.138	0.105	8.297	-2.256	0.829	0.3086
44	27.233	72.834	7.106	7.650	0.089	8.252	-2.420	0.896	0.3257
45	26.689	73.378	6.562	7.022	0.082	8.129	-2.500	0.928	0.3300
46	25.593	74.474	5.466	5.782	0.068	8.071	-2.683	1.002	0.3486
47	24.681	75.386	4.554	4.771	0.057	7.996	-2.865	1.076	0.3663
48	24.054	76.013	3.927	4.088	0.049	7.894	-3.013	1.136	0.3787
49	23.433	76.634	3.306	3.419	0.041	7.796	-3.185	1.206	0.3938
50	23.338	76.729	3.211	3.318	0.040	7.650	-3.215	1.218	0.3897

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 180 W

Thickness of drying bed 6 mm

Dryin g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying			$D_{eff} \times 10^9$ (m ² /s)
						rate, (g/100g bdm)	ln (MR)	F ₀	
0	105.000	0.000	83.940	522.665	1.000	0.000	0.000	-0.085	0
1	103.884	1.116	82.824	482.208	0.987	5.563	-0.013	-0.080	-2.868
2	102.588	2.412	81.528	441.360	0.971	6.012	-0.029	-0.073	-1.319
3	100.710	4.290	79.650	391.400	0.949	7.129	-0.052	-0.064	-0.766
4	98.988	6.012	77.928	353.063	0.928	7.493	-0.074	-0.055	-0.495
5	97.134	7.866	76.074	317.955	0.906	7.842	-0.098	-0.045	-0.325
6	94.944	10.056	73.884	282.907	0.880	8.355	-0.128	-0.033	-0.200
7	93.084	11.916	72.024	257.449	0.858	8.486	-0.153	-0.023	-0.118
8	91.482	13.518	70.422	238.089	0.839	8.423	-0.176	-0.014	-0.062
9	89.682	15.318	68.622	218.695	0.818	8.485	-0.201	-0.003	-0.013
10	87.702	17.298	66.642	199.778	0.794	8.623	-0.231	0.008	0.030
11	85.902	19.098	64.842	184.430	0.772	8.655	-0.258	0.020	0.063
12	84.252	20.748	63.192	171.680	0.753	8.619	-0.284	0.030	0.089
13	82.524	22.476	61.464	159.498	0.732	8.619	-0.312	0.041	0.114
14	80.544	24.456	59.484	146.816	0.709	8.708	-0.344	0.054	0.140
15	78.000	27.000	56.940	132.234	0.678	8.973	-0.388	0.072	0.173
16	76.352	28.648	55.292	123.676	0.659	8.926	-0.417	0.084	0.189
17	74.994	30.006	53.934	117.080	0.643	8.799	-0.442	0.094	0.199
18	72.882	32.118	51.822	107.564	0.617	8.895	-0.482	0.110	0.220
19	70.920	34.080	49.860	99.442	0.594	8.942	-0.521	0.126	0.238
20	68.544	36.456	47.484	90.418	0.566	9.087	-0.570	0.146	0.262
21	67.500	37.500	46.440	86.706	0.553	8.902	-0.592	0.155	0.265
22	64.608	40.392	43.548	77.142	0.519	9.153	-0.656	0.181	0.295
23	62.922	42.078	41.862	72.005	0.499	9.120	-0.696	0.197	0.308
24	60.924	44.076	39.864	66.290	0.475	9.155	-0.745	0.217	0.325
25	58.704	46.296	37.644	60.369	0.448	9.232	-0.802	0.240	0.345
26	56.544	48.456	35.484	55.000	0.423	9.291	-0.861	0.264	0.365
27	55.056	49.944	33.996	51.506	0.405	9.221	-0.904	0.281	0.374
28	52.350	52.650	31.290	45.539	0.373	9.374	-0.987	0.315	0.404
29	50.607	54.393	29.547	41.939	0.352	9.350	-1.044	0.338	0.419
30	49.260	55.740	28.200	39.276	0.336	9.262	-1.091	0.357	0.428
31	47.400	57.600	26.340	35.759	0.314	9.263	-1.159	0.385	0.446
32	46.200	58.800	25.140	33.583	0.299	9.160	-1.206	0.404	0.454
33	44.988	60.012	23.928	31.454	0.285	9.066	-1.255	0.424	0.462
34	43.548	61.452	22.488	29.012	0.268	9.010	-1.317	0.449	0.475
35	42.600	62.400	21.540	27.453	0.257	8.888	-1.360	0.466	0.479

36	41.646	63.354	20.586	25.922	0.245	8.773	-1.405	0.485	0.484
37	40.788	64.212	19.728	24.576	0.235	8.651	-1.448	0.502	0.488
38	39.000	66.000	17.940	21.862	0.214	8.658	-1.543	0.540	0.511
39	38.094	66.906	17.034	20.531	0.203	8.552	-1.595	0.561	0.518
40	36.750	68.250	15.690	18.610	0.187	8.506	-1.677	0.595	0.535
41	35.808	69.192	14.748	17.299	0.176	8.413	-1.739	0.620	0.544
42	35.088	69.912	14.028	16.317	0.167	8.298	-1.789	0.640	0.548
43	34.260	70.740	13.200	15.207	0.157	8.201	-1.850	0.665	0.556
44	33.588	71.412	12.528	14.322	0.149	8.091	-1.902	0.686	0.561
45	33.000	72.000	11.940	13.559	0.142	7.976	-1.950	0.705	0.564
46	32.484	72.516	11.424	12.897	0.136	7.859	-1.994	0.723	0.566
47	31.716	73.284	10.656	11.927	0.127	7.773	-2.064	0.751	0.575
48	31.200	73.800	10.140	11.284	0.121	7.665	-2.114	0.771	0.578
49	30.744	74.256	9.684	10.722	0.115	7.554	-2.160	0.790	0.580
50	30.024	74.976	8.964	9.847	0.107	7.475	-2.237	0.821	0.591
51	29.340	75.660	8.280	9.027	0.099	7.395	-2.316	0.854	0.602
52	28.776	76.224	7.716	8.361	0.092	7.307	-2.387	0.882	0.610
53	28.200	76.800	7.140	7.689	0.085	7.224	-2.464	0.914	0.620
54	27.720	77.280	6.660	7.135	0.079	7.134	-2.534	0.942	0.627
55	27.408	77.592	6.348	6.778	0.076	7.033	-2.582	0.961	0.629
56	26.832	78.168	5.772	6.126	0.069	6.958	-2.677	1.000	0.642
57	26.346	78.654	5.286	5.581	0.063	6.879	-2.765	1.036	0.654
58	25.200	79.800	4.140	4.319	0.049	6.859	-3.009	1.135	0.704

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 360 W

Thickness of drying bed 2 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	100.650	0.000	80.450	411.509	1.000	0.000	0.000	-0.085	-
1	98.175	2.475	77.975	354.030	0.969	12.338	-0.031	-0.072	0.289
2	94.050	6.600	73.850	282.409	0.918	16.451	-0.086	-0.050	0.100
3	89.925	10.725	69.725	230.306	0.867	17.822	-0.143	-0.027	0.036
4	87.450	13.200	67.250	205.344	0.836	16.451	-0.179	-0.012	0.012
5	84.150	16.500	63.950	177.393	0.795	16.451	-0.230	0.008	0.006
6	80.850	19.800	60.650	154.130	0.754	16.451	-0.283	0.029	0.019
7	77.550	23.100	57.350	134.467	0.713	16.451	-0.338	0.052	0.029
8	74.250	26.400	54.050	117.628	0.672	16.451	-0.398	0.076	0.038
9	70.950	29.700	50.750	103.046	0.631	16.451	-0.461	0.102	0.045
10	68.475	32.175	48.275	93.330	0.600	16.039	-0.511	0.122	0.048
11	66.000	34.650	45.800	84.502	0.569	15.703	-0.563	0.143	0.052
12	62.700	37.950	42.500	73.913	0.528	15.765	-0.638	0.174	0.057
13	60.225	40.425	40.025	66.736	0.498	15.502	-0.698	0.198	0.060
14	57.750	42.900	37.550	60.128	0.467	15.276	-0.762	0.224	0.063
15	55.275	45.375	35.075	54.024	0.436	15.080	-0.830	0.251	0.067
16	52.800	47.850	32.600	48.368	0.405	14.908	-0.903	0.281	0.070
17	49.500	51.150	29.300	41.443	0.364	14.999	-1.010	0.324	0.076
18	47.025	53.625	26.825	36.659	0.333	14.851	-1.098	0.360	0.080
19	44.550	56.100	24.350	32.188	0.303	14.719	-1.195	0.399	0.084
20	42.900	57.750	22.700	29.366	0.282	14.394	-1.265	0.428	0.085
21	40.425	60.225	20.225	25.353	0.251	14.296	-1.381	0.474	0.090
22	38.775	61.875	18.575	22.812	0.231	14.020	-1.466	0.509	0.092
23	37.125	63.525	16.925	20.373	0.210	13.768	-1.559	0.547	0.095
24	33.000	67.650	12.800	14.679	0.159	14.052	-1.838	0.660	0.110
25	31.350	69.300	11.150	12.549	0.139	13.819	-1.976	0.716	0.114
26	29.700	70.950	9.500	10.497	0.118	13.603	-2.136	0.781	0.120
27	28.050	72.600	7.850	8.519	0.098	13.404	-2.327	0.858	0.127
28	27.225	73.425	7.025	7.556	0.087	13.072	-2.438	0.903	0.129
29	26.400	74.250	6.200	6.610	0.077	12.763	-2.563	0.954	0.131
30	25.575	75.075	5.375	5.680	0.067	12.475	-2.706	1.012	0.134
31	24.750	75.900	4.550	4.767	0.057	12.205	-2.873	1.079	0.139
32	24.750	75.900	4.550	4.767	0.057	11.824	-2.873	1.079	0.134

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 360 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} × 10 ⁹ (m ² /s)
0.0	100.586	0.000	78.048	355.534	1.000	0.000	0.000	-0.085	0
1.0	99.663	0.923	76.698	329.146	0.983	4.120	-0.017	-0.078	-19.27
2.0	99.106	1.480	76.141	319.131	0.976	3.302	-0.025	-0.075	-8.188
3.0	98.447	2.139	75.482	307.860	0.967	3.182	-0.033	-0.072	-4.316
4.0	97.861	2.725	74.896	298.338	0.960	3.041	-0.041	-0.068	-2.475
5.0	96.982	3.604	74.017	284.861	0.948	3.217	-0.053	-0.064	-1.066
6.0	96.469	4.117	73.504	277.412	0.942	3.062	-0.060	-0.061	-0.444
7.0	95.663	4.923	72.698	266.272	0.931	3.139	-0.071	-0.056	0.217
8.0	94.022	6.564	71.057	245.505	0.910	3.662	-0.094	-0.047	1.256
9.0	92.586	8.000	69.621	229.175	0.892	3.967	-0.114	-0.039	1.946
10.0	91.348	9.238	68.383	216.284	0.876	4.123	-0.132	-0.032	2.395
11.0	89.883	10.703	66.918	202.276	0.857	4.343	-0.154	-0.023	2.869
12.0	88.248	12.338	65.283	188.039	0.836	4.589	-0.179	-0.013	3.338
13.0	86.733	13.853	63.768	175.995	0.817	4.756	-0.202	-0.003	3.687
14.0	85.685	14.901	62.720	168.239	0.804	4.750	-0.219	0.003	3.813
15.0	83.802	16.784	60.837	155.344	0.779	4.994	-0.249	0.016	4.211
16.0	83.289	17.297	60.324	152.043	0.773	4.825	-0.258	0.019	4.115
17.0	81.604	18.982	58.639	141.775	0.751	4.983	-0.286	0.031	4.388
18.0	80.278	20.308	57.313	134.265	0.734	5.035	-0.309	0.040	4.527
19.0	78.645	21.941	55.680	125.630	0.713	5.154	-0.338	0.052	4.735
20.0	77.538	23.048	54.573	120.135	0.699	5.143	-0.358	0.060	4.786
21.0	75.231	25.355	52.266	109.493	0.670	5.388	-0.401	0.077	5.129
22.0	72.513	28.073	49.548	98.207	0.635	5.695	-0.454	0.099	5.538
23.0	71.033	29.553	48.068	92.559	0.616	5.734	-0.485	0.111	5.632
24.0	69.626	30.960	46.661	87.481	0.598	5.757	-0.514	0.123	5.702
25.0	68.835	31.751	45.870	84.741	0.588	5.668	-0.532	0.130	5.638
26.0	67.890	32.696	44.925	81.571	0.576	5.612	-0.552	0.139	5.611
27.0	66.315	34.271	43.350	76.522	0.555	5.665	-0.588	0.153	5.706
28.0	64.967	35.619	42.002	72.420	0.538	5.677	-0.620	0.166	5.752
29.0	63.997	36.589	41.032	69.583	0.526	5.631	-0.643	0.175	5.728
30.0	62.777	37.810	39.811	66.145	0.510	5.625	-0.673	0.188	5.748
31.0	61.824	38.762	38.859	63.557	0.498	5.580	-0.697	0.198	5.723
32.0	60.322	40.264	37.357	59.635	0.479	5.615	-0.737	0.213	5.788
33.0	59.077	41.509	36.112	56.523	0.463	5.614	-0.771	0.227	5.809
34.0	57.033	43.553	34.068	51.671	0.436	5.717	-0.829	0.251	5.950
35.0	55.194	45.392	32.229	47.556	0.413	5.788	-0.884	0.273	6.053
36.0	53.729	46.857	30.764	44.433	0.394	5.809	-0.931	0.292	6.097
37.0	52.300	48.286	29.335	41.513	0.376	5.824	-0.979	0.311	6.133
38.0	50.821	49.766	27.855	38.611	0.357	5.845	-1.030	0.332	6.174
39.0	49.993	50.593	27.028	37.038	0.346	5.790	-1.060	0.345	6.126
40.0	49.788	50.799	26.822	36.654	0.344	5.668	-1.068	0.348	5.999
41.0	48.249	52.337	25.284	33.840	0.324	5.697	-1.127	0.372	6.048

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 360 W

Thickness of drying bed 6 mm

Drying g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	105.000	0.000	83.940	497.758	1.000	0.000	0.000	-0.085	0.00
1	103.200	1.800	82.140	459.910	0.979	8.973	-0.022	-0.076	2.747
2	100.800	4.200	79.740	393.583	0.950	10.469	-0.051	-0.064	1.157
3	97.200	7.800	76.140	319.111	0.907	12.961	-0.098	-0.046	0.547
4	91.800	13.200	70.740	241.763	0.843	16.451	-0.171	-0.016	0.142
5	88.200	16.800	67.140	204.321	0.800	16.750	-0.223	0.005	0.038
6	84.000	21.000	62.940	169.833	0.750	17.448	-0.288	0.032	0.189
7	80.400	24.600	59.340	145.942	0.707	17.519	-0.347	0.055	0.285
8	78.000	27.000	56.940	132.234	0.678	16.825	-0.388	0.072	0.324
9	75.000	30.000	53.940	117.108	0.643	16.617	-0.442	0.094	0.376
10	72.600	32.400	51.540	106.356	0.614	16.152	-0.488	0.113	0.405
11	70.200	34.800	49.140	96.618	0.585	15.771	-0.535	0.132	0.431
12	66.000	39.000	44.940	81.620	0.535	16.201	-0.625	0.168	0.504
13	63.000	42.000	41.940	72.236	0.500	16.106	-0.694	0.196	0.543
14	60.000	45.000	38.940	63.773	0.464	16.023	-0.768	0.226	0.581
15	57.000	48.000	35.940	56.104	0.428	15.952	-0.848	0.259	0.620
16	54.000	51.000	32.940	49.120	0.392	15.890	-0.935	0.294	0.661
17	51.000	54.000	29.940	42.735	0.357	15.835	-1.031	0.333	0.704
18	48.600	56.400	27.540	38.007	0.328	15.620	-1.114	0.367	0.733
19	47.400	57.600	26.340	35.759	0.314	15.113	-1.159	0.385	0.728
20	46.200	58.800	25.140	33.583	0.299	14.656	-1.206	0.404	0.726
21	45.000	60.000	23.940	31.475	0.285	14.243	-1.255	0.423	0.725
22	43.800	61.200	22.740	29.433	0.271	13.867	-1.306	0.444	0.726
23	42.600	62.400	21.540	27.453	0.257	13.525	-1.360	0.466	0.729
24	41.400	63.600	20.340	25.534	0.242	13.210	-1.418	0.489	0.734
25	40.800	64.200	19.740	24.595	0.235	12.802	-1.447	0.502	0.722
26	39.000	66.000	17.940	21.862	0.214	12.654	-1.543	0.540	0.748
27	37.200	67.800	16.140	19.246	0.192	12.518	-1.649	0.583	0.777
28	36.000	69.000	14.940	17.564	0.178	12.285	-1.726	0.614	0.790
29	35.400	69.600	14.340	16.741	0.171	11.964	-1.767	0.631	0.783
30	34.800	70.200	13.740	15.929	0.164	11.665	-1.810	0.648	0.778
31	34.200	70.800	13.140	15.128	0.157	11.385	-1.854	0.666	0.774
32	33.600	71.400	12.540	14.338	0.149	11.123	-1.901	0.685	0.771
33	33.000	72.000	11.940	13.559	0.142	10.876	-1.950	0.705	0.769
34	32.400	72.600	11.340	12.790	0.135	10.645	-2.002	0.726	0.768
35	31.800	73.200	10.740	12.032	0.128	10.426	-2.056	0.748	0.769
36	31.200	73.800	10.140	11.284	0.121	10.219	-2.114	0.771	0.771
37	30.600	74.400	9.540	10.546	0.114	10.024	-2.175	0.796	0.774
38	30.000	75.000	8.940	9.818	0.107	9.839	-2.240	0.823	0.779
39	29.400	75.600	8.340	9.099	0.099	9.663	-2.309	0.851	0.785
40	28.200	76.800	7.140	7.689	0.085	9.571	-2.464	0.914	0.822
41	27.600	77.400	6.540	6.998	0.078	9.411	-2.552	0.949	0.833
42	27.000	78.000	5.940	6.315	0.071	9.258	-2.648	0.988	0.847
43	26.400	78.600	5.340	5.641	0.064	9.112	-2.755	1.031	0.863
44	25.800	79.200	4.740	4.976	0.056	8.973	-2.874	1.080	0.883
45	25.200	79.800	4.140	4.319	0.049	8.840	-3.009	1.135	0.907
46	25.200	79.800	4.140	4.319	0.049	8.648	-3.009	1.135	0.887

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 540 W

Thickness of drying bed 2 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0	103.478	0.000	82.720	478.704	1.000	0.000	0.000	-0.085	0.00
1	96.522	6.957	75.763	312.600	0.916	34.679	-0.088	-0.050	0.198
2	92.174	11.304	71.416	249.841	0.863	28.176	-0.147	-0.026	0.051
3	86.957	16.522	66.198	195.842	0.800	27.454	-0.223	0.005	0.006
4	82.609	20.870	61.850	162.126	0.748	26.009	-0.291	0.033	0.032
5	77.391	26.087	56.633	130.590	0.685	26.009	-0.379	0.068	0.054
6	72.174	31.304	51.416	105.827	0.622	26.009	-0.476	0.108	0.071
7	67.826	35.652	47.068	88.921	0.569	25.390	-0.564	0.143	0.081
8	62.609	40.870	41.850	71.970	0.506	25.467	-0.681	0.191	0.095
9	60.000	43.478	39.242	64.587	0.474	24.082	-0.746	0.217	0.096
10	58.261	45.217	37.503	60.007	0.453	22.541	-0.791	0.235	0.094
11	55.652	47.826	34.894	53.595	0.422	21.674	-0.863	0.265	0.096
12	52.174	51.304	31.416	45.806	0.380	21.313	-0.968	0.307	0.102
13	50.435	53.044	29.676	42.200	0.359	20.340	-1.025	0.330	0.101
14	46.087	57.391	25.329	33.920	0.306	20.436	-1.184	0.395	0.112
15	43.478	60.000	22.720	29.400	0.275	19.940	-1.292	0.439	0.117
16	40.870	62.609	20.111	25.174	0.243	19.507	-1.414	0.488	0.122
17	39.130	64.348	18.372	22.507	0.222	18.869	-1.505	0.525	0.123
18	36.522	66.957	15.763	18.713	0.191	18.543	-1.658	0.587	0.130
19	33.913	69.565	13.155	15.147	0.159	18.252	-1.839	0.660	0.139
20	31.304	72.174	10.546	11.789	0.127	17.990	-2.060	0.750	0.149
21	28.696	74.783	7.937	8.622	0.096	17.752	-2.344	0.865	0.164
22	26.957	76.522	6.198	6.608	0.075	17.339	-2.591	0.965	0.175
23	25.217	78.261	4.459	4.667	0.054	16.962	-2.921	1.099	0.191
24	24.348	79.130	3.590	3.723	0.043	16.436	-3.137	1.186	0.197
25	23.478	80.000	2.720	2.796	0.033	15.952	-3.415	1.299	0.207
26	22.609	80.870	1.850	1.885	0.022	15.505	-3.800	1.455	0.223

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 540 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0	103.750	0.000	82.940	486.166	1.000	0.000	0.000	-0.085	0.00
1	100.000	3.750	79.190	380.538	0.955	18.694	-0.046	-0.066	1.061
2	98.750	5.000	77.940	353.309	0.940	12.463	-0.062	-0.060	0.479
3	93.750	10.000	72.940	269.549	0.879	16.617	-0.128	-0.033	0.176
4	89.375	14.375	68.565	218.117	0.827	17.915	-0.190	-0.008	0.031
5	85.000	18.750	64.190	179.252	0.774	18.694	-0.256	0.019	0.060
6	81.250	22.500	60.440	152.781	0.729	18.694	-0.316	0.043	0.115
7	76.875	26.875	56.065	127.609	0.676	19.139	-0.392	0.074	0.168
8	73.125	30.625	52.315	109.710	0.631	19.083	-0.461	0.102	0.203
9	69.375	34.375	48.565	94.420	0.586	19.040	-0.535	0.132	0.234
10	65.625	38.125	44.815	81.209	0.540	19.005	-0.616	0.164	0.263
11	62.500	41.250	41.690	71.497	0.503	18.694	-0.688	0.194	0.281
12	59.375	44.375	38.565	62.774	0.465	18.434	-0.766	0.225	0.300
13	56.875	46.875	36.065	56.409	0.435	17.975	-0.833	0.252	0.310
14	54.375	49.375	33.565	50.523	0.405	17.581	-0.905	0.282	0.321
15	52.500	51.250	31.690	46.391	0.382	17.032	-0.962	0.305	0.325
16	50.000	53.750	29.190	41.223	0.352	16.747	-1.044	0.338	0.338
17	48.125	55.625	27.315	37.580	0.329	16.311	-1.111	0.365	0.343
18	45.625	58.125	24.815	33.005	0.299	16.098	-1.207	0.404	0.359
19	42.500	61.250	21.690	27.698	0.262	16.070	-1.341	0.458	0.386
20	40.000	63.750	19.190	23.747	0.231	15.890	-1.464	0.508	0.406
21	37.500	66.250	16.690	20.034	0.201	15.727	-1.603	0.565	0.430
22	35.000	68.750	14.190	16.537	0.171	15.578	-1.766	0.630	0.458
23	33.125	70.625	12.315	14.045	0.148	15.307	-1.907	0.688	0.478
24	31.250	72.500	10.440	11.657	0.126	15.059	-2.072	0.755	0.503
25	28.750	75.000	7.940	8.625	0.096	14.955	-2.346	0.866	0.554
26	26.875	76.875	6.065	6.457	0.073	14.739	-2.616	0.975	0.600
27	25.625	78.125	4.815	5.059	0.058	14.424	-2.846	1.068	0.633
28	23.750	80.000	2.940	3.029	0.035	14.243	-3.340	1.268	0.724
29	23.125	80.625	2.315	2.370	0.028	13.859	-3.579	1.365	0.753

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 540 W

Thickness of drying bed 6 mm

Drying g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	100.000	0.000	79.940	398.504	1.000	0.000	0.000	-0.085	0.000
1	97.627	2.373	77.567	345.772	0.970	11.830	-0.030	-0.073	2.624
2	93.074	6.927	73.014	270.556	0.913	17.264	-0.091	-0.048	0.870
3	89.640	10.361	69.580	228.726	0.870	17.216	-0.139	-0.029	0.346
4	82.552	17.448	62.492	166.610	0.782	21.745	-0.246	0.015	0.132
5	79.500	20.500	59.440	146.548	0.744	20.439	-0.296	0.035	0.251
6	76.500	23.500	56.440	129.568	0.706	19.525	-0.348	0.056	0.335
7	73.513	26.488	53.453	114.834	0.669	18.863	-0.402	0.078	0.401
8	70.500	29.500	50.440	101.776	0.631	18.382	-0.460	0.102	0.456
9	67.500	32.500	47.440	90.259	0.593	18.002	-0.522	0.126	0.505
10	65.435	34.565	45.375	83.066	0.568	17.231	-0.566	0.144	0.519
11	62.500	37.500	42.440	73.732	0.531	16.994	-0.633	0.172	0.561
12	60.370	39.630	40.310	67.532	0.504	16.463	-0.685	0.192	0.577
13	57.000	43.000	36.940	58.579	0.462	16.489	-0.772	0.228	0.630
14	54.824	45.177	34.764	53.288	0.435	16.086	-0.833	0.252	0.648
15	52.000	48.000	31.940	46.929	0.400	15.952	-0.917	0.287	0.688
16	49.577	50.423	29.517	41.878	0.369	15.710	-0.996	0.319	0.717
17	47.979	52.022	27.919	38.732	0.349	15.255	-1.052	0.341	0.722
18	45.000	55.000	24.940	33.227	0.312	15.232	-1.165	0.387	0.773
19	43.000	57.000	22.940	29.769	0.287	14.955	-1.248	0.421	0.797
20	41.205	58.795	21.145	26.815	0.265	14.655	-1.330	0.454	0.816
21	39.000	61.000	18.940	23.365	0.237	14.480	-1.440	0.498	0.854
22	37.225	62.775	17.165	20.722	0.215	14.224	-1.538	0.538	0.881
23	34.500	65.500	14.440	16.877	0.181	14.197	-1.711	0.608	0.952
24	32.210	67.790	12.150	13.830	0.152	14.081	-1.884	0.678	1.017
25	30.000	70.000	9.940	11.037	0.124	13.958	-2.085	0.760	1.094
26	28.375	71.625	8.315	9.069	0.104	13.733	-2.263	0.832	1.152
27	26.345	73.655	6.285	6.707	0.079	13.599	-2.543	0.946	1.260
28	24.177	75.823	4.117	4.294	0.052	13.499	-2.966	1.117	1.436
29	23.105	76.895	3.045	3.141	0.038	13.218	-3.268	1.239	1.538
30	22.575	77.425	2.515	2.580	0.031	12.866	-3.459	1.317	1.580
31	22.020	77.980	1.960	1.999	0.025	12.540	-3.708	1.418	1.646

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 720 W

Thickness of drying bed 2 mm

Drying g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	103.350	0.000	82.610	475.043	1.000	0.000	0.000	-0.085	0.000
1	99.450	3.900	78.710	369.704	0.953	19.442	-0.048	-0.066	0.262
2	95.550	7.800	74.810	296.983	0.906	19.442	-0.099	-0.045	0.089
3	88.725	14.625	67.985	212.354	0.823	24.302	-0.195	-0.006	0.008
4	84.825	18.525	64.085	178.435	0.776	23.087	-0.254	0.018	0.017
5	78.975	24.375	58.235	139.435	0.705	24.302	-0.350	0.057	0.045
6	74.100	29.250	53.360	114.408	0.646	24.302	-0.437	0.092	0.061
7	72.150	31.200	51.410	105.804	0.622	22.219	-0.474	0.107	0.061
8	69.225	34.125	48.485	94.118	0.587	21.264	-0.533	0.131	0.065
9	66.300	37.050	45.560	83.688	0.552	20.522	-0.595	0.156	0.069
10	63.375	39.975	42.635	74.322	0.516	19.928	-0.661	0.183	0.07
11	58.500	44.850	37.760	60.668	0.457	20.325	-0.783	0.232	0.084
12	54.600	48.750	33.860	51.194	0.410	20.252	-0.892	0.276	0.09
13	51.675	51.675	30.935	44.791	0.374	19.816	-0.982	0.313	0.096
14	48.750	54.600	28.010	38.908	0.339	19.442	-1.082	0.353	0.100
15	45.825	57.525	25.085	33.485	0.304	19.118	-1.192	0.398	0.106
16	41.925	61.425	21.185	26.879	0.256	19.138	-1.361	0.466	0.116
17	39.975	63.375	19.235	23.816	0.233	18.584	-1.457	0.506	0.119
18	37.050	66.300	16.310	19.489	0.197	18.362	-1.622	0.572	0.127
19	34.125	69.225	13.385	15.453	0.162	18.163	-1.820	0.652	0.137
20	32.175	71.175	11.435	12.911	0.138	17.741	-1.977	0.716	0.143
21	30.225	73.125	9.485	10.479	0.115	17.359	-2.164	0.792	0.150
22	28.275	75.075	7.535	8.149	0.091	17.011	-2.395	0.885	0.161
23	24.375	78.975	3.635	3.772	0.044	17.117	-3.124	1.181	0.205
23.5	23.400	79.950	2.660	2.733	0.032	16.960	-3.436	1.307	0.222
24	23.400	79.950	2.660	2.733	0.032	16.606	-3.436	1.307	0.217

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 720 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) db	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	108.000	0.000	86.335	631.797	1.000	0.000	0.000	-0.085	0.0000
1	104.667	3.333	83.002	488.293	0.961	16.617	-0.039	-0.069	1.1065
2	99.333	8.667	77.668	347.795	0.900	21.602	-0.106	-0.042	0.3379
3	91.333	16.667	69.668	229.688	0.807	27.695	-0.214	0.002	0.0097
4	86.000	22.000	64.335	180.387	0.745	27.418	-0.294	0.034	0.1364
5	79.333	28.667	57.668	136.230	0.668	28.581	-0.404	0.078	0.2510
6	74.667	33.333	53.002	112.774	0.614	27.695	-0.488	0.113	0.3003
7	70.000	38.000	48.335	93.555	0.560	27.062	-0.580	0.150	0.3428
8	65.333	42.667	43.668	77.520	0.506	26.587	-0.682	0.191	0.3823
9	60.000	48.000	38.335	62.167	0.444	26.587	-0.812	0.244	0.4336
10	56.667	51.333	35.002	53.850	0.405	25.590	-0.903	0.281	0.4493
11	53.333	54.667	31.668	46.345	0.367	24.774	-1.003	0.321	0.4674
12	50.000	58.000	28.335	39.538	0.328	24.094	-1.114	0.366	0.4886
13	46.667	61.333	25.002	33.336	0.290	23.519	-1.239	0.417	0.5134
14	43.333	64.667	21.668	27.662	0.251	23.026	-1.382	0.475	0.5430
15	41.333	66.667	19.668	24.484	0.228	22.156	-1.479	0.514	0.5487
16	40.000	68.000	18.335	22.451	0.212	21.186	-1.549	0.543	0.5428
17	38.000	70.000	16.335	19.524	0.189	20.527	-1.665	0.590	0.5550
18	36.667	71.333	15.002	17.649	0.174	19.756	-1.750	0.624	0.5548
19	33.333	74.667	11.668	13.210	0.135	19.590	-2.001	0.726	0.6114
20	30.667	77.333	9.002	9.892	0.104	19.276	-2.261	0.831	0.6649
21	29.333	78.667	7.668	8.305	0.089	18.674	-2.421	0.896	0.6828
22	28.000	80.000	6.335	6.763	0.073	18.127	-2.612	0.974	0.7080
23	26.667	81.333	5.002	5.265	0.058	17.628	-2.848	1.069	0.7439
24	25.333	82.667	3.668	3.808	0.042	17.171	-3.158	1.195	0.7966
25	24.667	83.333	3.002	3.095	0.035	16.617	-3.359	1.276	0.8168

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 720 W

Thickness of drying bed 6 mm

Drying g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	103.800	0.000	82.980	487.544	1.000	0.000	0.000	-0.085	0.00
1	99.000	4.800	78.180	358.295	0.942	23.928	-0.060	-0.061	2.194
2	94.200	9.600	73.380	275.657	0.884	23.928	-0.123	-0.035	0.635
3	88.200	15.600	67.380	206.560	0.812	25.922	-0.208	-0.001	0.008
4	81.000	22.800	60.180	151.130	0.725	28.415	-0.321	0.045	0.40
5	74.400	29.400	53.580	115.424	0.646	29.312	-0.437	0.092	0.663
6	68.400	35.400	47.580	90.767	0.573	29.412	-0.556	0.140	0.84
7	66.000	37.800	45.180	82.415	0.544	26.919	-0.608	0.161	0.829
8	63.000	40.800	42.180	72.951	0.508	25.424	-0.677	0.189	0.851
9	58.800	45.000	37.980	61.238	0.458	24.925	-0.782	0.232	0.92
10	55.200	48.600	34.380	52.393	0.414	24.227	-0.881	0.272	0.979
11	51.000	52.800	30.180	43.225	0.364	23.928	-1.011	0.325	1.063
12	47.400	56.400	26.580	36.203	0.320	23.430	-1.138	0.376	1.128
13	45.000	58.800	24.180	31.891	0.291	22.548	-1.233	0.415	1.148
14	42.000	61.800	21.180	26.871	0.255	22.005	-1.366	0.468	1.20
15	39.600	64.200	18.780	23.122	0.226	21.336	-1.486	0.517	1.240
16	37.200	66.600	16.380	19.589	0.197	20.750	-1.623	0.572	1.28
17	34.200	69.600	13.380	15.447	0.161	20.409	-1.825	0.654	1.385
18	33.600	70.200	12.780	14.653	0.154	19.442	-1.871	0.673	1.346
19	32.400	71.400	11.580	13.097	0.140	18.733	-1.969	0.713	1.35
20	31.200	72.600	10.380	11.582	0.125	18.096	-2.079	0.757	1.363
21	29.400	74.400	8.580	9.385	0.103	17.661	-2.269	0.835	1.430
22	28.200	75.600	7.380	7.968	0.089	17.130	-2.420	0.896	1.465
23	27.600	76.200	6.780	7.273	0.082	16.516	-2.505	0.930	1.455
24	27.000	76.800	6.180	6.587	0.074	15.952	-2.597	0.968	1.451
25	25.800	78.000	4.980	5.241	0.060	15.553	-2.813	1.055	1.51
26	25.200	78.600	4.380	4.581	0.053	15.070	-2.942	1.107	1.532
27	24.000	79.800	3.180	3.284	0.038	14.734	-3.262	1.237	1.649
28	22.800	81.000	1.980	2.020	0.024	14.421	-3.736	1.429	1.837
29	22.200	81.600	1.380	1.399	0.017	14.027	-4.097	1.575	1.955

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 900 W

Thickness of drying bed 2 mm

Drying g time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	103.350	0.000	82.620	475.374	1.000	0.000	0.000	-0.085	0.000
1	100.425	2.925	79.695	392.490	0.965	14.581	-0.036	-0.071	0.282
2	93.600	9.750	72.870	268.596	0.882	24.302	-0.126	-0.034	0.068
3	86.775	16.575	66.045	194.507	0.799	27.542	-0.224	0.006	0.007
4	81.900	21.450	61.170	157.533	0.740	26.732	-0.301	0.037	0.036
5	75.075	28.275	54.345	119.034	0.658	28.190	-0.419	0.085	0.067
6	69.225	34.125	48.495	94.156	0.587	28.352	-0.533	0.131	0.087
7	62.400	40.950	41.670	71.438	0.504	29.163	-0.684	0.192	0.109
8	56.550	46.800	35.820	55.812	0.434	29.163	-0.836	0.254	0.126
9	51.675	51.675	30.945	44.812	0.375	28.622	-0.982	0.313	0.139
10	45.825	57.525	25.095	33.502	0.304	28.676	-1.192	0.398	0.159
11	43.875	59.475	23.145	30.115	0.280	26.953	-1.272	0.431	0.156
11.5	40.950	62.400	20.220	25.345	0.245	27.049	-1.408	0.485	0.168
12	39.000	64.350	18.270	22.354	0.221	26.732	-1.509	0.526	0.175
12.5	37.050	66.300	16.320	19.503	0.198	26.441	-1.622	0.572	0.183
13	35.100	68.250	14.370	16.782	0.174	26.171	-1.749	0.624	0.19
13.5	33.150	70.200	12.420	14.181	0.150	25.922	-1.895	0.683	0.202
14	32.175	71.175	11.445	12.924	0.139	25.344	-1.977	0.716	0.204
14.5	31.200	72.150	10.470	11.694	0.127	24.805	-2.066	0.752	0.207
15	30.225	73.125	9.495	10.491	0.115	24.302	-2.163	0.792	0.211
15.5	29.250	74.100	8.520	9.314	0.103	23.832	-2.272	0.836	0.215
16	28.275	75.075	7.545	8.161	0.091	23.391	-2.393	0.885	0.221
16.5	27.300	76.050	6.570	7.032	0.080	22.977	-2.532	0.941	0.228
17	25.350	78.000	4.620	4.844	0.056	22.873	-2.884	1.084	0.255
17.5	24.375	78.975	3.645	3.783	0.044	22.497	-3.121	1.180	0.269
18	23.400	79.950	2.670	2.743	0.032	22.142	-3.432	1.306	0.290

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 900 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	101.250	0.000	80.940	424.659	1.000	0.000	0.000	-0.085	0.000
1	97.500	3.750	77.190	338.404	0.954	18.694	-0.047	-0.066	1.054
2	90.625	10.625	70.315	236.870	0.869	26.483	-0.141	-0.028	0.224
3	83.750	17.500	63.440	173.523	0.784	29.079	-0.244	0.014	0.072
4	76.250	25.000	55.940	126.963	0.691	31.157	-0.369	0.065	0.258
5	70.000	31.250	49.690	98.768	0.614	31.157	-0.488	0.113	0.360
6	64.375	36.875	44.065	78.779	0.544	30.637	-0.608	0.161	0.430
7	60.000	41.250	39.690	65.810	0.490	29.376	-0.713	0.204	0.465
8	55.625	45.625	35.315	54.595	0.436	28.430	-0.829	0.251	0.50
9	51.250	50.000	30.940	44.802	0.382	27.695	-0.962	0.305	0.541
10	47.500	53.750	27.190	37.344	0.336	26.795	-1.091	0.357	0.571
11	43.750	57.500	23.440	30.617	0.290	26.058	-1.239	0.417	0.606
12	40.625	60.625	20.315	25.494	0.251	25.185	-1.382	0.475	0.633
13	38.125	63.125	17.815	21.677	0.220	24.206	-1.514	0.528	0.650
13.5	36.250	65.000	15.940	18.963	0.197	24.002	-1.625	0.573	0.679
14	35.625	65.625	15.315	18.085	0.189	23.367	-1.665	0.590	0.673
14.5	35.000	66.250	14.690	17.220	0.181	22.776	-1.707	0.607	0.669
15	33.750	67.500	13.440	15.527	0.166	22.433	-1.795	0.643	0.685
15.5	33.125	68.125	12.815	14.699	0.158	21.910	-1.843	0.662	0.683
16	31.875	69.375	11.565	13.077	0.143	21.615	-1.946	0.703	0.703
16.5	30.000	71.250	9.690	10.730	0.120	21.526	-2.123	0.775	0.751
17	28.750	72.500	8.440	9.218	0.104	21.260	-2.261	0.831	0.782
17.5	27.500	73.750	7.190	7.747	0.089	21.008	-2.421	0.896	0.819
18	26.250	75.000	5.940	6.315	0.073	20.771	-2.612	0.973	0.865
18.5	25.000	76.250	4.690	4.921	0.058	20.546	-2.848	1.069	0.924
19	24.375	76.875	4.065	4.237	0.050	20.170	-2.991	1.127	0.949
19.5	23.125	78.125	2.815	2.897	0.035	19.972	-3.359	1.276	1.047
20	22.500	78.750	2.190	2.239	0.027	19.629	-3.610	1.378	1.102

Data on Microwave drying of foamed Nagpur mandarin juice

Microwave power 900 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0	100.000	0.000	79.940	398.504	1.000	0.000	0.000	-0.085	0.000
1	96.000	4.000	75.940	315.628	0.950	19.940	-0.051	-0.064	2.315
2	94.500	5.500	74.440	291.236	0.931	13.709	-0.071	-0.056	1.012
3	90.000	10.000	69.940	232.668	0.875	16.617	-0.134	-0.031	0.371
4	86.000	14.000	65.940	193.600	0.825	17.448	-0.193	-0.007	0.063
5	82.500	17.500	62.440	166.241	0.781	17.448	-0.247	0.015	0.108
6	79.500	20.500	59.440	146.548	0.744	17.032	-0.296	0.035	0.209
7	75.000	25.000	54.940	121.926	0.687	17.804	-0.375	0.067	0.343
8	71.000	29.000	50.940	103.832	0.637	18.071	-0.451	0.098	0.438
9	67.000	33.000	46.940	88.466	0.587	18.278	-0.532	0.131	0.522
10	62.500	37.500	42.440	73.732	0.531	18.694	-0.633	0.172	0.617
11	59.500	40.500	39.440	65.125	0.493	18.354	-0.706	0.201	0.658
12	56.500	43.500	36.440	57.332	0.456	18.071	-0.786	0.233	0.699
13	53.000	47.000	32.940	49.120	0.412	18.023	-0.887	0.274	0.759
14	50.000	50.000	29.940	42.735	0.375	17.804	-0.982	0.313	0.804
15	47.000	53.000	26.940	36.874	0.337	17.614	-1.088	0.356	0.853
16	44.000	56.000	23.940	31.475	0.299	17.448	-1.206	0.404	0.908
17	41.000	59.000	20.940	26.486	0.262	17.301	-1.340	0.458	0.969
18	37.500	62.500	17.440	21.124	0.218	17.309	-1.523	0.532	1.063
19	35.000	65.000	14.940	17.564	0.187	17.054	-1.677	0.595	1.126
20	32.500	67.500	12.440	14.207	0.156	16.825	-1.860	0.669	1.203
21	30.500	69.500	10.440	11.657	0.131	16.498	-2.036	0.740	1.268
22	29.000	71.000	8.940	9.818	0.112	16.088	-2.191	0.803	1.313
22.5	27.500	72.500	7.440	8.038	0.093	16.063	-2.374	0.877	1.403
23	26.000	74.000	5.940	6.315	0.074	16.039	-2.600	0.968	1.515
23.5	25.000	75.000	4.940	5.197	0.062	15.910	-2.784	1.043	1.598
24	24.000	76.000	3.940	4.102	0.049	15.786	-3.010	1.135	1.702
24.5	23.500	76.500	3.440	3.563	0.043	15.566	-3.146	1.190	1.748
25	23.000	77.000	2.940	3.029	0.037	15.354	-3.303	1.253	1.805

APPENDIX – C

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 180 W

Thickness of drying bed 2 mm

Initial moisture content of foamed juice is 77.593% (wb)

BDM = 20.06 g/100g

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) (wb)	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0.0	100.00	0.000	77.593	346.289	1.000	0.000	0.000	-0.085	0.000
1.0	99.768	0.232	77.389	342.263	0.997	1.035	-0.003	-0.084	25.223
2.0	99.010	0.990	76.631	327.917	0.988	2.209	-0.012	-0.080	10.630
3.0	98.400	1.600	76.021	317.032	0.980	2.380	-0.020	-0.077	6.023
4.0	97.100	2.900	74.721	295.585	0.963	3.236	-0.038	-0.070	2.818
5.0	96.450	3.550	74.071	285.669	0.955	3.169	-0.046	-0.066	1.574
6.0	95.400	4.600	73.021	270.659	0.941	3.422	-0.061	-0.061	0.397
7.0	94.100	5.900	71.721	253.619	0.924	3.762	-0.079	-0.053	0.630
8.0	93.690	6.310	71.311	248.566	0.919	3.520	-0.084	-0.051	0.819
9.0	92.010	7.990	69.631	229.283	0.897	3.962	-0.108	-0.041	1.704
10.0	90.390	9.610	68.011	212.607	0.877	4.289	-0.132	-0.032	2.381
11.0	89.410	10.590	67.031	203.315	0.864	4.297	-0.146	-0.026	2.630
12.0	87.210	12.790	64.831	184.341	0.836	4.757	-0.180	-0.012	3.369
13.0	86.010	13.990	63.631	174.959	0.820	4.803	-0.198	-0.005	3.593
14.0	85.420	14.580	63.041	170.570	0.812	4.648	-0.208	-0.001	3.556
15.0	84.345	15.655	61.966	162.923	0.799	4.658	-0.225	0.006	3.694
16.0	83.680	16.320	61.301	158.405	0.790	4.552	-0.236	0.010	3.680
17.0	82.370	17.630	59.991	149.944	0.773	4.628	-0.257	0.019	3.867
18.0	81.395	18.605	59.016	143.998	0.761	4.613	-0.274	0.026	3.935
19.0	80.345	19.655	57.966	137.903	0.747	4.617	-0.292	0.033	4.017
20.0	79.870	20.130	57.491	135.244	0.741	4.492	-0.300	0.036	3.940
21.0	78.254	21.746	55.875	126.629	0.720	4.621	-0.328	0.048	4.155
22.0	76.950	23.050	54.571	120.124	0.703	4.676	-0.352	0.058	4.276
23.0	75.100	24.900	52.721	111.510	0.679	4.832	-0.386	0.072	4.511
24.0	74.689	25.311	52.310	109.688	0.674	4.707	-0.394	0.075	4.412
25.0	73.345	26.655	50.966	103.940	0.657	4.758	-0.420	0.085	4.517
26.0	72.100	27.900	49.721	98.890	0.641	4.789	-0.445	0.095	4.593
27.0	71.640	28.360	49.261	97.087	0.635	4.688	-0.454	0.099	4.512
28.0	70.030	29.970	47.651	91.026	0.614	4.777	-0.488	0.112	4.652
29.0	69.040	30.960	46.661	87.480	0.601	4.765	-0.509	0.121	4.670
30.0	68.020	31.980	45.641	83.962	0.588	4.757	-0.531	0.130	4.692
31.0	66.380	33.620	44.001	78.575	0.567	4.840	-0.567	0.145	4.817
32.0	64.960	35.040	42.581	74.158	0.549	4.887	-0.600	0.158	4.899
33.0	63.400	36.600	41.021	69.552	0.529	4.950	-0.637	0.173	4.997
34.0	62.745	37.255	40.366	67.690	0.520	4.890	-0.653	0.180	4.951
35.0	61.080	38.920	38.701	63.135	0.499	4.963	-0.696	0.197	5.058
36.0	60.390	39.610	38.011	61.319	0.490	4.910	-0.714	0.204	5.018
37.0	59.640	40.360	37.261	59.390	0.480	4.868	-0.734	0.212	4.988
38.0	58.960	41.040	36.581	57.681	0.471	4.820	-0.752	0.220	4.951
39.0	57.345	42.655	34.966	53.766	0.451	4.881	-0.797	0.238	5.040
40.0	56.960	43.040	34.581	52.861	0.446	4.802	-0.808	0.242	4.965

41.0	56.040	43.960	33.661	50.741	0.434	4.785	-0.835	0.253	4.961
42.0	55.700	44.300	33.321	49.972	0.429	4.707	-0.845	0.257	4.885
43.0	54.500	45.500	32.121	47.321	0.414	4.722	-0.882	0.272	4.917
44.0	53.047	46.953	30.668	44.234	0.395	4.762	-0.928	0.291	4.978
45.0	52.420	47.580	30.041	42.941	0.387	4.719	-0.949	0.299	4.940
46.0	51.240	48.760	28.861	40.570	0.372	4.731	-0.989	0.316	4.967
47.0	50.690	49.310	28.311	39.491	0.365	4.682	-1.008	0.324	4.923
48.0	49.850	50.150	27.471	37.876	0.354	4.663	-1.038	0.336	4.912
49.0	49.050	50.950	26.671	36.372	0.344	4.640	-1.068	0.348	4.897
50.0	48.103	51.897	25.724	34.633	0.332	4.632	-1.104	0.362	4.898
51.0	46.864	53.136	24.485	32.424	0.316	4.650	-1.153	0.382	4.929
52.0	46.250	53.750	23.871	31.356	0.308	4.613	-1.179	0.393	4.896
53.0	45.890	54.110	23.511	30.738	0.303	4.556	-1.194	0.399	4.839
54.0	45.680	54.320	23.301	30.380	0.300	4.489	-1.203	0.402	4.770
55.0	45.010	54.990	22.631	29.251	0.292	4.462	-1.232	0.414	4.746
56.0	44.380	55.620	22.001	28.207	0.284	4.433	-1.260	0.426	4.721
57.0	43.670	56.330	21.291	27.050	0.274	4.410	-1.293	0.439	4.703
58.0	42.960	57.040	20.581	25.914	0.265	4.389	-1.327	0.453	4.686
59.0	42.680	57.320	20.301	25.472	0.262	4.336	-1.341	0.458	4.631
60.0	42.010	57.990	19.631	24.426	0.253	4.313	-1.374	0.472	4.612
61.0	41.390	58.610	19.011	23.474	0.245	4.288	-1.406	0.485	4.590
62.0	40.980	59.020	18.601	22.852	0.240	4.248	-1.428	0.494	4.550
63.0	40.340	59.660	17.961	21.893	0.231	4.226	-1.463	0.508	4.531
64.0	39.670	60.330	17.291	20.906	0.223	4.207	-1.501	0.523	4.515
65.0	39.000	61.000	16.621	19.934	0.214	4.188	-1.541	0.539	4.500
66.0	38.470	61.530	16.091	19.177	0.207	4.161	-1.573	0.552	4.473
67.0	38.392	61.608	16.013	19.066	0.206	4.104	-1.578	0.554	4.413
68.0	37.940	62.060	15.561	18.429	0.201	4.073	-1.607	0.566	4.383
69.0	37.100	62.900	14.721	17.262	0.190	4.068	-1.662	0.589	4.383
70.0	36.450	63.550	14.071	16.375	0.181	4.052	-1.707	0.607	4.369
71.0	35.960	64.040	13.581	15.715	0.175	4.025	-1.743	0.621	4.343
72.0	35.500	64.500	13.121	15.103	0.169	3.998	-1.777	0.635	4.316
73.0	35.030	64.970	12.651	14.483	0.163	3.972	-1.814	0.650	4.291
74.0	34.590	65.410	12.211	13.909	0.157	3.945	-1.849	0.664	4.264
75.0	34.370	65.630	11.991	13.625	0.155	3.905	-1.867	0.672	4.222
76.0	34.100	65.900	11.721	13.277	0.151	3.870	-1.890	0.681	4.185

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 180 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0.0	100.200	0.000	77.748	349.402	1.000	0.000	0.000	-0.085	0.000
1.0	99.814	0.386	77.235	339.271	0.993	1.723	-0.007	-0.082	23.61
2.0	99.010	1.190	76.431	324.286	0.983	2.655	-0.017	-0.078	9.708
3.0	98.340	1.860	75.761	312.558	0.974	2.767	-0.026	-0.075	5.306
4.0	97.420	2.780	74.841	297.472	0.963	3.102	-0.038	-0.070	2.780
5.0	96.470	3.730	73.891	283.010	0.950	3.329	-0.051	-0.064	1.232
6.0	95.340	4.860	72.761	267.121	0.936	3.615	-0.066	-0.058	0.044
7.0	94.391	5.809	71.812	254.761	0.924	3.704	-0.079	-0.053	0.669
8.0	93.430	6.770	70.851	243.065	0.911	3.777	-0.093	-0.047	1.212
9.0	92.348	7.852	69.769	230.786	0.897	3.894	-0.108	-0.041	1.705
10.0	91.980	8.220	69.401	226.808	0.893	3.668	-0.114	-0.039	1.726
11.0	90.140	10.060	67.561	208.271	0.869	4.082	-0.140	-0.028	2.442
12.0	89.140	11.060	66.561	199.052	0.856	4.113	-0.155	-0.022	2.673
13.0	88.394	11.806	65.815	192.526	0.847	4.053	-0.167	-0.018	2.767
14.0	87.140	13.060	64.561	182.175	0.830	4.163	-0.186	-0.010	3.037
15.0	85.478	14.722	62.899	169.535	0.809	4.380	-0.212	0.001	3.413
16.0	84.370	15.830	61.791	161.718	0.795	4.415	-0.230	0.008	3.561
17.0	83.024	17.176	60.445	152.813	0.777	4.509	-0.252	0.017	3.764
18.0	81.397	18.803	58.818	142.825	0.757	4.662	-0.279	0.028	4.027
19.0	80.100	20.100	57.521	135.410	0.740	4.721	-0.301	0.037	4.171
20.0	79.045	21.155	56.466	129.706	0.726	4.721	-0.320	0.045	4.238
21.0	77.680	22.520	55.101	122.722	0.709	4.786	-0.344	0.054	4.375
22.0	76.034	24.166	53.455	114.846	0.688	4.902	-0.375	0.067	4.567
23.0	74.691	25.509	52.112	108.821	0.670	4.950	-0.400	0.077	4.673
24.0	73.689	26.511	51.110	104.541	0.657	4.930	-0.419	0.085	4.696
25.0	72.540	27.660	49.961	99.844	0.643	4.938	-0.442	0.094	4.748
26.0	71.395	28.805	48.816	95.374	0.628	4.944	-0.465	0.104	4.795
27.0	70.450	29.750	47.871	91.832	0.616	4.917	-0.485	0.111	4.800
28.0	69.960	30.240	47.381	90.045	0.609	4.820	-0.495	0.116	4.720
29.0	69.030	31.170	46.451	86.745	0.597	4.797	-0.515	0.124	4.724
30.0	68.150	32.050	45.571	83.726	0.586	4.768	-0.534	0.131	4.720
31.0	67.438	32.762	44.859	81.353	0.577	4.717	-0.550	0.138	4.688
32.0	66.104	34.096	43.525	77.069	0.560	4.755	-0.580	0.150	4.759
33.0	65.740	34.460	43.161	75.936	0.555	4.660	-0.589	0.153	4.672
34.0	65.204	34.996	42.625	74.292	0.548	4.594	-0.601	0.158	4.617
35.0	64.687	35.513	42.108	72.735	0.542	4.528	-0.613	0.163	4.562
36.0	64.000	36.200	41.421	70.710	0.533	4.488	-0.630	0.170	4.535
37.0	63.410	36.790	40.831	69.007	0.525	4.438	-0.644	0.176	4.495
38.0	62.980	37.220	40.401	67.788	0.520	4.371	-0.655	0.180	4.436
39.0	62.398	37.802	39.819	66.165	0.512	4.326	-0.669	0.186	4.400
40.0	61.387	38.813	38.808	63.420	0.499	4.330	-0.695	0.196	4.422
41.0	60.870	39.330	38.291	62.051	0.493	4.281	-0.708	0.202	4.380
42.0	59.960	40.240	37.381	59.696	0.481	4.276	-0.732	0.212	4.389
43.0	59.290	40.910	36.711	58.005	0.472	4.246	-0.750	0.219	4.368
44.0	58.480	41.720	35.901	56.009	0.462	4.232	-0.773	0.228	4.365

45.0	57.680	42.520	35.101	54.086	0.451	4.217	-0.795	0.237	4.361
46.0	57.000	43.200	34.421	52.488	0.443	4.191	-0.815	0.245	4.343
47.0	56.290	43.910	33.711	50.855	0.434	4.169	-0.836	0.254	4.329
48.0	55.380	44.820	32.801	48.812	0.422	4.167	-0.863	0.265	4.338
49.0	54.960	45.240	32.381	47.887	0.416	4.120	-0.876	0.270	4.294
50.0	54.280	45.920	31.701	46.415	0.408	4.099	-0.897	0.278	4.279
51.0	53.280	46.920	30.701	44.302	0.395	4.106	-0.929	0.291	4.298
52.0	52.840	47.360	30.261	43.392	0.389	4.065	-0.944	0.297	4.259
53.0	52.100	48.100	29.521	41.886	0.380	4.050	-0.968	0.307	4.252
54.0	51.678	48.522	29.099	41.042	0.374	4.010	-0.983	0.313	4.214
55.0	51.080	49.120	28.501	39.862	0.367	3.986	-1.004	0.322	4.194
56.0	50.340	49.860	27.761	38.429	0.357	3.974	-1.030	0.332	4.188
57.0	49.389	50.811	26.810	36.631	0.345	3.978	-1.065	0.346	4.201
58.0	48.395	51.805	25.816	34.800	0.332	3.986	-1.102	0.362	4.218
59.0	47.345	52.855	24.766	32.919	0.319	3.998	-1.144	0.379	4.240
60.0	46.487	53.713	23.908	31.420	0.308	3.995	-1.179	0.393	4.244
61.0	45.347	54.853	22.768	29.480	0.293	4.013	-1.228	0.413	4.272
62.0	44.395	55.805	21.816	27.903	0.281	4.017	-1.271	0.430	4.283
63.0	43.647	56.553	21.068	26.691	0.271	4.006	-1.306	0.444	4.277
64.0	42.330	57.870	19.751	24.612	0.254	4.035	-1.370	0.470	4.317
65.0	41.390	58.810	18.811	23.169	0.242	4.038	-1.419	0.490	4.326
66.0	40.968	59.232	18.389	22.533	0.237	4.005	-1.442	0.499	4.294
67.0	39.960	60.240	17.381	21.038	0.224	4.013	-1.498	0.522	4.309
68.0	38.689	61.511	16.110	19.204	0.207	4.037	-1.574	0.553	4.343
69.0	37.890	62.310	15.311	18.079	0.197	4.030	-1.625	0.573	4.340
70.0	37.100	63.100	14.521	16.988	0.187	4.023	-1.678	0.595	4.337
71.0	36.850	63.350	14.271	16.647	0.184	3.982	-1.695	0.602	4.294
72.0	36.040	64.160	13.461	15.555	0.173	3.977	-1.754	0.626	4.294
73.0	35.140	65.060	12.561	14.365	0.162	3.977	-1.823	0.654	4.299
74.0	34.880	65.320	12.301	14.026	0.158	3.939	-1.844	0.662	4.259
75.0	34.500	65.700	11.921	13.534	0.153	3.909	-1.875	0.675	4.229
76.0	34.020	66.180	11.441	12.919	0.147	3.886	-1.916	0.692	4.206
77.0	33.890	66.310	11.311	12.754	0.145	3.843	-1.928	0.696	4.160
78.0	33.500	66.700	10.921	12.260	0.140	3.816	-1.963	0.710	4.133
79.0	33.210	66.990	10.631	11.896	0.137	3.784	-1.990	0.721	4.100

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 180 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0.0	100.59	0.000	78.051	355.597	1.000	0.000	0.000	-0.085	0.000
1.0	99.698	0.892	76.729	329.719	0.983	3.981	-0.017	-0.078	19.48
2.0	98.960	1.630	75.991	316.510	0.974	3.637	-0.027	-0.074	7.790
3.0	98.000	2.590	75.031	300.497	0.961	3.853	-0.039	-0.069	3.530
4.0	97.102	3.488	74.133	286.593	0.950	3.892	-0.052	-0.064	1.481
5.0	96.245	4.345	73.276	274.195	0.939	3.878	-0.063	-0.060	0.293
6.0	95.346	5.244	72.377	262.017	0.927	3.901	-0.075	-0.055	0.533
7.0	94.348	6.242	71.379	249.394	0.915	3.980	-0.089	-0.049	1.198
8.0	93.580	7.010	70.611	240.263	0.905	3.911	-0.100	-0.045	1.547
9.0	92.345	8.245	69.376	226.541	0.889	4.089	-0.118	-0.037	2.089
10.0	91.540	9.050	68.571	218.177	0.879	4.039	-0.129	-0.033	2.298
11.0	90.678	9.912	67.709	209.684	0.867	4.021	-0.142	-0.028	2.497
12.0	89.680	10.910	66.711	200.400	0.855	4.058	-0.157	-0.021	2.721
13.0	88.378	12.212	65.409	189.093	0.838	4.192	-0.177	-0.014	3.032
14.0	87.042	13.548	64.073	178.342	0.821	4.319	-0.197	-0.005	3.311
15.0	85.680	14.910	62.711	168.176	0.803	4.436	-0.219	0.004	3.563
16.0	84.457	16.133	61.488	159.659	0.788	4.500	-0.239	0.012	3.737
17.0	83.070	17.520	60.101	150.633	0.770	4.599	-0.261	0.021	3.941
18.0	82.030	18.560	59.061	144.266	0.757	4.602	-0.279	0.028	4.023
19.0	81.170	19.420	58.201	139.240	0.746	4.562	-0.293	0.034	4.046
20.0	79.690	20.900	56.721	131.059	0.727	4.664	-0.319	0.044	4.229
21.0	77.590	23.000	54.621	120.366	0.700	4.888	-0.357	0.060	4.547
22.0	75.380	25.210	52.411	110.133	0.671	5.114	-0.398	0.076	4.862
23.0	74.950	25.640	51.981	108.251	0.666	4.975	-0.406	0.080	4.748
24.0	72.674	27.916	49.705	98.827	0.637	5.191	-0.451	0.098	5.043
25.0	70.658	29.932	47.689	91.164	0.611	5.343	-0.493	0.115	5.261
26.0	69.650	30.940	46.681	87.550	0.598	5.311	-0.514	0.123	5.260
27.0	67.960	32.630	44.991	81.788	0.576	5.393	-0.551	0.138	5.390
28.0	66.780	33.810	43.811	77.971	0.561	5.389	-0.577	0.149	5.417
29.0	65.570	35.020	42.601	74.219	0.546	5.389	-0.605	0.160	5.447
30.0	64.514	36.076	41.545	71.073	0.532	5.367	-0.631	0.170	5.448
31.0	63.840	36.750	40.871	69.122	0.524	5.291	-0.647	0.177	5.386
32.0	62.420	38.170	39.451	65.155	0.505	5.323	-0.682	0.191	5.448
33.0	61.340	39.250	38.371	62.261	0.492	5.308	-0.710	0.203	5.453
34.0	59.740	40.850	36.771	58.155	0.471	5.362	-0.753	0.220	5.537
35.0	59.175	41.415	36.206	56.755	0.464	5.281	-0.768	0.226	5.463
36.0	58.620	41.970	35.651	55.403	0.457	5.203	-0.784	0.232	5.391
37.0	58.100	42.490	35.131	54.157	0.450	5.125	-0.798	0.238	5.319
38.0	57.587	43.003	34.618	52.947	0.444	5.050	-0.813	0.244	5.249
39.0	56.940	43.650	33.971	51.449	0.435	4.995	-0.832	0.252	5.200
40.0	56.480	44.110	33.511	50.401	0.429	4.921	-0.845	0.258	5.130
41.0	56.045	44.545	33.076	49.423	0.424	4.849	-0.859	0.263	5.060
42.0	55.540	45.050	32.571	48.304	0.417	4.787	-0.874	0.269	5.002
43.0	55.040	45.550	32.071	47.213	0.411	4.728	-0.889	0.275	4.946
44.0	54.670	45.920	31.701	46.415	0.406	4.658	-0.901	0.280	4.878

45.0	54.127	46.463	31.158	45.260	0.399	4.608	-0.918	0.287	4.832
46.0	53.697	46.893	30.728	44.358	0.394	4.550	-0.932	0.293	4.775
47.0	53.000	47.590	30.031	42.920	0.385	4.519	-0.955	0.302	4.751
48.0	52.490	48.100	29.521	41.886	0.378	4.472	-0.972	0.309	4.707
49.0	51.830	48.760	28.861	40.570	0.370	4.441	-0.995	0.318	4.681
50.0	51.200	49.390	28.231	39.336	0.362	4.408	-1.017	0.327	4.653
51.0	50.398	50.192	27.429	37.796	0.351	4.392	-1.046	0.339	4.643
52.0	49.980	50.610	27.011	37.007	0.346	4.344	-1.061	0.345	4.596
53.0	49.204	51.386	26.235	35.566	0.336	4.327	-1.090	0.357	4.585
54.0	48.240	52.350	25.271	33.817	0.324	4.327	-1.128	0.372	4.593
55.0	47.590	53.000	24.621	32.663	0.315	4.301	-1.154	0.382	4.571
56.0	46.389	54.201	23.420	30.582	0.300	4.320	-1.204	0.403	4.601
57.0	45.930	54.660	22.961	29.804	0.294	4.280	-1.224	0.411	4.562
58.0	45.204	55.386	22.235	28.593	0.285	4.262	-1.256	0.424	4.548
59.0	44.389	56.201	21.420	27.259	0.274	4.251	-1.293	0.439	4.543
60.0	43.647	56.943	20.678	26.068	0.265	4.236	-1.328	0.453	4.532
61.0	43.100	57.490	20.131	25.205	0.258	4.206	-1.355	0.464	4.504
62.0	42.120	58.470	19.151	23.687	0.245	4.209	-1.405	0.484	4.513
63.0	41.341	59.249	18.372	22.507	0.235	4.197	-1.447	0.501	4.506
64.0	40.648	59.942	17.679	21.476	0.227	4.180	-1.485	0.517	4.492
65.0	40.000	60.590	17.031	20.527	0.218	4.160	-1.522	0.532	4.475
66.0	37.357	63.233	14.388	16.806	0.184	4.276	-1.691	0.600	4.615
67.0	38.698	61.892	15.729	18.665	0.202	4.123	-1.602	0.564	4.442
68.0	37.590	63.000	14.621	17.125	0.187	4.135	-1.675	0.594	4.461
69.0	37.014	63.576	14.045	16.340	0.180	4.112	-1.715	0.610	4.440
70.0	36.540	64.050	13.571	15.702	0.174	4.084	-1.749	0.624	4.412
71.0	36.010	64.580	13.041	14.997	0.167	4.059	-1.789	0.640	4.389
72.0	35.100	65.490	12.131	13.806	0.155	4.059	-1.862	0.669	4.393
73.0	34.640	65.950	11.671	13.213	0.150	4.032	-1.900	0.685	4.366
74.0	34.260	66.330	11.291	12.728	0.145	4.000	-1.933	0.698	4.334
75.0	34.010	66.580	11.041	12.411	0.141	3.962	-1.956	0.708	4.293
76.0	33.410	67.180	10.441	11.658	0.134	3.945	-2.012	0.730	4.278
77.0	33.140	67.450	10.171	11.323	0.130	3.909	-2.038	0.741	4.240
78.0	33.975	66.615	11.006	12.367	0.141	3.811	-1.959	0.709	4.130
79.0	33.576	67.014	10.607	11.866	0.136	3.786	-1.996	0.724	4.104
80.0	33.247	67.343	10.278	11.455	0.132	3.757	-2.027	0.737	4.074

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 360 W

Thickness of drying bed 2 mm

Dryingtime (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.036	0.000	77.621	346.842	1.000	0.000	0.000	-0.085	0.000
1.0	99.436	0.600	77.021	335.180	0.992	2.678	-0.008	-0.082	23.15
2.0	98.345	1.691	75.930	315.460	0.978	3.773	-0.022	-0.076	8.726
3.0	97.314	2.721	74.900	298.400	0.965	4.048	-0.036	-0.071	4.021
4.0	96.400	3.636	73.985	284.398	0.953	4.056	-0.048	-0.066	1.821
5.0	95.007	5.029	72.592	264.863	0.935	4.488	-0.067	-0.058	0.001
6.0	94.257	5.779	71.842	255.144	0.926	4.298	-0.077	-0.054	0.652
7.0	93.136	6.900	70.721	241.542	0.911	4.399	-0.093	-0.047	1.396
8.0	92.114	7.921	69.700	230.028	0.898	4.419	-0.108	-0.041	1.889
9.0	90.200	9.836	67.785	210.417	0.873	4.877	-0.135	-0.030	2.790
10.0	88.607	11.429	66.192	195.792	0.853	5.100	-0.159	-0.021	3.344
11.0	87.907	12.129	65.492	189.792	0.844	4.921	-0.170	-0.016	3.372
12.0	86.207	13.829	63.792	176.185	0.822	5.143	-0.196	-0.006	3.832
13.0	84.257	15.779	61.842	162.071	0.797	5.417	-0.227	0.007	4.321
14.0	82.757	17.279	60.342	152.159	0.777	5.508	-0.252	0.017	4.572
15.0	81.329	18.707	58.914	143.391	0.759	5.566	-0.276	0.027	4.765
16.0	79.529	20.507	57.114	133.176	0.736	5.720	-0.307	0.039	5.055
17.0	77.421	22.614	55.007	122.255	0.709	5.937	-0.344	0.054	5.406
18.0	75.686	24.350	53.271	114.000	0.686	6.037	-0.376	0.067	5.610
19.0	73.271	26.764	50.857	103.487	0.655	6.287	-0.423	0.086	5.978
20.0	70.993	29.043	48.578	94.470	0.626	6.481	-0.469	0.105	6.275
21.0	69.779	30.257	47.364	89.984	0.610	6.430	-0.494	0.115	6.278
22.0	68.600	31.436	46.185	85.823	0.595	6.377	-0.519	0.125	6.273
23.0	67.414	32.621	45.000	81.817	0.580	6.330	-0.545	0.136	6.270
24.0	66.173	33.863	43.758	77.804	0.564	6.297	-0.573	0.147	6.279
25.0	63.644	36.391	41.230	70.154	0.531	6.496	-0.633	0.171	6.556
26.0	62.421	37.614	40.007	66.685	0.515	6.456	-0.663	0.184	6.550
27.0	60.993	39.043	38.578	62.809	0.497	6.453	-0.699	0.198	6.584
28.0	59.900	40.136	37.485	59.962	0.483	6.397	-0.728	0.210	6.553
29.0	58.136	41.900	35.721	55.572	0.460	6.448	-0.776	0.229	6.645
30.0	56.693	43.343	34.278	52.156	0.442	6.448	-0.817	0.246	6.674
31.0	55.243	44.793	32.828	48.872	0.423	6.449	-0.861	0.264	6.704
32.0	54.700	45.336	32.285	47.678	0.416	6.323	-0.877	0.270	6.583

33.0	53.136	46.900	30.721	44.344	0.396	6.343	-0.927	0.291	6.631
34.0	52.200	47.836	29.785	42.420	0.384	6.279	-0.958	0.303	6.580
35.0	51.750	48.286	29.335	41.513	0.378	6.157	-0.973	0.309	6.459
36.0	50.957	49.079	28.542	39.943	0.368	6.084	-1.000	0.320	6.395
37.0	49.824	50.211	27.410	37.759	0.353	6.056	-1.041	0.337	6.382
38.0	48.894	51.141	26.480	36.017	0.341	6.006	-1.075	0.351	6.342
39.0	47.864	52.171	25.450	34.137	0.328	5.970	-1.115	0.367	6.317
40.0	47.114	52.921	24.700	32.801	0.318	5.905	-1.145	0.379	6.257
41.0	45.721	54.314	23.307	30.390	0.300	5.912	-1.203	0.402	6.282
42.0	44.986	55.050	22.571	29.151	0.291	5.850	-1.235	0.415	6.224
43.0	43.804	56.232	21.389	27.208	0.276	5.836	-1.289	0.437	6.223
44.0	42.629	57.407	20.214	25.335	0.260	5.823	-1.345	0.460	6.221
45.0	41.736	58.300	19.321	23.948	0.249	5.782	-1.391	0.478	6.187
46.0	40.771	59.264	18.357	22.484	0.236	5.750	-1.442	0.499	6.162
47.0	39.971	60.064	17.557	21.296	0.226	5.703	-1.486	0.517	6.120
48.0	38.589	61.446	16.175	19.296	0.208	5.713	-1.568	0.551	6.143
49.0	37.829	62.207	15.414	18.223	0.199	5.666	-1.617	0.570	6.098
50.0	36.914	63.121	14.500	16.958	0.187	5.634	-1.678	0.595	6.072
51.0	35.175	64.861	12.760	14.627	0.164	5.676	-1.805	0.647	6.131
52.0	34.186	65.850	11.771	13.341	0.152	5.652	-1.886	0.679	6.113
53.0	32.829	67.207	10.414	11.624	0.134	5.659	-2.009	0.729	6.131
54.0	30.893	69.143	8.478	9.264	0.109	5.714	-2.214	0.812	6.205
55.0	30.321	69.714	7.907	8.586	0.102	5.657	-2.284	0.841	6.146
56.0	29.300	70.736	6.885	7.394	0.089	5.637	-2.422	0.897	6.132
57.0	28.893	71.143	6.478	6.927	0.083	5.570	-2.483	0.921	6.062
58.0	28.493	71.543	6.078	6.472	0.078	5.505	-2.547	0.947	5.993
59.0	28.293	71.743	5.878	6.245	0.076	5.427	-2.581	0.961	5.909
60.0	28.229	71.807	5.814	6.173	0.075	5.341	-2.592	0.965	5.817
61.0	27.857	72.179	5.442	5.756	0.070	5.281	-2.658	0.992	5.753
62.0	27.793	72.243	5.378	5.684	0.069	5.200	-2.669	0.997	5.666

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 360 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} × 10 ⁹ (m ² /s)
0.0	100.586	0.000	78.048	355.534	1.000	0.000	0.000	-0.085	0.00
1.0	99.663	0.923	76.698	329.146	0.983	4.120	-0.017	-0.078	-19.27
2.0	99.106	1.480	76.141	319.131	0.976	3.302	-0.025	-0.075	-8.188
3.0	98.447	2.139	75.482	307.860	0.967	3.182	-0.033	-0.072	-4.316
4.0	97.861	2.725	74.896	298.338	0.960	3.041	-0.041	-0.068	-2.475
5.0	96.982	3.604	74.017	284.861	0.948	3.217	-0.053	-0.064	-1.066
6.0	96.469	4.117	73.504	277.412	0.942	3.062	-0.060	-0.061	-0.444
7.0	95.663	4.923	72.698	266.272	0.931	3.139	-0.071	-0.056	0.217
8.0	94.022	6.564	71.057	245.505	0.910	3.662	-0.094	-0.047	1.256
9.0	92.586	8.000	69.621	229.175	0.892	3.967	-0.114	-0.039	1.946
10.0	91.348	9.238	68.383	216.284	0.876	4.123	-0.132	-0.032	2.395
11.0	89.883	10.703	66.918	202.276	0.857	4.343	-0.154	-0.023	2.869
12.0	88.248	12.338	65.283	188.039	0.836	4.589	-0.179	-0.013	3.338
13.0	86.733	13.853	63.768	175.995	0.817	4.756	-0.202	-0.003	3.687
14.0	85.685	14.901	62.720	168.239	0.804	4.750	-0.219	0.003	3.813
15.0	83.802	16.784	60.837	155.344	0.779	4.994	-0.249	0.016	4.211
16.0	83.289	17.297	60.324	152.043	0.773	4.825	-0.258	0.019	4.115
17.0	81.604	18.982	58.639	141.775	0.751	4.983	-0.286	0.031	4.388
18.0	80.278	20.308	57.313	134.265	0.734	5.035	-0.309	0.040	4.527
19.0	78.645	21.941	55.680	125.630	0.713	5.154	-0.338	0.052	4.735
20.0	77.538	23.048	54.573	120.135	0.699	5.143	-0.358	0.060	4.786
21.0	75.231	25.355	52.266	109.493	0.670	5.388	-0.401	0.077	5.129
22.0	72.513	28.073	49.548	98.207	0.635	5.695	-0.454	0.099	5.538
23.0	71.033	29.553	48.068	92.559	0.616	5.734	-0.485	0.111	5.632
24.0	69.626	30.960	46.661	87.481	0.598	5.757	-0.514	0.123	5.702
25.0	68.835	31.751	45.870	84.741	0.588	5.668	-0.532	0.130	5.638
26.0	67.890	32.696	44.925	81.571	0.576	5.612	-0.552	0.139	5.611
27.0	66.315	34.271	43.350	76.522	0.555	5.665	-0.588	0.153	5.706
28.0	64.967	35.619	42.002	72.420	0.538	5.677	-0.620	0.166	5.752
29.0	63.997	36.589	41.032	69.583	0.526	5.631	-0.643	0.175	5.728
30.0	62.777	37.810	39.811	66.145	0.510	5.625	-0.673	0.188	5.748
31.0	61.824	38.762	38.859	63.557	0.498	5.580	-0.697	0.198	5.723

32.0	60.322	40.264	37.357	59.635	0.479	5.615	-0.737	0.213	5.788
33.0	59.077	41.509	36.112	56.523	0.463	5.614	-0.771	0.227	5.809
34.0	57.033	43.553	34.068	51.671	0.436	5.717	-0.829	0.251	5.950
35.0	55.194	45.392	32.229	47.556	0.413	5.788	-0.884	0.273	6.053
36.0	53.729	46.857	30.764	44.433	0.394	5.809	-0.931	0.292	6.097
37.0	52.300	48.286	29.335	41.513	0.376	5.824	-0.979	0.311	6.133
38.0	50.821	49.766	27.855	38.611	0.357	5.845	-1.030	0.332	6.174
39.0	49.993	50.593	27.028	37.038	0.346	5.790	-1.060	0.345	6.126
40.0	49.788	50.799	26.822	36.654	0.344	5.668	-1.068	0.348	5.999
41.0	48.249	52.337	25.284	33.840	0.324	5.697	-1.127	0.372	6.048
42.0	47.590	52.996	24.625	32.669	0.316	5.631	-1.154	0.382	5.985
43.0	46.161	54.425	23.196	30.202	0.297	5.649	-1.213	0.407	6.019
44.0	45.824	54.762	22.859	29.633	0.293	5.554	-1.228	0.413	5.922
45.0	44.718	55.868	21.753	27.800	0.279	5.541	-1.278	0.433	5.918
46.0	43.853	56.733	20.888	26.404	0.268	5.504	-1.318	0.449	5.887
47.0	42.498	58.088	19.533	24.275	0.250	5.516	-1.385	0.476	5.912
48.0	41.374	59.212	18.409	22.562	0.236	5.505	-1.445	0.500	5.910
49.0	40.325	60.261	17.360	21.007	0.222	5.489	-1.503	0.524	5.901
50.0	39.741	60.845	16.776	20.158	0.215	5.431	-1.537	0.538	5.844
51.0	39.402	61.184	16.437	19.670	0.211	5.354	-1.558	0.546	5.764
52.0	38.564	62.022	15.599	18.482	0.200	5.323	-1.610	0.567	5.737
53.0	38.081	62.506	15.115	17.807	0.194	5.263	-1.642	0.580	5.676
54.0	36.894	63.692	13.929	16.183	0.178	5.264	-1.723	0.613	5.685
55.0	35.868	64.718	12.903	14.815	0.165	5.251	-1.800	0.644	5.678
56.0	34.681	65.905	11.716	13.271	0.150	5.252	-1.896	0.683	5.687
57.0	33.879	66.707	10.914	12.251	0.140	5.223	-1.967	0.712	5.661
58.0	32.974	67.612	10.009	11.123	0.128	5.202	-2.054	0.747	5.644
59.0	32.513	68.073	9.548	10.556	0.122	5.149	-2.101	0.766	5.589
60.0	32.125	68.462	9.159	10.083	0.117	5.092	-2.143	0.783	5.529
61.0	31.165	69.421	8.200	8.932	0.105	5.079	-2.253	0.828	5.521
62.0	30.103	70.484	7.137	7.686	0.091	5.074	-2.392	0.884	5.521
63.0	29.780	70.806	6.815	7.314	0.087	5.016	-2.438	0.903	5.460
64.0	29.311	71.275	6.346	6.776	0.081	4.970	-2.509	0.932	5.412
65.0	29.048	71.538	6.083	6.476	0.078	4.912	-2.552	0.949	5.350
66.0	28.645	71.941	5.680	6.022	0.073	4.865	-2.620	0.977	5.301
67.0	28.535	72.051	5.570	5.898	0.071	4.799	-2.640	0.985	5.230
68.0	28.381	72.205	5.416	5.726	0.069	4.739	-2.668	0.996	5.165
69.0	28.234	72.352	5.269	5.562	0.068	4.680	-2.695	1.007	5.101
70.0	27.912	72.674	4.947	5.204	0.063	4.633	-2.759	1.033	5.052

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 360 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.17	0.000	77.732	349.066	1.000	0.000	0.000	-0.085	0.00
1.0	99.614	0.564	77.057	335.857	0.991	2.518	-0.009	-0.082	-22.76
2.0	99.257	0.921	76.700	329.176	0.987	2.056	-0.013	-0.080	-10.45
3.0	98.036	2.143	75.478	307.799	0.971	3.188	-0.029	-0.073	-4.841
4.0	97.843	2.336	75.285	304.617	0.969	2.606	-0.032	-0.072	3.379
5.0	96.529	3.650	73.971	284.186	0.952	3.258	-0.050	-0.065	1.331
6.0	96.071	4.107	73.514	277.556	0.946	3.055	-0.056	-0.063	-0.712
7.0	94.700	5.479	72.142	258.968	0.928	3.493	-0.075	-0.055	0.412
8.0	94.029	6.150	71.471	250.520	0.919	3.431	-0.084	-0.051	0.798
9.0	93.264	6.914	70.707	241.375	0.910	3.429	-0.095	-0.047	1.153
10.0	91.671	8.507	69.114	223.769	0.889	3.797	-0.118	-0.037	1.869
11.0	90.286	9.893	67.728	209.867	0.871	4.014	-0.138	-0.029	2.356
12.0	89.293	10.886	66.735	200.619	0.859	4.048	-0.153	-0.023	2.592
13.0	88.321	11.857	65.764	192.089	0.846	4.071	-0.167	-0.017	2.782
14.0	86.436	13.743	63.878	176.840	0.822	4.381	-0.196	-0.006	3.286
15.0	85.386	14.793	62.828	169.021	0.808	4.401	-0.213	0.001	3.433
16.0	83.850	16.329	61.292	158.347	0.789	4.555	-0.238	0.011	3.719
17.0	82.414	17.764	59.857	149.107	0.770	4.664	-0.261	0.021	3.941
18.0	81.000	19.179	58.442	140.630	0.752	4.755	-0.285	0.030	4.132
19.0	79.779	20.400	57.221	133.759	0.736	4.792	-0.306	0.039	4.250
20.0	77.957	22.221	55.400	124.213	0.713	4.959	-0.339	0.052	4.513
21.0	76.707	23.471	54.150	118.100	0.697	4.988	-0.362	0.061	4.609
22.0	75.279	24.900	52.721	111.510	0.678	5.051	-0.388	0.072	4.738
23.0	73.979	26.200	51.421	105.850	0.662	5.084	-0.413	0.082	4.827
24.0	71.671	28.507	49.114	96.517	0.632	5.301	-0.459	0.101	5.128
25.0	70.410	29.769	47.852	91.763	0.616	5.314	-0.485	0.112	5.186
26.0	69.036	31.143	46.478	86.839	0.598	5.346	-0.514	0.123	5.262
27.0	67.114	33.064	44.557	80.364	0.573	5.465	-0.557	0.140	5.439
28.0	64.532	35.646	41.975	72.338	0.540	5.682	-0.616	0.165	5.726
29.0	62.414	37.764	39.857	66.270	0.513	5.812	-0.668	0.186	5.909
30.0	61.756	38.423	39.198	64.469	0.504	5.716	-0.685	0.192	5.827
31.0	60.686	39.493	38.128	61.624	0.491	5.686	-0.712	0.204	5.819
32.0	59.050	41.129	36.492	57.461	0.469	5.736	-0.756	0.221	5.904
33.0	57.529	42.650	34.971	53.777	0.450	5.768	-0.799	0.239	5.966

34.0	56.400	43.779	33.842	51.154	0.435	5.746	-0.832	0.252	5.964
35.0	54.971	45.207	32.414	47.959	0.417	5.764	-0.875	0.269	6.006
36.0	53.643	46.536	31.085	45.107	0.400	5.769	-0.917	0.286	6.032
37.0	52.829	47.350	30.271	43.412	0.389	5.711	-0.943	0.297	5.984
38.0	50.929	49.250	28.371	39.608	0.365	5.784	-1.008	0.323	6.087
39.0	49.550	50.629	26.992	36.972	0.347	5.794	-1.058	0.344	6.116
40.0	49.064	51.114	26.507	36.067	0.341	5.703	-1.076	0.351	6.026
41.0	47.929	52.250	25.371	33.996	0.326	5.687	-1.120	0.369	6.024
42.0	47.621	52.557	25.064	33.447	0.322	5.585	-1.132	0.374	5.918
43.0	46.621	53.557	24.064	31.690	0.310	5.559	-1.173	0.390	5.902
44.0	46.274	53.904	23.717	31.090	0.305	5.467	-1.187	0.396	5.809
45.0	45.336	54.843	22.778	29.497	0.293	5.439	-1.227	0.412	5.789
46.0	44.571	55.607	22.014	28.228	0.283	5.395	-1.262	0.426	5.750
47.0	43.543	56.636	20.985	26.559	0.270	5.378	-1.309	0.446	5.742
48.0	42.429	57.750	19.871	24.799	0.256	5.369	-1.364	0.468	5.743
49.0	41.436	58.743	18.878	23.271	0.243	5.350	-1.415	0.488	5.732
50.0	40.293	59.886	17.735	21.559	0.228	5.345	-1.478	0.514	5.736
51.0	39.529	60.650	16.971	20.440	0.218	5.307	-1.522	0.532	5.702
52.0	38.971	61.207	16.414	19.637	0.211	5.253	-1.555	0.545	5.648
53.0	38.343	61.836	15.785	18.744	0.203	5.207	-1.594	0.561	5.604
54.0	37.386	62.793	14.828	17.410	0.191	5.190	-1.657	0.586	5.592
55.0	36.443	63.736	13.885	16.124	0.179	5.172	-1.722	0.613	5.580
56.0	36.057	64.121	13.500	15.606	0.174	5.110	-1.751	0.624	5.517
57.0	35.264	64.914	12.707	14.556	0.163	5.083	-1.811	0.649	5.492
58.0	34.529	65.650	11.971	13.599	0.154	5.052	-1.871	0.673	5.464
59.0	33.857	66.321	11.300	12.739	0.145	5.017	-1.929	0.696	5.431
60.0	33.543	66.636	10.985	12.341	0.141	4.956	-1.957	0.708	5.367
61.0	32.886	67.293	10.328	11.518	0.133	4.923	-2.018	0.733	5.336
62.0	32.464	67.714	9.907	10.996	0.127	4.874	-2.060	0.750	5.285
63.0	32.214	67.964	9.657	10.689	0.124	4.815	-2.086	0.760	5.222
64.0	31.679	68.500	9.121	10.036	0.117	4.777	-2.143	0.783	5.184
65.0	31.414	68.764	8.857	9.717	0.114	4.721	-2.172	0.795	5.125
66.0	30.907	69.271	8.350	9.110	0.107	4.684	-2.231	0.819	5.088
67.0	30.686	69.493	8.128	8.847	0.105	4.629	-2.258	0.830	5.029
68.0	30.364	69.814	7.807	8.468	0.100	4.582	-2.298	0.846	4.980
69.0	30.036	70.143	7.478	8.083	0.096	4.537	-2.341	0.864	4.933
70.0	29.764	70.414	7.207	7.766	0.093	4.489	-2.378	0.879	4.882
71.0	29.507	70.671	6.950	7.469	0.089	4.442	-2.415	0.893	4.832
72.0	29.293	70.886	6.735	7.222	0.087	4.394	-2.446	0.906	4.781
73.0	28.479	71.700	5.921	6.294	0.076	4.383	-2.575	0.958	4.774

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 540 W

Thickness of drying bed 2 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} × 10 ⁹ (m ² /s)
0.0	100.000	0.000	77.593	346.289	1.000	0.000	0.000	-0.085	0.00
1.0	99.513	0.487	77.258	339.722	0.994	2.165	-0.006	-0.083	23.74
2.0	99.020	0.980	76.765	330.385	0.987	2.179	-0.013	-0.080	10.58
3.0	97.053	2.947	74.798	296.799	0.962	4.369	-0.039	-0.069	3.637
4.0	96.233	3.767	73.978	284.295	0.952	4.188	-0.050	-0.065	1.658
5.0	93.767	6.233	71.512	251.021	0.920	5.545	-0.084	-0.051	1.276
6.0	92.673	7.327	70.418	238.047	0.906	5.431	-0.099	-0.045	1.906
7.0	90.173	9.827	67.918	211.705	0.874	6.244	-0.135	-0.030	3.599
8.0	88.027	11.973	65.772	192.156	0.846	6.657	-0.167	-0.017	4.523
9.0	86.373	13.627	64.118	178.694	0.825	6.734	-0.193	-0.007	4.979
10.0	82.567	17.433	60.312	151.963	0.776	7.754	-0.254	0.018	6.468
11.0	79.580	20.420	57.325	134.329	0.737	8.257	-0.305	0.038	7.297
12.0	77.973	22.027	55.718	125.827	0.717	8.164	-0.333	0.050	7.387
13.0	75.360	24.640	53.105	113.242	0.683	8.430	-0.381	0.069	7.868
14.0	73.900	26.100	51.645	106.804	0.664	8.292	-0.409	0.081	7.850
15.0	70.853	29.147	48.598	94.546	0.625	8.643	-0.470	0.105	8.387
16.0	68.431	31.569	46.176	85.792	0.594	8.776	-0.521	0.126	8.652
17.0	65.505	34.495	43.250	76.212	0.556	9.025	-0.586	0.153	9.042
18.0	61.029	38.971	38.774	63.328	0.499	9.630	-0.696	0.197	9.837
19.0	59.307	40.693	37.052	58.860	0.477	9.526	-0.741	0.215	9.792
20.0	57.647	42.353	35.392	54.779	0.455	9.419	-0.787	0.234	9.736
21.0	55.427	44.573	33.172	49.637	0.427	9.441	-0.852	0.260	9.824
22.0	53.973	46.027	31.718	46.452	0.408	9.305	-0.897	0.278	9.722
23.0	51.987	48.013	29.732	42.312	0.382	9.285	-0.961	0.304	9.750
24.0	49.790	50.210	27.535	37.998	0.354	9.305	-1.038	0.336	9.821
25.0	47.760	52.240	25.505	34.237	0.328	9.294	-1.115	0.367	9.852
26.0	45.641	54.359	23.386	30.525	0.301	9.299	-1.201	0.402	9.898
27.0	43.523	56.477	21.268	27.013	0.274	9.304	-1.296	0.440	9.947
28.0	42.300	57.700	20.045	25.070	0.258	9.166	-1.355	0.464	9.814
29.0	40.465	59.535	18.210	22.265	0.234	9.131	-1.451	0.503	9.802
30.0	38.187	61.813	15.932	18.951	0.205	9.164	-1.585	0.557	9.875
31.0	36.453	63.547	14.198	16.548	0.183	9.117	-1.700	0.604	9.848
32.0	35.607	64.393	13.352	15.409	0.172	8.950	-1.762	0.629	9.679
33.0	34.693	65.307	12.438	14.205	0.160	8.802	-1.833	0.658	9.530
34.0	32.893	67.107	10.638	11.905	0.137	8.779	-1.989	0.721	9.526
35.0	32.067	67.933	9.812	10.879	0.126	8.633	-2.070	0.754	9.377
36.0	31.340	68.660	9.085	9.993	0.117	8.483	-2.147	0.785	9.222
37.0	30.493	69.507	8.238	8.978	0.106	8.355	-2.245	0.825	9.093
38.0	29.987	70.013	7.732	8.380	0.099	8.195	-2.308	0.850	8.922
39.0	29.267	70.733	7.012	7.540	0.090	8.067	-2.406	0.890	8.790
40.0	29.120	70.880	6.865	7.371	0.088	7.881	-2.427	0.899	8.589
41.0	28.700	71.300	6.445	6.889	0.083	7.735	-2.490	0.924	8.433
42.0	28.233	71.767	5.978	6.358	0.077	7.600	-2.565	0.955	8.290
43.0	27.787	72.213	5.532	5.856	0.071	7.469	-2.643	0.986	8.152
44.0	27.560	72.440	5.305	5.602	0.068	7.323	-2.685	1.003	7.993
45.0	26.647	73.353	4.392	4.593	0.056	7.250	-2.874	1.080	7.922
46.0	26.380	73.620	4.125	4.302	0.053	7.118	-2.936	1.105	7.780

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 540 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.236	0.000	77.776	349.973	1.000	0.000	0.000	-0.085	0.000
1.0	99.016	1.220	76.556	326.541	0.984	5.434	-0.016	-0.079	19.92
2.0	97.738	2.498	75.278	304.492	0.968	5.562	-0.033	-0.072	6.628
3.0	96.703	3.534	74.242	288.236	0.955	5.244	-0.046	-0.066	2.619
4.0	96.006	4.230	73.546	278.015	0.946	4.708	-0.056	-0.062	1.056
5.0	93.834	6.403	71.373	249.326	0.918	5.701	-0.086	-0.050	1.421
6.0	92.428	7.808	69.968	232.975	0.900	5.794	-0.106	-0.042	2.406
7.0	90.326	9.911	67.865	211.192	0.873	6.304	-0.136	-0.030	3.629
8.0	88.466	11.770	66.006	194.170	0.849	6.551	-0.164	-0.019	4.388
9.0	86.441	13.796	63.980	177.627	0.823	6.825	-0.195	-0.006	5.074
10.0	84.633	15.604	62.172	164.356	0.799	6.947	-0.224	0.006	5.510
11.0	82.978	17.259	60.517	153.275	0.778	6.986	-0.251	0.017	5.794
12.0	80.812	19.425	58.351	140.102	0.750	7.207	-0.287	0.031	6.252
13.0	79.208	21.029	56.747	131.199	0.730	7.202	-0.315	0.043	6.415
14.0	76.984	23.252	54.524	119.894	0.701	7.395	-0.355	0.059	6.785
15.0	74.639	25.597	52.179	109.111	0.671	7.598	-0.399	0.077	7.148
16.0	71.981	28.256	49.520	98.100	0.637	7.863	-0.451	0.098	7.568
17.0	69.827	30.409	47.367	89.995	0.609	7.964	-0.496	0.116	7.784
18.0	67.521	32.716	45.060	82.018	0.579	8.092	-0.546	0.136	8.020
19.0	65.150	35.086	42.690	74.489	0.549	8.222	-0.600	0.158	8.248
20.0	62.358	37.879	39.897	66.382	0.513	8.432	-0.668	0.185	8.564
21.0	59.201	41.035	36.741	58.080	0.472	8.700	-0.750	0.219	8.940
22.0	57.751	42.486	35.290	54.537	0.454	8.598	-0.790	0.235	8.878
23.0	56.447	43.789	33.987	51.485	0.437	8.477	-0.828	0.250	8.788
24.0	54.422	45.815	31.961	46.975	0.411	8.499	-0.889	0.275	8.862
25.0	53.399	46.837	30.939	44.799	0.398	8.341	-0.922	0.288	8.720
26.0	52.198	48.038	29.738	42.324	0.382	8.226	-0.961	0.305	8.626
27.0	50.607	49.629	28.147	39.172	0.362	8.184	-1.016	0.327	8.614
28.0	49.617	50.620	27.156	37.280	0.349	8.049	-1.052	0.341	8.491
29.0	49.080	51.157	26.619	36.276	0.342	7.854	-1.072	0.349	8.295
30.0	47.508	52.728	25.048	33.418	0.322	7.826	-1.133	0.374	8.291
31.0	46.236	54.000	23.776	31.192	0.306	7.756	-1.185	0.395	8.238

32.0	44.735	55.502	22.274	28.658	0.286	7.722	-1.250	0.422	8.225
33.0	43.687	56.549	21.227	26.946	0.273	7.630	-1.299	0.441	8.142
34.0	42.767	57.470	20.306	25.481	0.261	7.526	-1.343	0.459	8.047
35.0	41.559	58.677	19.099	23.607	0.246	7.464	-1.404	0.484	7.938
36.0	40.671	59.565	18.211	22.265	0.234	7.367	-1.452	0.503	7.900
37.0	38.569	61.668	16.108	19.201	0.207	7.421	-1.574	0.553	7.983
38.0	37.284	62.952	14.824	17.404	0.191	7.376	-1.658	0.587	7.949
39.0	35.936	64.300	13.476	15.574	0.173	7.341	-1.753	0.625	7.926
40.0	34.728	65.508	12.268	13.984	0.158	7.292	-1.847	0.663	7.885
41.0	33.597	66.639	11.137	12.533	0.143	7.237	-1.944	0.703	7.836
42.0	32.780	67.457	10.319	11.507	0.133	7.151	-2.020	0.733	7.751
43.0	31.546	68.690	9.086	9.994	0.117	7.112	-2.147	0.785	7.721
44.0	30.428	69.808	7.968	8.658	0.102	7.064	-2.278	0.838	7.678
45.0	29.930	70.307	7.469	8.072	0.096	6.956	-2.343	0.864	7.565
46.0	29.182	71.054	6.722	7.206	0.086	6.877	-2.448	0.907	7.485
47.0	28.543	71.693	6.083	6.477	0.078	6.792	-2.548	0.948	7.397
48.0	28.179	72.057	5.719	6.065	0.074	6.684	-2.610	0.973	7.282
49.0	27.783	72.454	5.322	5.622	0.068	6.583	-2.682	1.002	7.176
50.0	27.476	72.760	5.016	5.280	0.064	6.479	-2.741	1.026	7.064
51.0	27.278	72.958	4.818	5.061	0.062	6.369	-2.782	1.042	6.946
52.0	26.869	73.367	4.409	4.612	0.057	6.282	-2.870	1.078	6.854

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 540 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moistu re remov ed (g)	Moistu re conten t (%) wb	Moistur e content (%) (db)	MR	Dryi ng rate, (g/10 0g bdm)		ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.236	0.000	77.776	349.973	1.000	0.000	0.000	-0.085	0.000	
1.0	99.246	0.990	76.786	330.767	0.987	4.420	-0.013	-0.080	21.1230	
2.0	98.019	2.217	75.559	309.145	0.971	4.948	-0.029	-0.073	7.3618	
3.0	96.901	3.335	74.441	291.245	0.957	4.962	-0.044	-0.067	2.9636	
4.0	95.578	4.658	73.118	271.994	0.940	5.197	-0.062	-0.060	0.4978	
5.0	94.345	5.891	71.885	255.678	0.924	5.258	-0.079	-0.053	0.8883	
6.0	92.831	7.406	70.370	237.499	0.905	5.508	-0.100	-0.045	2.0568	
7.0	91.917	8.319	69.457	227.402	0.893	5.304	-0.113	-0.039	2.4439	
8.0	89.681	10.556	67.220	205.065	0.864	5.889	-0.146	-0.026	3.5966	
9.0	87.770	12.466	65.310	188.264	0.840	6.182	-0.175	-0.014	4.3043	
10.0	86.064	14.173	63.603	174.752	0.818	6.325	-0.201	-0.004	4.7638	
11.0	84.275	15.962	61.814	161.879	0.795	6.476	-0.230	0.008	5.1791	
12.0	81.406	18.831	58.945	143.578	0.758	7.003	-0.277	0.027	5.9946	
13.0	78.364	21.872	55.904	126.777	0.719	7.509	-0.330	0.049	6.7539	
14.0	76.281	23.955	53.821	116.547	0.692	7.636	-0.368	0.064	7.0476	
15.0	73.700	26.537	51.239	105.083	0.659	7.895	-0.417	0.084	7.4755	
16.0	71.054	29.182	48.594	94.529	0.625	8.140	-0.470	0.106	7.8707	
17.0	68.019	32.217	45.559	83.684	0.586	8.458	-0.535	0.132	8.3390	
18.0	65.994	34.243	43.533	77.095	0.560	8.490	-0.580	0.150	8.4627	
19.0	63.668	36.569	41.207	70.089	0.530	8.590	-0.635	0.172	8.6558	
20.0	60.262	39.974	37.802	60.776	0.486	8.920	-0.721	0.207	9.1113	
21.0	58.058	42.179	35.597	55.273	0.458	8.964	-0.782	0.232	9.2250	
22.0	55.105	45.131	32.645	48.467	0.420	9.155	-0.868	0.267	9.5056	
23.0	52.805	47.431	30.345	43.564	0.390	9.204	-0.941	0.296	9.6140	
24.0	51.093	49.144	28.632	40.119	0.368	9.138	-0.999	0.320	9.5856	
25.0	50.249	49.987	27.789	38.483	0.357	8.923	-1.029	0.332	9.3782	
26.0	49.080	51.157	26.619	36.276	0.342	8.781	-1.072	0.349	9.2521	
27.0	47.502	52.735	25.041	33.407	0.322	8.717	-1.133	0.374	9.2143	
28.0	46.236	54.000	23.776	31.192	0.306	8.607	-1.185	0.395	9.1209	
29.0	45.125	55.112	22.664	29.306	0.291	8.481	-1.233	0.415	9.0064	
30.0	43.847	56.390	21.386	27.204	0.275	8.389	-1.291	0.438	8.9284	
31.0	42.671	57.565	20.211	25.330	0.260	8.287	-1.348	0.461	8.8382	

32.0	41.054	59.182	18.594	22.841	0.239	8.254	-1.431	0.495	8.8255
33.0	39.834	60.403	17.373	21.026	0.223	8.169	-1.499	0.522	8.7510
34.0	38.447	61.789	15.987	19.029	0.206	8.111	-1.582	0.556	8.7064
35.0	37.732	62.505	15.271	18.024	0.196	7.970	-1.628	0.575	8.5643
36.0	37.310	62.926	14.850	17.439	0.191	7.801	-1.656	0.586	8.3875
37.0	36.396	63.840	13.936	16.192	0.179	7.700	-1.719	0.612	8.2896
38.0	35.770	64.466	13.310	15.353	0.171	7.571	-1.765	0.630	8.1574
39.0	34.741	65.495	12.281	14.000	0.158	7.495	-1.846	0.663	8.0858
40.0	34.486	65.751	12.025	13.669	0.155	7.336	-1.867	0.671	7.9170
41.0	32.888	67.348	10.428	11.642	0.134	7.331	-2.009	0.729	7.9272
42.0	32.058	68.179	9.597	10.616	0.123	7.245	-2.092	0.763	7.8416
43.0	31.610	68.626	9.150	10.071	0.118	7.123	-2.140	0.782	7.7135
44.0	30.939	69.297	8.479	9.264	0.109	7.029	-2.216	0.813	7.6177
45.0	30.607	69.629	8.147	8.869	0.105	6.906	-2.256	0.829	7.4869
46.0	29.936	70.300	7.476	8.080	0.096	6.820	-2.342	0.864	7.4003
47.0	29.182	71.054	6.722	7.206	0.086	6.747	-2.448	0.907	7.3265
48.0	28.754	71.482	6.294	6.716	0.081	6.646	-2.514	0.934	7.2204
49.0	28.543	71.693	6.083	6.477	0.078	6.530	-2.548	0.948	7.0955
50.0	28.179	72.057	5.719	6.065	0.074	6.432	-2.610	0.973	6.9916
51.0	28.089	72.147	5.629	5.965	0.072	6.313	-2.626	0.979	6.8636
52.0	27.821	72.415	5.361	5.664	0.069	6.215	-2.675	0.999	6.7585
53.0	27.482	72.754	5.022	5.288	0.065	6.126	-2.740	1.025	6.6644
54.0	27.054	73.182	4.594	4.815	0.059	6.048	-2.829	1.061	6.5823
55.0	26.856	73.380	4.396	4.598	0.057	5.954	-2.873	1.079	6.4814
56.0	26.748	73.489	4.287	4.479	0.055	5.857	-2.898	1.089	6.3758

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 720 W

Thickness of drying bed 2 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.195	0.000	77.745	349.329	1.000	0.000	0.000	-0.085	0.000
1.0	98.837	1.358	76.387	323.494	0.983	6.049	-0.018	-0.078	19.202
2.0	97.247	2.949	74.796	296.766	0.962	6.567	-0.039	-0.069	5.450
3.0	95.386	4.809	72.936	269.491	0.938	7.140	-0.064	-0.059	0.397
4.0	92.225	7.970	69.775	230.850	0.897	8.875	-0.108	-0.041	3.825
5.0	90.088	10.107	67.638	209.005	0.870	9.004	-0.139	-0.029	5.290
6.0	87.315	12.880	64.865	184.617	0.834	9.562	-0.181	-0.012	6.820
7.0	84.776	15.419	62.326	165.432	0.802	9.812	-0.221	0.004	7.739
8.0	83.112	17.084	60.661	154.203	0.780	9.512	-0.248	0.015	7.857
9.0	77.642	22.553	55.192	123.172	0.710	11.162	-0.343	0.054	10.155
10.0	74.116	26.079	51.666	106.894	0.665	11.616	-0.409	0.080	10.979
11.0	71.060	29.136	48.609	94.587	0.625	11.798	-0.470	0.105	11.431
12.0	67.315	32.880	44.865	81.373	0.577	12.204	-0.550	0.138	12.107
13.0	62.647	37.549	40.196	67.213	0.517	12.865	-0.660	0.182	13.050
14.0	59.418	40.778	36.967	58.648	0.475	12.974	-0.743	0.216	13.321
15.0	54.577	45.619	32.126	47.333	0.413	13.546	-0.884	0.273	14.117
16.0	52.530	47.665	30.080	43.020	0.387	13.269	-0.950	0.300	13.902
17.0	50.586	49.609	28.136	39.151	0.362	12.998	-1.016	0.327	13.681
18.0	48.688	51.507	26.238	35.571	0.337	12.746	-1.086	0.355	13.471
19.0	47.935	52.260	25.485	34.200	0.328	12.251	-1.115	0.367	12.969
20.0	45.600	54.595	23.150	30.123	0.298	12.159	-1.211	0.406	12.930
21.0	44.512	55.684	22.061	28.306	0.284	11.811	-1.260	0.425	12.585
22.0	42.753	57.442	20.303	25.476	0.261	11.630	-1.343	0.459	12.430
23.0	40.420	59.775	17.970	21.907	0.231	11.576	-1.465	0.509	12.418
24.0	38.465	61.730	16.015	19.069	0.206	11.457	-1.580	0.555	12.326
25.0	37.805	62.391	15.354	18.140	0.197	11.116	-1.622	0.572	11.971
26.0	35.872	64.324	13.421	15.502	0.173	11.020	-1.757	0.627	11.898
27.0	33.941	66.254	11.491	12.983	0.148	10.930	-1.912	0.690	11.831
28.0	32.205	67.991	9.754	10.809	0.125	10.816	-2.076	0.756	11.732
29.0	30.186	70.009	7.736	8.384	0.100	10.753	-2.308	0.850	11.691
30.0	29.623	70.572	7.173	7.727	0.092	10.478	-2.383	0.881	11.399
31.0	28.130	72.065	5.680	6.022	0.073	10.355	-2.616	0.975	11.282
32.0	26.549	73.646	4.099	4.274	0.053	10.251	-2.943	1.108	11.188
33.0	26.009	74.186	3.559	3.690	0.046	10.013	-3.084	1.165	10.934
34.0	25.647	74.549	3.196	3.302	0.041	9.766	-3.191	1.208	10.668

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 720 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, g (g/100 g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.340	0.000	77.857	351.606	1.000	0.000	0.000	-0.085	0.000
1.0	98.833	1.507	76.238	320.846	0.981	6.701	-0.020	-0.077	18.426
2.0	97.713	2.627	75.118	301.902	0.966	5.841	-0.034	-0.071	6.291
3.0	96.200	4.140	73.605	278.860	0.947	6.138	-0.055	-0.063	1.561
4.0	94.167	6.173	71.572	251.762	0.921	6.864	-0.083	-0.052	1.481
5.0	91.400	8.940	68.805	220.564	0.885	7.953	-0.122	-0.036	4.072
6.0	88.967	11.373	66.372	197.368	0.854	8.431	-0.158	-0.021	5.510
7.0	86.760	13.580	64.165	179.057	0.825	8.629	-0.192	-0.007	6.367
8.0	84.800	15.540	62.205	164.585	0.800	8.640	-0.223	0.005	6.850
9.0	83.013	17.327	60.418	152.642	0.777	8.563	-0.252	0.017	7.125
10.0	80.893	19.447	58.298	139.799	0.750	8.649	-0.288	0.032	7.518
11.0	79.080	21.260	56.485	129.806	0.727	8.596	-0.319	0.044	7.695
12.0	76.167	24.173	53.572	115.386	0.689	8.960	-0.372	0.066	8.321
13.0	72.900	27.440	50.305	101.227	0.647	9.388	-0.435	0.091	8.992
14.0	68.967	31.373	46.372	86.469	0.596	9.967	-0.517	0.124	9.816
15.0	65.260	35.080	42.665	74.414	0.549	10.402	-0.600	0.158	10.451
16.0	62.067	38.273	39.472	65.212	0.508	10.639	-0.678	0.190	10.839
17.0	57.853	42.487	35.258	54.460	0.454	11.116	-0.791	0.235	11.495
18.0	53.560	46.780	30.965	44.854	0.398	11.559	-0.921	0.288	12.101
19.0	50.980	49.360	28.385	39.636	0.365	11.555	-1.008	0.323	12.172
20.0	48.760	51.580	26.165	35.437	0.337	11.471	-1.089	0.356	12.143
21.0	47.768	52.572	25.173	33.642	0.324	11.135	-1.128	0.372	11.811
22.0	46.160	54.180	23.565	30.830	0.303	10.954	-1.194	0.399	11.656
23.0	44.807	55.533	22.212	28.554	0.286	10.739	-1.253	0.423	11.456
24.0	43.427	56.913	20.832	26.313	0.268	10.547	-1.317	0.449	11.279
25.0	42.007	58.333	19.412	24.087	0.250	10.378	-1.388	0.477	11.124
26.0	40.300	60.040	17.705	21.514	0.228	10.271	-1.480	0.515	11.039
27.0	39.040	61.300	16.445	19.682	0.212	10.098	-1.553	0.544	10.873
28.0	38.173	62.167	15.578	18.453	0.200	9.875	-1.608	0.566	10.647
29.0	36.640	63.700	14.045	16.340	0.181	9.770	-1.711	0.608	10.555
30.0	35.400	64.940	12.805	14.685	0.165	9.628	-1.804	0.646	10.419
31.0	33.973	66.367	11.378	12.839	0.146	9.522	-1.922	0.694	10.323

32.0	32.640	67.700	10.045	11.167	0.129	9.410	-2.046	0.744	10.2184
33.0	31.589	68.751	8.994	9.883	0.116	9.266	-2.157	0.789	10.074
34.0	31.073	69.267	8.478	9.264	0.109	9.061	-2.216	0.813	9.857
35.0	30.027	70.313	7.432	8.028	0.096	8.935	-2.348	0.866	9.732
36.0	29.247	71.093	6.652	7.126	0.086	8.784	-2.459	0.911	9.574
37.0	28.433	71.907	5.838	6.200	0.075	8.644	-2.589	0.964	9.430
38.0	27.967	72.373	5.372	5.677	0.069	8.471	-2.672	0.998	9.246
39.0	27.240	73.100	4.645	4.871	0.060	8.337	-2.818	1.057	9.106
40.0	26.100	74.240	3.505	3.632	0.045	8.255	-3.099	1.171	9.027
41.0	25.973	74.367	3.378	3.496	0.043	8.067	-3.136	1.186	8.823
42.0	25.760	74.580	3.165	3.268	0.041	7.898	-3.201	1.212	8.640

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 720 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0.0	100.340	0.000	77.857	351.606	1.000	0.000	0.000	-0.085	0.000
1.0	99.400	0.940	76.805	331.127	0.988	4.181	-0.012	-0.080	21.383
2.0	98.007	2.333	75.412	306.697	0.970	5.189	-0.030	-0.073	7.0565
3.0	96.827	3.513	74.232	288.073	0.955	5.209	-0.046	-0.066	2.6518
4.0	95.760	4.580	73.165	272.648	0.941	5.093	-0.061	-0.061	0.5973
5.0	94.007	6.333	71.412	249.793	0.919	5.634	-0.085	-0.051	1.3520
6.0	91.560	8.780	68.965	222.217	0.887	6.509	-0.120	-0.037	3.2546
7.0	89.953	10.387	67.358	206.357	0.866	6.600	-0.143	-0.027	3.9874
8.0	88.680	11.660	66.085	194.855	0.850	6.483	-0.162	-0.019	4.3195
9.0	86.080	14.260	63.485	173.860	0.817	7.047	-0.203	-0.003	5.3471
10.0	82.913	17.427	60.318	152.006	0.776	7.751	-0.254	0.018	6.4648
11.0	81.105	19.235	58.510	141.024	0.753	7.777	-0.284	0.030	6.7348
12.0	80.387	19.953	57.792	136.920	0.743	7.396	-0.297	0.035	6.4861
13.0	78.760	21.580	56.165	128.128	0.722	7.383	-0.325	0.047	6.6401
14.0	77.360	22.980	54.765	121.068	0.704	7.301	-0.350	0.057	6.6877
15.0	75.653	24.687	53.058	113.030	0.682	7.320	-0.382	0.070	6.8355
16.0	73.360	26.980	50.765	103.108	0.653	7.500	-0.426	0.088	7.1563
17.0	71.560	28.780	48.965	95.944	0.630	7.530	-0.462	0.102	7.2878
18.0	69.300	31.040	46.705	87.635	0.601	7.670	-0.510	0.121	7.5381
19.0	65.753	34.587	43.158	75.927	0.555	8.097	-0.589	0.153	8.1155
20.0	62.333	38.007	39.738	65.943	0.511	8.452	-0.671	0.187	8.6020
21.0	59.053	41.287	36.458	57.377	0.469	8.744	-0.757	0.222	9.0075
22.0	56.465	43.875	33.870	51.218	0.436	8.870	-0.831	0.252	9.2119
23.0	54.640	45.700	32.045	47.156	0.412	8.838	-0.886	0.274	9.2255
24.0	52.833	47.507	30.238	43.345	0.389	8.804	-0.944	0.298	9.2339
25.0	50.933	49.407	28.338	39.545	0.365	8.790	-1.009	0.324	9.2612
26.0	49.236	51.104	26.641	36.316	0.343	8.742	-1.071	0.349	9.2456
27.0	47.312	53.028	24.717	32.832	0.318	8.735	-1.146	0.379	9.2751
28.0	46.383	53.957	23.788	31.212	0.306	8.571	-1.184	0.395	9.1170
29.0	44.733	55.607	22.138	28.433	0.285	8.528	-1.256	0.424	9.0994
30.0	42.933	57.407	20.338	25.531	0.262	8.511	-1.341	0.458	9.1092
31.0	40.080	60.260	17.485	21.190	0.225	8.646	-1.492	0.520	9.2956

32.0	38.373	61.967	15.778	18.734	0.203	8.613	-1.595	0.561	9.2835
33.0	36.981	63.359	14.386	16.803	0.185	8.540	-1.687	0.599	9.2224
34.0	35.853	64.487	13.258	15.285	0.171	8.436	-1.769	0.632	9.1241
35.0	34.733	65.607	12.138	13.815	0.156	8.337	-1.857	0.668	9.0304
36.0	34.456	65.884	11.861	13.457	0.153	8.140	-1.880	0.677	8.8198
37.0	33.513	66.827	10.918	12.257	0.140	8.033	-1.963	0.710	8.7144
38.0	31.900	68.440	9.305	10.260	0.120	8.011	-2.123	0.775	8.7066
39.0	30.067	70.273	7.472	8.075	0.096	8.014	-2.342	0.864	8.7287
40.0	29.300	71.040	6.705	7.187	0.086	7.899	-2.451	0.908	8.6105
41.0	28.733	71.607	6.138	6.540	0.079	7.768	-2.539	0.944	8.4726
42.0	28.067	72.273	5.472	5.788	0.070	7.654	-2.654	0.990	8.3537
43.0	27.767	72.573	5.172	5.454	0.067	7.507	-2.710	1.013	8.1958
44.0	27.307	73.033	4.712	4.945	0.061	7.383	-2.803	1.051	8.0641
45.0	26.660	73.680	4.065	4.237	0.052	7.282	-2.951	1.111	7.9599
46.0	26.100	74.240	3.505	3.632	0.045	7.178	-3.099	1.171	7.8504
47.0	25.973	74.367	3.378	3.496	0.043	7.038	-3.136	1.186	7.6974

Thickness of drying bed 2 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	In (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.000	0.000	77.593	346.289	1.000	0.000	0.000	-0.085	0.000
1.0	98.310	1.690	75.903	314.989	0.978	7.542	-0.022	-0.076	17.452
2.0	96.310	3.690	73.903	283.186	0.952	8.234	-0.049	-0.065	3.497
3.0	94.240	5.760	71.833	255.025	0.926	8.569	-0.077	-0.054	1.275
4.0	91.387	8.613	68.980	222.373	0.889	9.610	-0.118	-0.037	4.686
5.0	89.043	10.957	66.636	199.724	0.859	9.780	-0.152	-0.023	6.199
6.0	86.980	13.020	64.573	182.271	0.832	9.684	-0.184	-0.011	6.964
7.0	83.010	16.990	60.603	153.826	0.781	10.832	-0.247	0.015	8.934
8.0	79.254	20.746	56.847	131.734	0.733	11.573	-0.311	0.041	10.272
9.0	73.450	26.550	51.043	104.261	0.658	13.166	-0.419	0.085	12.503
10.0	70.630	29.370	48.223	93.136	0.621	13.108	-0.476	0.108	12.727
11.0	66.890	33.110	44.483	80.125	0.573	13.433	-0.556	0.140	13.347
12.0	63.100	36.900	40.693	68.614	0.524	13.723	-0.645	0.176	13.886
13.0	60.470	39.530	38.063	61.454	0.491	13.571	-0.712	0.204	13.876
14.0	58.630	41.370	36.223	56.796	0.467	13.188	-0.762	0.224	13.572
15.0	54.765	45.235	32.358	47.837	0.417	13.459	-0.875	0.269	14.014
16.0	52.486	47.514	30.079	43.019	0.388	13.253	-0.948	0.299	13.883
17.0	51.900	48.100	29.493	41.830	0.380	12.627	-0.967	0.307	13.247
18.0	49.410	50.590	27.003	36.992	0.348	12.543	-1.056	0.343	13.234
19.0	47.540	52.460	25.133	33.570	0.324	12.322	-1.127	0.372	13.052
20.0	45.230	54.770	22.823	29.572	0.294	12.222	-1.224	0.411	13.003
21.0	43.134	56.866	20.727	26.146	0.267	12.085	-1.320	0.450	12.906
21.5	41.389	58.611	18.982	23.429	0.245	12.166	-1.408	0.486	13.030
22.0	39.410	60.590	17.003	20.486	0.219	12.291	-1.518	0.530	13.204
22.5	36.310	63.690	13.903	16.148	0.179	12.633	-1.719	0.612	13.631
23.0	33.540	66.460	11.133	12.528	0.143	12.896	-1.942	0.702	13.961
23.5	32.875	67.125	10.468	11.692	0.135	12.748	-2.003	0.727	13.815
24.0	31.490	68.510	9.083	9.990	0.117	12.740	-2.145	0.784	13.829
24.5	29.984	70.016	7.577	8.198	0.098	12.754	-2.326	0.858	13.869
25.0	28.230	71.770	5.823	6.183	0.075	12.812	-2.590	0.964	13.958
25.5	27.890	72.110	5.483	5.801	0.071	12.620	-2.650	0.989	13.754
26.0	26.580	73.420	4.173	4.355	0.054	12.603	-2.923	1.099	13.753
26.5	25.860	74.140	3.453	3.576	0.045	12.486	-3.112	1.176	13.636
27.0	25.500	74.500	3.093	3.192	0.040	12.314	-3.222	1.221	13.453

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 900 W

Thickness of drying bed 4 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100 g bdm)	ln (MR)	F ₀	D _{eff} X 10 ⁹ (m ² /s)
0.0	100.516	0.000	77.993	354.407	1.000	0.000	0.000	-0.085	0.000
1.0	97.979	2.537	75.456	307.430	0.967	11.265	-0.033	-0.072	52.367
2.0	95.866	4.650	73.343	275.134	0.940	10.323	-0.061	-0.060	4.200
3.0	94.311	6.205	71.788	254.460	0.920	9.183	-0.083	-0.052	7.982
4.0	92.876	7.640	70.353	237.307	0.902	8.480	-0.103	-0.043	13.449
5.0	90.714	9.802	68.191	214.375	0.874	8.704	-0.134	-0.031	19.758
6.0	88.311	12.205	65.788	192.296	0.844	9.032	-0.170	-0.016	24.798
7.0	85.764	14.752	63.241	172.043	0.811	9.357	-0.210	0.000	28.826
8.0	83.416	17.100	60.893	155.711	0.781	9.490	-0.247	0.015	31.329
9.0	80.240	20.276	57.717	136.504	0.740	10.003	-0.301	0.037	35.190
10.0	77.484	23.032	54.961	122.031	0.705	10.226	-0.350	0.057	37.406
11.0	73.901	26.615	51.378	105.669	0.659	10.743	-0.417	0.084	40.783
12.0	70.300	30.216	47.777	91.488	0.613	11.180	-0.490	0.113	43.627
13.0	66.837	33.679	44.314	79.578	0.568	11.503	-0.565	0.144	45.815
14.0	63.583	36.933	41.060	69.664	0.526	11.713	-0.642	0.175	47.378
15.0	61.661	38.855	39.138	64.306	0.502	11.501	-0.690	0.194	46.886
16.0	60.252	40.264	37.729	60.589	0.484	11.173	-0.726	0.209	45.787
17.0	57.647	42.869	35.124	54.140	0.450	11.196	-0.798	0.238	46.283
18.0	53.908	46.608	31.385	45.741	0.402	11.497	-0.910	0.284	48.033
19.0	51.908	48.608	29.385	41.613	0.377	11.359	-0.976	0.310	47.695
20.0	50.389	50.127	27.866	38.632	0.357	11.128	-1.029	0.332	46.890
21.0	48.233	52.283	25.710	34.608	0.330	11.054	-1.110	0.365	46.794
22.0	45.477	55.039	22.954	29.793	0.294	11.108	-1.223	0.411	47.273
23.0	42.106	58.410	19.583	24.352	0.251	11.276	-1.382	0.475	48.268
24.0	38.360	62.155	15.838	18.818	0.203	11.499	-1.594	0.561	49.504
25.0	38.049	62.466	15.527	18.380	0.199	11.094	-1.614	0.569	47.782
26.0	37.428	63.088	14.905	17.515	0.191	10.774	-1.655	0.586	46.442
27.0	36.141	64.375	13.618	15.765	0.175	10.586	-1.745	0.622	45.713
28.0	35.155	65.360	12.633	14.459	0.162	10.364	-1.820	0.653	44.813
29.0	33.657	66.859	11.134	12.529	0.143	10.236	-1.947	0.704	44.343
30.0	32.057	68.459	9.534	10.538	0.122	10.132	-2.102	0.767	43.975
31.0	31.085	69.431	8.562	9.364	0.110	9.944	-2.209	0.810	43.209
32.0	29.577	70.939	7.054	7.589	0.090	9.843	-2.403	0.889	42.839
32.5	28.198	72.318	5.675	6.016	0.073	9.880	-2.621	0.977	43.063
33.0	27.102	73.413	4.580	4.799	0.059	9.877	-2.835	1.064	43.101
33.5	26.926	73.590	4.403	4.606	0.056	9.753	-2.874	1.080	42.567
34.0	26.488	74.028	3.965	4.128	0.051	9.667	-2.979	1.122	42.209
35.0	25.894	74.622	3.371	3.489	0.043	9.466	-3.141	1.188	41.356
36.0	25.802	74.714	3.279	3.390	0.042	9.215	-3.169	1.199	40.261

Data on Microwave drying of Nagpur mandarin juice using natural foaming agents

Microwave power 900 W

Thickness of drying bed 6 mm

Drying time (min)	Avg Initial wt. of sample (g)	Moisture removed (g)	Moisture content (%) wb	Moisture content (%) (db)	MR	Drying rate, (g/100g bdm)	ln (MR)	F ₀	D _{eff} x 10 ⁹ (m ² /s)
0.0	100.506	0.000	77.986	354.253	1.000	0.000	0.000	-0.085	0.00
1.0	99.591	0.916	77.070	336.116	0.988	4.066	-0.012	-0.080	-21.52
2.0	98.528	1.978	76.008	316.803	0.975	4.392	-0.026	-0.075	-7.999
3.0	96.238	4.269	73.717	280.477	0.945	6.318	-0.056	-0.062	-1.360
4.0	94.363	6.144	71.842	255.141	0.921	6.820	-0.082	-0.052	1.418
5.0	92.091	8.416	69.570	228.627	0.892	7.474	-0.114	-0.039	3.498
6.0	90.241	10.266	67.720	209.792	0.868	7.597	-0.141	-0.028	4.519
7.0	88.361	12.145	65.841	192.748	0.844	7.704	-0.169	-0.017	5.270
8.0	86.655	13.851	64.135	178.821	0.822	7.688	-0.196	-0.006	5.721
9.0	84.125	16.381	61.605	160.449	0.790	8.082	-0.236	0.010	6.547
10.0	81.674	18.832	59.154	144.822	0.759	8.362	-0.276	0.027	7.167
11.0	78.719	21.788	56.198	128.302	0.721	8.795	-0.328	0.048	7.913
12.0	74.881	25.625	52.361	109.912	0.671	9.482	-0.398	0.076	8.918
13.0	70.363	30.144	47.842	91.726	0.613	10.296	-0.489	0.113	10.040
14.0	65.922	34.584	43.402	76.683	0.557	10.969	-0.586	0.152	10.973
15.0	62.214	38.293	39.693	65.819	0.509	11.336	-0.675	0.189	11.527
16.0	57.786	42.720	35.266	54.478	0.452	11.856	-0.794	0.237	12.246
17.0	54.600	45.906	32.080	47.231	0.411	11.991	-0.888	0.275	12.501
18.0	52.096	48.410	29.576	41.997	0.379	11.942	-0.970	0.308	12.530
19.0	49.919	50.588	27.398	37.738	0.351	11.823	-1.046	0.339	12.467
20.0	47.279	53.227	24.759	32.906	0.317	11.817	-1.147	0.380	12.530
21.0	44.594	55.913	22.073	28.326	0.283	11.823	-1.262	0.426	12.598
22.0	40.216	60.291	17.695	21.500	0.227	12.169	-1.483	0.516	13.061
23.0	38.838	61.669	16.317	19.499	0.209	11.906	-1.564	0.549	12.805
24.0	37.088	63.419	14.567	17.051	0.187	11.734	-1.678	0.595	12.651
25.0	35.644	64.863	13.123	15.106	0.168	11.521	-1.782	0.637	12.445
26.0	34.467	66.039	11.947	13.567	0.153	11.279	-1.876	0.675	12.202
27.0	32.717	67.789	10.197	11.354	0.131	11.149	-2.034	0.739	12.087
28.0	30.859	69.647	8.339	9.098	0.107	11.045	-2.236	0.821	12.000
29.0	30.506	70.000	7.986	8.679	0.102	10.718	-2.279	0.838	11.650
30.0	29.591	70.916	7.070	7.608	0.091	10.496	-2.401	0.888	11.420
31.0	29.294	71.213	6.773	7.266	0.087	10.200	-2.444	0.905	11.102
32.0	28.113	72.394	5.592	5.923	0.072	10.046	-2.635	0.983	10.947
33.0	27.506	73.000	4.986	5.248	0.064	9.823	-2.750	1.029	10.711
34.0	27.244	73.263	4.723	4.958	0.061	9.568	-2.804	1.051	10.436
35.0	26.881	73.625	4.361	4.560	0.056	9.341	-2.884	1.084	10.192
36.0	26.681	73.825	4.161	4.342	0.053	9.106	-2.931	1.103	9.937
37.0	26.256	74.250	3.736	3.881	0.048	8.911	-3.039	1.146	9.729
38.0	26.163	74.344	3.642	3.780	0.047	8.687	-3.064	1.157	9.485
39.0	25.963	74.544	3.442	3.565	0.044	8.487	-3.120	1.180	9.269
40.0	25.750	74.756	3.230	3.337	0.041	8.299	-3.184	1.205	9.065
41.0	25.646	74.860	3.126	3.227	0.040	8.108	-3.217	1.219	8.857

APPENDIX- D
Modelling used in drying of artificial foamed Nagpur Mandarin juice

Mod el	DBT (mm)	MP W	Drying constants										Statistical parameters							
			k	K0	K1	K2	n	A	a ₀	B	C	G	I	R ²	χ ²	MBE	E _{RMS}	SEE	P(%)	
Lewis/ Newtons' model	2	180	0.05												0.9723	0.0053	0.0008	0.0109	0.0053	64.884
		360	0.06												0.9808	0.0034	0.0017	0.0100	0.0034	23.585
		540	0.09												0.9890	0.0019	-0.0028	0.0083	0.0019	38.015
		720	0.08												0.9818	0.0032	0.0014	0.0111	-0.9969	31.377
		900	0.12												0.9765	0.0044	0.0008	0.0128	-0.9957	33.727
		180	0.04												0.9705	0.0054	0.0050	0.0102	0.0054	32.457
	4	360	0.05												0.9843	0.0027	0.0037	0.0080	0.0027	17.816
		540	0.07												0.9814	0.0034	0.0023	0.0104	-0.9967	35.937
		720	0.09												0.9906	0.0017	0.0001	0.0079	-0.9983	28.483
		900	0.11												0.9889	0.0019	0.0001	0.0083	-0.9982	25.527
		180	0.04												0.9775	0.0041	0.0045	0.0083	0.0041	19.340
		360	0.06												0.9952	0.0008	0.0026	0.0041	0.0008	6.404
	6	540	0.07												0.9831	0.0030	-0.0004	0.0095	-0.9971	42.352
		720	0.10												0.9941	0.0011	-0.0013	0.0058	-0.9990	26.963
		900	0.08												0.9677	0.0066	0.0019	0.0148	-0.9937	59.741
		180	0.05					1.11							0.9803	0.0038	-0.0110	0.0092	0.0039	55.579
		360	0.07					1.09							0.9864	0.0024	-0.0079	0.0084	0.0025	20.275
		540	0.09					1.05							0.9907	0.0016	-0.0075	0.0076	0.0017	34.515
Henderson and Pabis	2	720	0.09					1.07							0.9861	0.0024	-0.0072	0.0097	-1.9977	28.053
		900	0.13					1.12							0.9853	0.0028	-0.0099	0.0101	-1.9973	28.154
		180	0.04					1.12							0.9809	0.0035	-0.0089	0.0082	0.0036	27.475
		360	0.05					1.09							0.9907	0.0016	-0.0061	0.0061	0.0016	14.751
		540	0.08					1.09							0.9875	0.0023	-0.0078	0.0086	0.0024	31.039
		720	0.10					1.08							0.9946	0.0010	-0.0068	0.0060	-1.9990	23.222
	4	900	0.12					1.08							0.9933	0.0012	-0.0065	0.0064	-1.9989	21.352
		180	0.04					1.12							0.9872	0.0024	-0.0078	0.0063	0.0024	15.077
		360	0.06					1.07							0.9980	0.0003	-0.0019	0.0026	0.0003	3.363
		540	0.07					1.07							0.9868	0.0023	-0.0078	0.0084	0.0024	37.774
		720	0.10					1.06							0.9965	0.0006	-0.0058	0.0045	-1.9994	0.065
		900	0.09					1.12							0.9774	0.0046	-0.0119	0.0124	-1.9955	51.622
	Mo	2	180	-0.02	-0.02	0.00		0.88		0.67	-0.52				0.9980	0.0004	-0.0002	0.0029	0.0004	8.007

difi ed He nd ers on an d Pe bis	4	360	-0.07	-0.07	-0.07		0.36	0.36	0.36	0.9864	0.0024	-0.0079	0.0084	0.0029	20.274
		540	-0.13	-0.12	-0.21		0.97	0.97	-0.97	0.9957	0.0007	-0.0043	0.0052	0.0009	21.633
		720	-0.09	-0.09	-0.09		0.23	0.24	0.60	0.9861	0.0024	-0.0072	0.0097	-5.9977	28.053
		900	-0.13	-0.13	-0.13		0.35	0.35	0.42	0.9853	0.0028	-0.0099	0.0101	-5.9973	28.154
		180	-0.02	-0.02	-0.52		0.77	0.77	0.00	0.9990	0.0002	0.0000	0.0019	0.0002	2.177
		360	-0.05	-0.05	-0.05		0.33	0.33	0.44	0.9907	0.0016	-0.0061	0.0061	0.0018	14.750
		540	-0.08	-0.08	-0.08		0.17	0.17	0.75	0.9875	0.0023	-0.0078	0.0086	0.0028	31.039
		720	-0.10	-0.10	-0.10		0.21	0.21	0.66	0.9946	0.0010	-0.0068	0.0060	-5.9990	23.223
		900	-0.12	-0.12	-0.12		0.23	0.23	0.62	0.9933	0.0012	-0.0065	0.0064	-5.9989	21.354
		180	-0.02	0.00	-0.02		0.62	-0.50	0.94	0.9969	0.0006	-0.0003	0.0031	0.0006	1.730
		360	-0.05	-0.03	-0.05		0.62	-0.33	0.76	0.9985	0.0003	0.0001	0.0023	0.0003	0.383
		540	-0.07	-0.07	-0.07		0.35	0.36	0.36	0.9868	0.0023	-0.0078	0.0084	0.0028	37.774
Pag es' mod el	6	720	-0.10	-0.10	-0.10		0.16	0.16	0.74	0.9965	0.0006	-0.0058	0.0045	-5.9994	0.065
		900	0.01	0.01	-0.03		-0.29	-0.29	1.60	0.9991	0.0002	0.0000	0.0025	-5.9998	3.114
		180	0.26			0.19				0.9723	0.0053	0.0008	0.0109	0.0055	64.920
		360	0.49			0.13				0.9808	0.0034	0.0017	0.0100	0.0035	23.588
		540	0.33			0.27				0.9890	0.0019	-0.0029	0.0083	0.0020	38.034
		720	0.62			0.13				0.9818	0.0032	0.0014	0.0111	-1.9969	31.378
		900	0.85			0.14				0.9765	0.0044	0.0008	0.0128	-1.9957	33.730
		180	0.34			0.11				0.9705	0.0054	0.0050	0.0102	0.0055	32.457
		360	0.41			0.12				0.9843	0.0027	0.0037	0.0080	0.0028	17.818
		540	0.59			0.12				0.9814	0.0034	0.0023	0.0104	0.0035	35.937
		720	0.66			0.14				0.9906	0.0019	0.0001	0.0085	-1.9982	30.764
		900	0.87			0.13				0.9889	0.0019	0.0001	0.0083	-1.9982	25.528
		180	0.27			0.13				0.9775	0.0041	0.0045	0.0083	0.0042	16.544
Log arith mic	6	360	0.25			0.23				0.9952	0.0008	0.0026	0.0041	0.0008	6.404
		540	0.55			0.12				0.9831	0.0030	-0.0004	0.0095	0.0031	42.357
		720	0.39			0.25				0.9941	0.0011	-0.0013	0.0058	-1.9990	0.081
		900	0.60			0.13				0.9677	0.0066	0.0019	0.0148	-1.9937	59.763
		180	0.02			1.71		-0.69		0.9981	0.0004	0.0000	0.0029	0.0004	8.539
		360	0.03			1.59		-0.57		0.9991	0.0002	0.0000	0.0022	0.0002	1.253
		540	0.05			1.30		-0.31		0.9992	0.0001	0.0000	0.0022	0.0001	0.412
		720	0.04			1.71		-0.71		0.9993	0.0001	0.0000	0.0022	-2.9999	1.039
		900	0.07			1.49		-0.44		0.9981	0.0004	0.0000	0.0037	-2.9996	3.206
		180	0.01			2.07		-1.04		0.9991	0.0002	0.0000	0.0018	0.0002	2.242
		360	0.03			1.45		-0.42		0.9994	0.0001	0.0000	0.0016	0.0001	0.347
		540	0.04			1.56		-0.53		0.9994	0.0001	0.0000	0.0019	0.0001	0.292
		720	0.07			1.20		-0.16		0.9992	0.0002	0.0000	0.0025	-2.9998	1.413

Two - term	6	900	0.08		1.26		-0.22	0.9992	0.0001	0.0000	0.0023	-2.9999	1.467
		180	0.02		1.44		-0.38	0.9969	0.0006	0.0000	0.0031	0.0006	2.143
		360	0.06		1.09		-0.03	0.9984	0.0003	0.0000	0.0024	0.0003	0.372
		540	0.03		1.55		-0.55	0.9992	0.0001	0.0000	0.0020	0.0001	0.214
		720	0.08		1.12		-0.09	0.9990	0.0002	0.0000	0.0024	-2.9998	0.006
		900	0.03		2.14		-1.12	0.9992	0.0002	0.0000	0.0024	-2.9998	3.114
	2	180	0.05	0.05	0.51	0.60		0.9803	0.0038	-0.0110	0.0092	0.0041	55.577
		360	0.07	0.07	0.78	0.31		0.9864	0.0024	-0.0079	0.0084	0.0027	20.273
		540	0.09	0.09	0.52	0.53		0.9907	0.0016	-0.0075	0.0076	0.0018	34.516
		720	0.09	0.09	0.54	0.54		0.9861	0.0024	-0.0072	0.0097	-3.9977	28.054
		900	0.25	0.23	-10.23	11.21		0.9985	0.0003	-0.0029	0.0032	-3.9997	10.175
		180	0.04	0.04	0.56	0.56		0.9809	0.0035	-0.0089	0.0082	0.0037	27.474
	4	360	0.05	0.05	0.45	0.64		0.9907	0.0016	-0.0061	0.0061	0.0017	14.750
		540	0.08	0.08	0.55	0.55		0.9875	0.0023	-0.0078	0.0086	0.0025	31.038
		720	0.10	0.10	0.53	0.55		0.9946	0.0011	-0.0073	0.0065	-3.9990	25.082
		900	0.19	0.21	9.32	-8.31		0.9984	0.0003	-0.0017	0.0032	-3.9997	9.817
		180	0.04	0.04	0.56	0.56		0.9872	0.0024	-0.0078	0.0063	0.0025	15.076
		360	0.06	0.06	0.52	0.55		0.9980	0.0003	-0.0019	0.0026	0.0004	3.363
Two - term exp one ntial	6	540	0.07	0.07	0.64	0.43		0.9868	0.0023	-0.0078	0.0084	0.0026	37.774
		720	0.10	0.10	0.38	0.69		0.9965	0.0006	-0.0058	0.0045	-3.9994	0.065
		900	0.09	0.09	0.57	0.56		0.9774	0.0046	-0.0119	0.0124	-3.9955	51.624
		180	23.05		0.00			0.9720	0.0055	0.0050	0.0102	0.0056	65.802
		360	0.09		1.89			0.9958	0.0008	-0.0058	0.0047	0.0008	10.942
		540	0.12		1.74			0.9954	0.0008	-0.0059	0.0054	0.0008	22.614
	2	720	0.12		1.85			0.9940	0.0011	-0.0055	0.0064	-1.9990	18.220
		900	0.18		2.01			0.9978	0.0004	-0.0049	0.0039	-1.9996	12.916
		180	18.58		0.00			0.9701	0.0036	0.0050	0.0083	0.0037	32.660
		360	0.07		1.88			0.9977	0.0004	-0.0029	0.0031	0.0004	7.112
		540	0.10		1.89			0.9958	0.0008	-0.0048	0.0050	0.0008	18.551
		720	34.33		0.00			0.9904	0.0018	-0.0006	0.0080	-1.9983	29.288
	4	900	0.16		1.83			0.9982	0.0003	-0.0019	0.0033	-1.9997	10.756
		180	19.16		0.00			0.9772	0.0042	0.0037	0.0083	0.0043	19.863
		360	0.08		1.70			0.9987	0.0002	0.0029	0.0021	0.0002	2.477
		540	0.10		1.81			0.9934	0.0012	-0.0061	0.0059	0.0012	25.703
		720	0.13		1.74			0.9992	0.0002	-0.0013	0.0022	-1.9999	0.026
		900	0.12		2.02			0.9933	0.0014	-0.0095	0.0068	-1.9987	31.327
Diffu sion	2	180	0.10		-22.79	0.96		0.9945	0.0011	-0.0083	0.0049	0.0011	30.064
		360	0.13		-12.88	0.94		0.9965	0.0006	-0.0053	0.0043	0.0007	9.606

appr oac h	4	540	0.09	0.27	1.00			0.9890	0.0019	-0.0028	0.0083	0.0021	38.028
		720	0.01	-1.69	2.93			0.9992	0.0001	0.0001	0.0023	-2.9999	1.068
		900	0.25	-16.31	0.94			0.9985	0.0003	-0.0038	0.0033	-2.9997	10.573
		180	0.08	-14.79	0.94			0.9956	0.0008	-0.0062	0.0039	0.0008	13.801
		360	0.10	-9.85	0.93			0.9980	0.0003	-0.0025	0.0028	0.0004	6.239
		540	0.14	-13.01	0.94			0.9963	0.0007	-0.0043	0.0047	0.0007	16.885
		720	0.18	-9.16	0.93			0.9990	0.0002	-0.0015	0.0029	-2.9998	9.509
		900	0.21	-9.72	0.93			0.9984	0.0003	-0.0014	0.0032	-2.9997	9.671
		180	0.08	-12.97	0.93			0.9990	0.0002	-0.0032	0.0018	0.0002	3.423
		360	0.41	-0.15	0.16			0.9993	0.0001	0.0003	0.0016	0.0001	0.154
		540	0.13	-14.18	0.95			0.9940	0.0011	-0.0057	0.0057	0.0011	23.927
		720	0.05	-3.55	1.18			0.9987	0.0002	0.0026	0.0027	-2.9998	0.009
	6	900	0.17	-22.74	0.96			0.9946	0.0011	-0.0086	0.0061	-2.9989	27.804
		180		1.11		0.00	0.23	0.9803	0.0038	-0.0110	0.0092	0.0040	55.573
		360		1.09		919.96	116.13	0.9864	0.0024	-0.0079	0.0084	0.0026	20.274
		540		1.05		400.84	65.63	0.9907	0.0016	-0.0075	0.0076	0.0018	34.510
		720		1.07		4200.8	219.60	0.9861	0.0024	-0.0072	0.0097	-2.9977	28.053
		900		1.12		0.01	0.22	0.9853	0.0028	-0.0099	0.0101	-2.9973	28.154
		180		1.12		623.08	121.63	0.9809	0.0022	-0.0089	0.0066	0.0023	27.474
		360		1.09		2190.9	201.99	0.9907	0.0016	-0.0061	0.0061	0.0017	14.744
		540		1.09		29218	195.79	0.9875	0.0023	-0.0078	0.0086	0.0025	31.041
		720		1.08		590.47	75.95	0.9946	0.0011	-0.0073	0.0065	-2.9990	25.081
		900		1.08		896.01	85.29	0.9933	0.0012	-0.0065	0.0064	-2.9989	21.351
		180		1.12		528.82	115.30	0.9872	0.0024	-0.0078	0.0063	0.0018	15.076
2	360		1.07		29.23	21.87	0.9980	0.0003	-0.0019	0.0026	0.0003	3.364	
	540		1.07		0.01	0.29	0.9875	0.0023	-0.0079	0.0084	0.0025	37.781	
	720		1.06		839.36	90.74	0.9965	0.0006	-0.0058	0.0045	-2.9994	0.065	
	900		1.12		0.00	0.22	0.9774	0.0046	-0.0119	0.0124	-2.9955	51.623	
	180	0.10	0.10			0.10	0.7008	0.0496	0.1855	0.0332	0.0521	52.498	
	360	0.10	0.00			0.10	0.8517	0.0247	0.1324	0.0269	0.0264	35.177	
	540	0.16	-8.68			0.15	0.9958	0.0007	-0.0055	0.0051	0.0008	20.984	
	720	0.16	-10.23			0.15	0.9946	0.0010	-0.0052	0.0061	-2.9991	16.909	
	900	0.02	-2.15			0.04	0.9969	0.0006	0.0044	0.0047	-2.9994	4.391	
	180	0.00	-1.76			0.01	0.9984	0.0003	0.0033	0.0024	0.0003	3.202	
	360	0.10	-8.97			0.09	0.9980	0.0003	-0.0025	0.0028	0.0004	6.241	
	540	0.14	-8.56			0.13	0.9963	0.0007	-0.0041	0.0047	0.0007	16.840	
4	720	0.18	-6.14			0.16	0.9989	0.0002	-0.0014	0.0029	-2.9998	9.496	
	900	0.03	-1.27			0.06	0.9987	0.0002	0.0024	0.0028	-2.9998	0.690	

Midil li et al	6	180	0.01			-2.13			0.01	0.9953	0.0009	0.0054	0.0038	0.0009	2.899
		360	0.41			-0.15			0.07	0.9993	0.0001	0.0003	0.0016	0.0001	0.154
		540	0.13			-14.41			0.12	0.9940	0.0011	-0.0058	0.0057	0.0011	23.934
		720	0.17			-4.47			0.15	0.9992	0.0001	-0.0008	0.0021	-2.9999	0.022
		900	0.17			-14.10			0.16	0.9945	0.0011	-0.0085	0.0061	-2.9989	27.766
	2	180	0.01	1.36	0.98	0.00				0.9989	0.0002	0.0000	0.0021	0.0002	2.898
		360	0.03	1.20	0.99	0.00				0.9993	0.0001	0.0000	0.0019	0.0001	0.546
		540	0.07	0.97	1.00	-0.01				0.9993	0.0001	0.0000	0.0021	0.0001	1.520
		720	0.05	0.96	1.01	-0.01				0.9993	0.0001	0.0000	0.0022	-3.9999	0.528
		900	0.04	1.39	1.00	0.00				0.9997	0.0001	0.0000	0.0014	-4.0000	0.531
	4	180	0.01	1.31	1.00	0.00				0.9996	0.0001	0.0000	0.0012	0.0001	0.628
		360	0.03	1.14	1.01	0.00				0.9996	0.0001	0.0000	0.0014	0.0001	0.210
		540	0.04	1.09	1.01	-0.01				0.9995	0.0001	0.0000	0.0018	0.0001	0.333
		720	0.06	1.14	1.01	0.00				0.9996	0.0001	0.0000	0.0018	-3.9999	0.729
		900	0.08	1.11	1.02	0.00				0.9994	0.0001	0.0000	0.0020	-3.9999	2.376
	6	180	0.01	1.52	0.98	0.00				0.9996	0.0001	0.0000	0.0011	0.0001	0.029
		360	0.04	1.18	1.01	0.00				0.9992	0.0001	0.0001	0.0017	0.0001	0.915
		540	0.05	0.92	1.01	-0.01				0.9994	0.0001	0.0000	0.0018	0.0001	1.241
		720	0.07	1.14	1.01	0.00				0.9994	0.0001	0.0000	0.0018	-3.9999	0.003
		900	0.02	1.34	0.99	-0.01				0.9998	0.0000	0.0000	0.0012	-4.0000	0.092
Wan g and sing	2	180				-0.03	0.00			0.9982	0.0004	0.0028	0.0028	0.0004	7.453
		360				-0.04	0.00			0.9993	0.0001	0.0015	0.0019	0.0001	0.931
		540				-0.07	0.00			0.9984	0.0003	-0.0031	0.0032	0.0003	3.160
		720				-0.06	0.00			0.9992	0.0002	-0.0004	0.0024	-1.9999	1.637
		900				-0.08	0.00			0.9976	0.0005	0.0049	0.0041	-1.9996	2.835
	4	180				-0.03	0.00			0.9986	0.0003	0.0037	0.0022	0.0003	2.922
		360				-0.04	0.00			0.9991	0.0002	0.0027	0.0019	0.0002	0.426
		540				-0.05	0.00			0.9992	0.0002	0.0017	0.0022	0.0002	0.075
		720				-0.07	0.00			0.9989	0.0002	0.0016	0.0030	-1.9998	1.839
		900				-0.08	0.00			0.9987	0.0002	0.0013	0.0029	-1.9998	2.693
	6	180				-0.03	0.00			0.9963	0.0007	0.0062	0.0034	0.0007	2.095
		360				-0.04	0.00			0.9974	0.0004	0.0010	0.0030	0.0004	1.433
		540				-0.05	0.00			0.9989	0.0002	-0.0013	0.0024	0.0002	1.676
		720				-0.07	0.00			0.9983	0.0003	-0.0009	0.0031	-1.9997	0.021
		900				-0.05	0.00			0.9989	0.0002	0.0031	0.0027	-1.9998	3.678
Tho mos e	2	180				-24.05	-3.55			0.9908	3.0349	0.5724	0.2596	3.1072	8.092
		360				-19.95	-3.32			0.9965	0.6576	0.1829	0.1390	0.6788	4.325
		540				-13.81	-1.92			0.9979	0.2634	0.0319	0.0969	0.2739	0.328

Wel bulli distri buti on	4	720				-15.47	-2.57	0.9983	0.1797	0.1026	0.0831	-1.8275	3.237
		900				-10.38	-1.54	0.9957	0.2557	0.1698	0.0972	-1.7541	7.131
		180				-33.27	-5.89	0.9933	2.9618	0.6009	0.2386	3.0222	8.782
		360				-25.30	-4.12	0.9988	0.3527	0.2100	0.0916	0.3617	5.560
		540				-17.73	-2.81	0.9974	0.4101	0.1885	0.1150	0.4248	5.265
		720				-12.50	-1.52	0.9989	0.1473	0.0950	0.0752	-1.8586	4.772
		900				-11.06	-1.58	0.9991	0.0636	0.0340	0.0476	-1.9387	2.937
		180				-33.46	-4.93	0.9941	3.4987	0.6451	0.2414	3.5600	9.295
		360				-18.81	-1.12	0.9978	0.7975	0.1272	0.1302	0.8156	4.899
		540				-18.47	-2.88	0.9972	0.4988	0.1137	0.1229	0.5154	2.938
	6	720				-12.04	-1.18	0.9989	0.1675	0.0411	0.0735	-1.8381	0.008
		900				-16.14	-2.69	0.9933	0.8578	0.3247	0.1690	-1.1717	7.786
		180	0.01		1.32	-0.19	-1.17	0.9990	0.0002	0.0000	0.0021	0.0002	2.805
		360	0.03		1.16	-0.27	-1.26	0.9994	0.0001	0.0000	0.0018	0.0001	0.546
		540	0.06		0.95	-0.40	-1.40	0.9993	0.0001	0.0000	0.0021	0.0001	1.278
		720	0.03		0.95	-0.94	-1.95	0.9993	0.0001	0.0000	0.0022	-3.9999	0.638
		900	0.04		1.37	-0.07	-1.08	0.9997	0.0001	0.0000	0.0014	-4.0000	0.588
		180	0.01		1.26	-0.30	-1.30	0.9996	0.0001	0.0000	0.0012	0.0001	0.596
		360	0.02		1.12	-0.23	-1.24	0.9995	0.0001	0.0000	0.0014	0.0001	0.274
		540	0.03		1.07	-0.38	-1.39	0.9994	0.0001	0.0000	0.0018	0.0001	0.500
	2	720	0.06		1.13	-0.07	-1.09	0.9996	0.0001	0.0000	0.0018	-3.9999	1.001
		900	0.07		1.09	-0.13	-1.15	0.9993	0.0001	0.0000	0.0020	-3.9999	2.630
		180	0.01		1.52	0.00	-0.98	0.9996	0.0001	0.0000	0.0011	0.0001	0.041
		360	0.03		1.20	0.03	-0.98	0.9992	0.0001	0.0000	0.0016	0.0001	1.055
		540	0.03		0.91	-0.91	-1.93	0.9994	0.0001	0.0000	0.0018	0.0001	0.967
		720	0.06		1.13	-0.03	-1.04	0.9994	0.0001	0.0000	0.0018	-3.9999	0.004
		900	0.02		1.28	-0.31	-1.30	0.9998	0.0000	0.0000	0.0012	-4.0000	0.029
		180		-53.50	-53.55			0.9723	0.0053	0.0008	0.0109	0.0055	64.882
		360		-52.55	-52.62			0.9808	0.0034	0.0017	0.0100	0.0035	23.587
		540		-86.77	-86.86			0.9890	0.0019	-0.0028	0.0083	0.0020	38.016
Aghl ash o et al	4	720				-55.76	-55.84	0.9818	0.0032	0.0014	0.0111	-1.9969	31.377
		900				-59.12	-59.24	0.9765	0.0044	0.0008	0.0128	-1.9957	33.730
		180				-51.54	-51.50	0.9705	0.0054	0.0050	0.0102	0.0055	32.457
		360				-56.98	-57.03	0.9843	0.0027	0.0037	0.0080	0.0028	17.816
		540				-56.78	-56.85	0.9814	0.0034	0.0023	0.0104	0.0035	35.937
		720				-127.09	-127.18	0.9906	0.0019	0.0001	0.0085	-1.9982	30.762
		900				-168.74	-168.85	0.9889	0.0019	0.0001	0.0083	-1.9982	25.528
		180				-55.98	-56.01	0.9775	0.0041	0.0045	0.0083	0.0042	19.338

Logistic	2	360		-99.71	-99.77					0.9952	0.0008	0.0026	0.0041	0.0008	6.404
		540		-50.86	-50.92					0.9831	0.0030	-0.0004	0.0095	0.0031	42.354
		720		-97.55	-97.65					0.9941	0.0011	-0.0013	0.0058	-1.9990	0.081
		900		-86.89	-86.97					0.9677	0.0066	0.0019	0.0148	-1.9937	59.738
		180	0.11			0.21	1.17			0.9978	0.0004	-0.0028	0.0031	0.0004	15.973
		360	0.13			0.31	1.28			0.9984	0.0003	-0.0019	0.0029	0.0003	4.824
		540	0.14			0.59	1.55			0.9967	0.0006	-0.0030	0.0045	0.0006	16.281
		720	0.16			1.34	0.37			0.9964	0.0006	-0.0025	0.0049	-2.9994	11.952
		900	0.24			0.28	1.29			0.9994	0.0001	-0.0011	0.0020	-2.9999	5.230
		180	0.09			0.22	1.20			0.9982	0.0003	-0.0022	0.0025	0.0003	7.178
		360	0.09			0.48	1.49			0.9986	0.0001	0.0000	0.0013	0.0001	0.200
		540	0.13			0.40	1.39			0.9973	0.0005	-0.0025	0.0040	0.0005	12.636
	4	720	0.15			0.79	1.81			0.9990	0.0002	-0.0016	0.0028	-2.9998	8.332
		900	0.18			0.71	1.73			0.9985	0.0003	-0.0014	0.0031	-2.9997	8.650
		180	0.04			-875.16	-980.62			0.9872	0.0024	-0.0078	0.0063	0.0024	15.082
		360	0.07			2.27	3.39			0.9989	0.0002	0.0008	0.0020	0.0002	1.393
		540	0.12			1.38	0.42			0.9956	0.0008	-0.0033	0.0048	0.0008	17.801
		720	0.14			1.07	2.08			0.9993	0.0001	-0.0009	0.0021	-2.9999	0.020
		900	0.18			0.18	1.15			0.9981	0.0004	-0.0030	0.0036	-2.9996	15.009
		180	0.03			1.41		0.04	-0.43	0.9985	0.0003	0.0000	0.0025	0.0005	5.944
		360	0.04			1.43		0.02	-0.43	0.9993	0.0001	0.0000	0.0020	0.0005	0.865
		540	0.05			1.35		-0.01	-0.35	0.9993	0.0001	0.0000	0.0021	0.0004	1.036
	6	720	0.03			1.77		0.00	-0.76	0.9993	0.0001	0.0035	0.0022	-3.9999	0.864
		900	0.11			1.21		0.10	-0.21	0.9995	0.0001	0.0000	0.0019	-3.9999	0.912
		180	0.02			1.58		0.03	-0.60	0.9995	0.0001	0.0000	0.0014	0.0003	1.263
		360	0.04			1.29		0.03	-0.29	0.9996	0.0001	0.0000	0.0013	0.0001	0.200
		540	0.04			1.42		0.02	-0.41	0.9995	0.0001	0.0000	0.0017	0.0002	0.577
		720	0.10			1.10		0.06	-0.10	0.9997	0.0001	0.0045	0.0015	-3.9999	0.702
		900	0.10			1.15		0.05	-0.15	0.9995	0.0001	0.0000	0.0018	-3.9999	2.760
		180	0.04			1.12		0.08	-0.16	0.9985	0.0003	0.0000	0.0021	0.0005	1.370
		360	0.08			0.98		0.07	0.01	0.9993	0.0001	0.0000	0.0016	0.0001	0.621
		540	0.03			1.68		-0.01	-0.67	0.9993	0.0001	0.0000	0.0019	0.0002	0.510
		720	0.10			1.05		0.05	-0.05	0.9995	0.0001	0.0000	0.0018	-3.9999	0.001
		900	0.04			1.63		0.04	-0.64	0.9996	0.0001	0.0000	0.0017	-3.9999	1.420
Demir et al	2	180	0.15			0.15	1.71		-0.69	0.9981	0.0003	0.0000	0.0025	0.0005	33.998
		360	-0.17			-0.18	1.59		-0.57	0.9991	0.0002	0.0000	0.0022	0.0001	1.248
		540	-0.23			-0.23	1.30		-0.31	0.9992	0.0001	0.0000	0.0022	0.0001	0.415
		720	-0.02			0.03	-64.31		65.24	0.9929	0.0012	0.0000	0.0069	-3.9988	10.117

4	900	-0.26	-0.25	1.49	-0.44	0.9981	0.0004	0.0000	0.0037	-3.9996	3.206
	180	-0.01	0.03	-63.08	64.05	0.9947	0.0010	-0.0002	0.0044	0.0001	3.116
	360	0.16	0.18	1.45	-0.42	0.9994	0.0001	0.0000	0.0016	0.0000	0.347
	540	-0.20	-0.18	1.56	-0.53	0.9994	0.0001	0.0000	0.0019	0.0001	0.292
	720	-0.25	-0.30	1.20	-0.16	0.9992	0.0002	0.0000	0.0025	-3.9998	1.412
	900	-0.29	-0.28	1.26	-0.22	0.9992	0.0001	0.0000	0.0023	-3.9999	1.470
6	180	0.14	0.15	1.44	-0.38	0.9969	0.0006	0.0000	0.0031	0.0001	2.224
	360	0.20	-0.03	1.09	0.28	0.9984	0.0003	0.0000	0.0024	0.0001	0.593
	540	-0.01	0.04	-61.94	62.85	0.9902	0.0017	-0.0001	0.0072	0.0003	19.045
	720	0.26	0.32	1.12	-0.09	0.9990	0.0002	0.0000	0.0024	-3.9998	0.006
	900	-0.02	0.03	-62.28	63.25	0.9952	0.0010	-0.0002	0.0057	-3.9990	15.719

APPENDIX E

Modelling used in drying of natural foamed Nagpur Mandarin juice

Model	DBT (mm)	MP W	k	K ₀	K ₁	K ₂	n	Drying constant							Statistical parameters					
								A	a ₀	B	c	d	g	l	R ²	χ ²	MBE	E _{RMS}	SEE	P(%)
Lewis/ Newtons' model	2	180	0.021												0.9696	0.0022	0.0082	0.0053	0.0022	4.375
		360	0.028												0.9440	0.0050	0.0080	0.0088	0.0050	19.767
		540	0.043												0.9281	0.0076	0.0081	0.0126	0.0076	28.398
		720	0.057												0.9386	0.0063	0.0072	0.0132	-0.9939	30.254
		900	0.063												0.9163	0.0084	0.0067	0.0155	-0.9918	43.414
	4	180	0.019												0.9692	0.0021	0.0064	0.0051	0.0021	5.637
		360	0.026												0.9384	0.0058	0.0076	0.0090	0.0058	22.157
		540	0.037												0.9462	0.0051	0.0064	0.0097	-0.9950	23.158
		720	0.050												0.9343	0.0069	0.0058	0.0125	-0.9933	31.774
		900	0.054												0.9334	0.0069	0.0053	0.0131	-0.9933	38.113
	6	180	0.021												0.9751	0.0018	0.0060	0.0047	0.0018	5.229
		360	0.025												0.9397	0.0057	0.0090	0.0087	0.0057	15.767
		540	0.040												0.9453	0.0056	0.0059	0.0098	-0.9945	22.498
		720	0.040												0.9184	0.0085	0.0073	0.0132	0.0085	36.940
		900	0.055												0.9109	0.0106	0.0051	0.0157	-0.9896	49.169
Henderson and Pabis	2	180	0.023					1.095							0.9866	0.0010	-0.0031	0.0035	0.0010	3.480
		360	0.033					1.131							0.9689	0.0028	-0.0071	0.0066	0.0028	16.229
		540	0.051					1.168							0.9612	0.0041	-0.0104	0.0093	0.0042	21.971
		720	0.066					1.145							0.9653	0.0035	-0.0092	0.0099	-1.9966	24.264
		900	0.073					1.150							0.9446	0.0056	-0.0103	0.0126	-1.9946	37.502
	4	180	0.021					1.077							0.9813	0.0013	-0.0030	0.0039	0.0013	4.935
		360	0.030					1.143							0.9656	0.0032	-0.0083	0.0067	0.0033	17.807
		540	0.043					1.136							0.9701	0.0028	-0.0083	0.0073	0.0029	18.404
		720	0.058					1.154							0.9617	0.0040	-0.0104	0.0096	-1.9961	24.677
		900	0.062					1.145							0.9592	0.0042	-0.0108	0.0103	-1.9959	31.346
	6	180	0.023					1.082							0.9869	0.0009	-0.0028	0.0034	0.0010	4.074

Mo difi ed He nd ers on an d Pa bis	2	360	0.030			1.150			0.9694	0.0029	-0.0074	0.0062	0.0029	11.994
		540	0.046			1.156			0.9721	0.0028	-0.0086	0.0070	0.0029	15.906
		720	0.047			1.158			0.9492	0.0053	-0.0113	0.0104	0.0054	30.285
		900	0.065			1.188			0.9459	0.0064	-0.0144	0.0122	-1.9937	37.792
		180	0.033	-0.009	0.018	0.069	1.305	-0.344	0.9988	0.0001	-0.0003	0.0010	0.0001	0.133
		360	0.052	-0.016	0.028	0.022	1.178	-0.159	0.9969	0.0003	-0.0005	0.0021	0.0003	0.752
		540	0.026	0.046	-0.002	-1.633	0.425	2.259	0.9973	0.0003	-0.0006	0.0025	0.0003	0.247
		720	-0.032	-0.032	0.000	0.808	0.808	-0.543	0.9912	0.0009	0.0000	0.0050	-5.9991	2.419
		900	0.017	0.017	-0.021	-0.277	-0.277	1.591	0.9951	0.0005	0.0000	0.0037	-5.9995	0.434
		180	-0.018	0.138	0.138	-0.188	0.188	1.038	0.9979	0.0001	-0.0002	0.0013	0.0001	0.118
	4	360	0.047	0.053	-0.016	-0.148	0.087	1.105	0.9973	0.0002	-0.0016	0.0018	0.0003	1.279
		540	-0.019	-0.019	-0.003	0.945	0.945	-0.827	0.9943	0.0005	0.0000	0.0032	0.0006	1.619
		720	-0.029	-0.030	-0.004	0.837	0.837	-0.589	0.9863	0.0014	-0.0003	0.0057	-5.9986	3.999
		900	0.010	-0.029	-0.030	-0.327	0.694	0.694	0.9939	0.0006	-0.0003	0.0040	-5.9994	2.773
	6	180	0.022	0.006	-0.015	0.022	-0.242	1.256	0.9944	0.0004	-0.0004	0.0022	0.0004	0.394
		360	0.037	0.047	-0.014	-0.181	0.078	1.158	0.9954	0.0004	-0.0008	0.0024	0.0005	0.532
		540	0.013	0.026	-0.006	-2.702	0.778	2.989	0.9935	0.0007	-0.0006	0.0034	0.0007	0.285
		720	-0.018	-0.019	0.003	1.228	0.474	-0.634	0.9899	0.0011	-0.0001	0.0046	0.0012	4.200
		900	-0.031	-0.031	-0.010	1.029	1.029	-0.940	0.9757	0.0029	0.0000	0.0082	-5.9972	6.612
		180	0.360			0.057			0.9696	0.0022	0.0082	0.0053	0.0022	4.376
Pa ge s' mo del	2	360	0.213			0.133			0.9440	0.0050	0.0080	0.0088	0.0051	19.776
		540	0.243			0.178			0.9281	0.0076	0.0080	0.0126	0.0078	28.425
		720	0.135			0.424			0.9386	0.0063	0.0072	0.0132	-1.9939	30.266
		900	0.092			0.687			0.9163	0.0084	0.0067	0.0155	-1.9918	43.411
	4	180	0.119			0.160			0.9692	0.0021	0.0064	0.0051	0.0021	5.634
		360	0.438			0.060			0.9384	0.0058	0.0076	0.0090	0.0059	22.160
		540	0.196			0.190			0.9462	0.0051	0.0063	0.0097	0.0052	23.174
		720	0.431			0.116			0.9343	0.0069	0.0058	0.0125	-1.9933	31.772
	6	900	0.435			0.123			0.9334	0.0069	0.0053	0.0131	-1.9933	38.112
		180	0.116			0.182			0.9751	0.0018	0.0060	0.0047	0.0018	5.233
		360	0.226			0.112			0.9397	0.0057	0.0090	0.0087	0.0058	15.767
		540	0.332			0.119			0.9453	0.0056	0.0059	0.0098	0.0057	22.500
		720	0.293			0.137			0.9184	0.0085	0.0073	0.0132	0.0087	36.942

Lo gar ith mic	2	900	0.155	0.355		0.9109	0.0106	0.0052	0.0157	-1.9896	49.166
		180	0.013	1.475	-0.428	0.9972	0.0002	0.0000	0.0016	0.0002	0.220
		360	0.012	1.894	-0.844	0.9965	0.0003	0.0000	0.0022	0.0003	0.428
		540	0.025	1.611	-0.518	0.9887	0.0012	0.0000	0.0050	0.0012	3.212
		720	0.032	1.614	-0.542	0.9912	0.0009	0.0000	0.0050	-2.9991	2.722
		900	0.008	4.976	-3.940	0.9952	0.0005	0.0000	0.0037	-2.9995	0.586
	4	180	0.009	1.792	-0.775	0.9965	0.0002	0.0000	0.0017	0.0002	0.370
		360	0.012	1.812	-0.752	0.9950	0.0005	0.0000	0.0026	0.0005	1.765
		540	0.021	1.588	-0.525	0.9942	0.0006	0.0000	0.0032	0.0006	1.813
		720	0.031	1.501	-0.417	0.9861	0.0015	0.0000	0.0059	-2.9985	4.819
		900	0.024	1.842	-0.784	0.9943	0.0006	0.0000	0.0038	-2.9994	3.243
		180	0.015	1.323	-0.284	0.9943	0.0007	0.0000	0.0038	0.0007	0.823
	6	360	0.015	1.584	-0.504	0.9909	0.0009	0.0000	0.0034	0.0009	1.440
		540	0.030	1.338	-0.238	0.9865	0.0014	0.0000	0.0049	0.0014	3.180
		720	0.016	2.070	-1.003	0.9901	0.0010	0.0000	0.0046	0.0011	4.554
		900	0.036	1.502	-0.386	0.9749	0.0030	0.0000	0.0083	-2.9971	7.307
		180	0.023	0.023	0.472	0.9866	0.0010	-0.0031	0.0035	0.0010	3.480
		360	0.007	0.006	14.695	0.9966	0.0003	0.0000	0.0022	0.0003	0.343
Tw o- ter m	2	540	0.051	0.051	0.575	0.9612	0.0041	-0.0104	0.0093	0.0044	21.969
		720	0.066	0.066	0.559	0.9653	0.0035	-0.0092	0.0099	-3.9966	24.264
		900	0.073	0.073	0.572	0.9446	0.0056	-0.0103	0.0126	-3.9946	37.501
		180	0.021	0.021	0.562	0.9813	0.0013	-0.0030	0.0039	0.0013	3.070
		360	0.030	0.030	0.571	0.9656	0.0032	-0.0083	0.0067	0.0034	17.806
		540	0.043	0.043	0.568	0.9701	0.0028	-0.0083	0.0073	0.0030	18.408
	4	720	0.058	0.058	0.572	0.9617	0.0040	-0.0104	0.0096	-3.9961	24.674
		900	0.062	0.062	0.897	0.9592	0.0042	-0.0108	0.0103	-3.9959	31.345
		180	0.004	0.013	-0.641	0.9944	0.0004	-0.0001	0.0022	0.0004	0.268
		360	0.030	0.030	0.590	0.9694	0.0029	-0.0074	0.0062	0.0030	11.997
		540	0.046	0.046	0.570	0.9721	0.0028	-0.0086	0.0070	0.0030	15.906
		720	0.047	0.047	0.579	0.9492	0.0053	-0.0113	0.0104	0.0057	30.285
	6	900	0.065	0.065	0.594	0.9459	0.0064	-0.0144	0.0122	-3.9937	37.795
		180	10.261		0.002	0.9688	0.0022	0.0076	0.0054	0.0023	4.649
Tw o- ter	2	360	15.411		0.002	0.9433	0.0051	0.0080	0.0089	0.0051	19.919
		540	0.073		2.113	0.9957	0.0076	0.0080	0.0126	0.0078	28.425

m ex po ne nti al	4	720	0.095	2.065			0.9954	0.0005	-0.0045	0.0036	-1.9995	9.670
		900	0.104	2.086			0.9813	0.0019	-0.0077	0.0073	-1.9982	23.169
		180	8.905	0.002			0.9685	0.0021	0.0058	0.0051	0.0022	5.913
		360	16.169	0.002			0.9377	0.0059	0.0069	0.0090	0.0059	22.643
		540	0.061	2.020			0.9960	0.0004	-0.0044	0.0026	0.0004	7.184
		720	0.083	2.086			0.9942	0.0006	-0.0056	0.0037	-1.9994	8.273
		900	0.088	2.065			0.9924	0.0008	-0.0074	0.0044	-1.9992	15.461
		180	10.638	0.002			0.9745	0.0019	0.0057	0.0048	0.0019	5.286
	6	360	15.699	0.002			0.9390	0.0057	0.0090	0.0087	0.0058	15.907
		540	0.065	2.070			0.9983	0.0002	-0.0019	0.0016	0.0002	1.119
		720	0.068	2.099			0.9882	0.0012	-0.0089	0.0050	0.0013	15.196
		900	0.094	2.183			0.9895	0.0012	-0.0093	0.0054	-1.9988	13.664
		180	0.046	-3.756	0.825		0.9995	0.0001	0.0002	0.0007	0.0000	0.018
		360	0.064	-10.66	0.917		0.9951	0.0004	-0.0033	0.0026	0.0005	6.455
		540	0.103	-14.79	0.929		0.9974	0.0003	-0.0042	0.0024	0.0003	5.023
		720	0.132	-14.35	0.932		0.9964	0.0004	-0.0032	0.0032	-2.9996	7.454
Diff usi on ap pro ac h	2	900	0.145	-20.25	0.949		0.9838	0.0016	-0.0068	0.0068	-2.9984	20.817
		180	0.039	-6.997	0.906		0.9922	0.0005	-0.0010	0.0026	0.0005	2.148
		360	0.060	-14.10	0.933		0.9966	0.0003	-0.0043	0.0021	0.0003	6.019
		540	0.083	-19.01	0.951		0.9971	0.0003	-0.0034	0.0023	0.0003	5.549
		720	0.114	-29.72	0.965		0.9957	0.0005	-0.0040	0.0032	-2.9996	5.395
		900	0.121	-22.83	0.956		0.9944	0.0006	-0.0063	0.0038	-2.9994	12.740
		180	0.079	-0.397	0.358		0.9950	0.0004	-0.0005	0.0021	0.0004	1.469
		360	0.059	-14.63	0.934		0.9989	0.0001	-0.0020	0.0012	0.0001	1.441
	6	540	0.092	-9.512	0.900		0.9986	0.0001	-0.0004	0.0014	0.0001	0.911
		720	0.095	-21.13	0.950		0.9911	0.0009	-0.0077	0.0044	0.0010	12.322
		900	0.133	-28.56	0.959		0.9926	0.0009	-0.0071	0.0045	-2.9991	8.298
		180		1.095	24931.54	1040.2	0.9866	0.0010	-0.0031	0.0035	0.0010	3.479
		360		1.131	0.000	0.092	0.9689	0.0028	-0.0071	0.0066	0.0015	16.240
		540		1.168	898.691	132.89	0.9612	0.0041	-0.0104	0.0093	0.0041	21.968
		720		1.145	7248.620	-330.9	0.9653	0.0035	-0.0092	0.0099	-2.9966	24.263
		900		1.150	2109.902	170.35	0.9446	0.0056	-0.0104	0.0126	-2.9946	37.531
Si	4	180		1.077	234260.7	-3348	0.9813	0.0013	-0.0030	0.0039	0.0013	4.935
		360		1.143	1263.268	203.86	0.9656	0.0032	-0.0083	0.0067	0.0019	17.806

mp life d Fic k's diff usi on	6	540		1.136		0.002		0.236	0.9701	0.0028	-0.0083	0.0073	0.0021	18.404
		720		1.154		721.899		111.82	0.9617	0.0040	-0.0104	0.0096	-2.9961	24.675
		900		1.145		959.348		124.66	0.9592	0.0042	-0.0108	0.0103	-2.9959	31.349
		180		1.082		480.914		143.72	0.9869	0.0009	-0.0028	0.0034	0.0010	4.074
		360		1.150		1528.777		227.51	0.9694	0.0029	-0.0074	0.0062	0.0030	11.996
		540		1.156		284.154		78.699	0.9721	0.0001	-0.0004	0.0014	0.0001	0.911
		720		1.158		1487.996		178.05	0.9492	0.0053	-0.0113	0.0104	0.0049	30.289
		900		1.188		782.626		109.77	0.9459	0.0064	-0.0144	0.0122	-2.9937	37.789
		180	0.047	-3.240			0.038		0.9995	0.0000	0.0002	0.0007	0.0000	0.020
		360	0.000	-1.612			0.008		0.9934	0.0006	0.0052	0.0030	0.0006	1.475
Ver ma et al	2	540	0.004	-2.492			0.012		0.9801	0.0021	0.0104	0.0065	0.0022	6.083
		720	0.057	0.016			0.057		0.9386	0.0063	0.0073	0.0132	-2.9939	30.252
		900	0.063	0.042			0.063		0.9163	0.0084	0.0067	0.0155	-2.9918	43.409
		180	-0.014	-0.096			0.012		0.9961	0.0003	0.0022	0.0018	0.0003	0.077
		360	0.061	-11.48			0.056		0.9966	0.0003	-0.0042	0.0021	0.0003	6.001
	4	540	0.085	-8.375			0.076		0.9971	0.0003	-0.0032	0.0023	0.0003	5.519
		720	0.118	-9.619			0.106		0.9957	0.0005	-0.0038	0.0032	-2.9996	5.363
		900	0.125	-9.893			0.113		0.9944	0.0006	-0.0061	0.0038	-2.9994	12.735
		180	0.079	-0.397			0.028		0.9950	0.0004	-0.0005	0.0021	0.0004	1.180
		360	0.060	-9.907			0.054		0.9989	0.0001	-0.0021	0.0012	0.0001	0.000
Mi dilli et al	6	540	0.097	-4.859			0.079		0.9986	0.0001	-0.0004	0.0014	0.0001	0.830
		720	0.000	-2.213			0.008		0.9851	0.0016	0.0072	0.0056	-2.9985	5.879
		900	0.055	0.021			0.055		0.9109	0.0106	0.0052	0.0157	-2.9896	49.163
		180	0.006	1.355	0.999	0.000			0.9995	0.0074	0.0000	0.0007	0.0000	0.010
		360	0.007	1.340	1.009	-0.002			0.9982	0.0002	0.0000	0.0016	0.0002	0.693
	2	540	0.005	1.721	0.995	0.000			0.9994	0.0001	0.0000	0.0011	0.0001	0.107
		720	0.012	1.529	1.004	-0.001			0.9973	0.0003	0.0000	0.0028	-3.9997	1.648
		900	-0.010	0.000	1.006	-0.037			0.9944	0.0006	0.0000	0.0040	-3.9995	2.390
		180	0.015	0.933	1.027	-0.004			0.9967	0.0002	0.0000	0.0017	0.0002	0.297
		360	0.004	1.524	0.993	-0.001			0.9995	0.0001	0.0000	0.0008	0.0001	0.075
	4	540	0.007	1.469	0.998	-0.001			0.9986	0.0001	0.0000	0.0016	0.0001	0.381
		720	0.006	1.715	0.986	0.001			0.9973	0.0003	0.0001	0.0025	-3.9997	1.141
		900	0.009	1.549	0.991	-0.001			0.9990	0.0001	0.0000	0.0016	-3.9999	0.439
		180	0.010	1.197	1.010	0.000			0.9953	0.0003	0.0000	0.0020	0.0004	0.295

W a n g a n d s i n g	2	360	0.002	1.650	0.992	0.000	0.9995	0.0000	0.0000	0.0008	0.0001	0.111
		540	0.005	1.659	0.996	0.001	0.9987	0.0001	0.0001	0.0014	0.0001	0.516
		720	0.003	1.758	0.978	-0.001	0.9983	0.0002	0.0000	0.0019	0.0002	0.472
		900	0.002	2.066	0.977	0.001	0.9990	0.0001	0.0001	0.0017	-3.9999	0.010
		180			-0.016	0.000	0.9950	0.0004	0.0051	0.0021	0.0004	0.678
		360			-0.020	0.000	0.9938	0.0006	0.0057	0.0030	0.0006	1.398
		540			-0.030	0.000	0.9816	0.0020	0.0113	0.0064	0.0020	3.869
		720			-0.040	0.000	0.9866	0.0014	0.0087	0.0062	-1.9987	3.759
		900			-0.037	0.000	0.9938	0.0006	0.0038	0.0042	-1.9994	0.918
		180			-0.014	0.000	0.9959	0.0003	0.0014	0.0018	0.0003	0.139
		360			-0.018	0.000	0.9914	0.0008	0.0071	0.0033	0.0008	2.659
		540			-0.027	0.000	0.9911	0.0008	0.0071	0.0040	0.0009	2.471
	4	720			-0.036	0.000	0.9815	0.0019	0.0100	0.0067	-1.9981	4.773
		900			-0.036	0.000	0.9914	0.0009	0.0068	0.0047	-1.9991	4.208
		180			-0.017	0.000	0.9930	0.0005	0.0034	0.0025	0.0005	0.159
		360			-0.018	0.000	0.9851	0.0014	0.0094	0.0043	0.0014	2.174
		540			-0.030	0.000	0.9818	0.0017	0.0098	0.0051	0.0017	2.487
		720			-0.026	0.000	0.9857	0.0015	0.0083	0.0055	0.0015	5.766
		900			-0.039	0.000	0.9671	0.0039	0.0146	0.0095	-1.9962	5.717
		180			-58.78	-10.59	0.9938	3.0853	0.6030	0.1989	3.1264	8.692
		360			-44.63	-8.584	0.9899	3.3895	0.6735	0.2301	3.4451	9.975
		540			-27.21	-4.352	0.9713	6.1927	0.9542	0.3554	6.3273	13.967
		720			-20.89	-3.381	0.9835	1.7365	0.5151	0.2195	-0.3131	12.316
		900			-20.73	-4.074	0.9774	1.6327	0.4361	0.2159	-0.4153	10.467
T h o m o s e	6	180			-67.48	-14.65	0.9963	1.9724	0.1855	0.1560	1.9977	4.402
		360			-47.01	-8.510	0.9845	6.5986	0.9726	0.3027	6.6942	10.846
		540			-32.67	-5.482	0.9871	3.0786	0.6330	0.2387	3.1389	10.281
		720			-23.08	-3.326	0.9782	3.2438	0.6554	0.2714	1.1683	12.915
		900			-22.85	-3.872	0.9824	2.1518	0.5492	0.2319	0.0966	10.952
		180			-57.15	-9.471	0.9934	3.6276	0.3540	0.2103	3.6735	4.798
		360			-47.37	-8.025	0.9806	8.9778	1.1349	0.3460	9.1025	12.980
		540			-28.11	-3.417	0.9815	4.6107	0.7592	0.2684	4.6863	11.740
		720			-29.87	-5.169	0.9684	6.1927	0.9542	0.3554	6.3273	13.967
		900			-19.67	-2.547	0.9530	7.0792	0.9865	0.4056	4.9106	17.086

We lbul li dist rib uti on	2	180	0.005		1.358	0.013	-0.986		0.9995	0.0000	0.0000	0.0007	0.0000	0.009
		360	0.007		1.309	-0.182	-1.190		0.9982	0.0002	0.0000	0.0016	0.0002	0.719
		540	0.005		1.728	<u>0.016</u>	-0.979		0.9994	0.0001	0.0000	0.0011	0.0001	0.155
		720	0.012		1.526	-0.021	-1.025		0.9973	0.0003	0.0000	0.0028	-3.9997	1.798
		900	0.014		1.196	-0.896	-1.910		0.9957	0.0004	0.0000	0.0035	-3.9996	1.834
	4	180	0.008		0.928	-1.317	-2.345		0.9966	0.0002	0.0000	0.0017	0.0002	0.298
		360	0.004		1.504	-0.058	-1.052		0.9995	0.0001	0.0000	0.0008	0.0001	0.079
		540	0.008		1.457	-0.043	-1.041		0.9985	0.0001	0.0000	0.0016	0.0001	0.418
		720	0.006		1.739	0.028	-0.957		0.9974	0.0003	0.0000	0.0025	-3.9997	1.329
		900	0.010		1.524	-0.072	-1.063		0.9990	0.0001	0.0000	0.0016	-3.9999	0.474
	6	180	0.009		1.195	-0.051	-1.061		0.9952	0.0003	0.0001	0.0021	0.0003	0.405
		360	0.002		1.671	0.039	-0.953		0.9995	0.0000	0.0000	0.0008	0.0001	0.130
		540	0.005		1.697	0.051	-0.945		0.9988	0.0001	0.0000	0.0013	0.0001	0.657
		720	0.003		1.743	-0.030	-1.008		0.9983	0.0002	0.0000	0.0019	0.0002	0.436
		900	0.002		2.111	0.039	-0.937		0.9990	0.0001	0.0000	0.0017	-3.9999	0.099
Ag hla sh o et al	2	180		-60.59	-60.61				0.9696	0.0022	0.0082	0.0053	0.0022	4.375
		360		-57.19	-57.22				0.9440	0.0050	0.0080	0.0088	0.0051	19.766
		540		-53.65	-53.69				0.9281	0.0076	0.0081	0.0126	0.0078	28.401
		720		-62.54	-62.60				0.9386	0.0063	0.0073	0.0132	-1.9939	30.253
		900		-67.27	-67.33				0.9163	0.0084	0.0067	0.0155	-1.9918	43.413
	4	180		-57.41	-57.43				0.9692	0.0021	0.0064	0.0051	0.0021	5.638
		360		-57.01	-57.04				0.9384	0.0058	0.0076	0.0090	0.0059	22.157
		540		-48.82	-48.86				0.9462	0.0051	0.0064	0.0097	0.0052	23.157
		720		-56.75	-56.80				0.9343	0.0064	0.0119	0.0120	-1.9938	17.753
		900		-66.38	-66.43				0.9334	0.0069	0.0053	0.0131	-1.9933	38.113
	6	180		-62.85	-62.87				0.9751	0.0018	0.0060	0.0047	0.0018	5.446
		360		-54.34	-54.36				0.9397	0.0057	0.0090	0.0087	0.0058	15.767
		540		-53.18	-53.22				0.9453	0.0050	0.0053	0.0089	0.0051	20.357
		720		-53.50	-53.54				0.9184	0.0085	0.0073	0.0132	0.0087	36.939
		900		-66.52	-66.58				0.9109	0.0106	0.0052	0.0157	-1.9896	49.161
Lo gist ic	2	180	0.000			-1.000	0.000		0.9161	0.0061	-0.0112	0.0088	-0.1534	12.102
		360	0.000			-1.000	0.000		0.8726	0.0114	-0.0180	0.0133	0.0117	37.173
		540	0.107			0.193	1.218		0.9992	0.0001	0.0007	0.0013	0.0001	1.453

Je na an d Da s	4	720	0.129		0.260	1.287		0.9965	0.0004	-0.0001	0.0032	-2.9997	2.923	
		900	0.069		-8.478	-8.63		0.9388	0.0062	-0.0055	0.0133	-2.9940	36.840	
		180	0.000		-1.000	0.000		0.9165	0.0056	-0.0097	0.0083	0.0058	12.742	
		360	0.000		-1.000	0.000		0.8614	0.0130	-0.0205	0.0134	0.0134	42.459	
		540	0.081		0.284	1.301		0.9980	0.0002	-0.0005	0.0019	0.0002	1.874	
		720	0.118		0.211	1.229		0.9969	0.0003	0.0013	0.0027	-2.9997	1.755	
	6	900	0.130		0.190	1.190		0.9984	0.0002	-0.0011	0.0020	-2.9998	4.520	
		180	0.021		-5.406	-4.81		0.9826	0.0013	-0.0001	0.0039	0.0013	4.054	
		360	0.000		-1.000	0.000		0.8674	0.0003	0.0000	0.0020	0.0003	0.670	
		540	0.084		0.310	1.355		0.9969	0.0003	0.0022	0.0021	0.0003	3.875	
		720	0.110		0.133	1.124		0.9987	0.0001	-0.0006	0.0017	0.0001	1.630	
		900	0.158		0.108	1.117		0.9983	0.0002	0.0036	0.0022	-2.9998	8.739	
	2	180	0.023		1.132		0.045	-0.155	0.9990	0.0001	0.0000	0.0010	0.0001	0.086
		360	0.024		1.362		0.043	-0.383	0.9982	0.0002	0.0000	0.0016	0.0005	0.383
		540	0.056		1.118		0.122	-0.170	0.9959	0.0004	0.0000	0.0030	0.0013	1.758
		720	0.066		1.171		0.105	-0.199	0.9961	0.0004	0.0014	0.0033	-3.9996	0.312
		900	0.023		2.406		0.022	-1.409	0.9959	0.0004	0.0000	0.0034	-3.9996	1.724
		180	0.008		1.846		-0.001	-0.825	0.9965	0.0002	0.0000	0.0017	0.0002	0.355
	4	360	0.027		1.240		0.064	-0.287	0.9983	0.0002	0.0000	0.0015	0.0000	0.731
		540	0.040		1.179		0.076	-0.215	0.9976	0.0002	0.0000	0.0021	0.0008	0.549
		720	0.066		1.087		0.130	-0.140	0.9932	0.0007	-0.0001	0.0040	-3.9993	2.185
		900	0.049		1.302		0.077	-0.332	0.9975	0.0003	0.0000	0.0025	-3.9998	1.380
		180	0.023		1.096		0.039	-0.115	0.9955	0.0003	0.0000	0.0020	0.0003	0.416
		360	0.034		1.074		0.097	-0.140	0.9969	0.0003	0.0000	0.0020	0.0003	0.670
	6	540	0.063		0.983		0.149	-0.053	0.9953	0.0004	0.0000	0.0026	0.0007	1.236
		720	0.039		1.320		0.080	-0.368	0.9946	0.0006	0.0000	0.0034	0.0008	2.840
		900	0.085		1.036		0.191	-0.117	0.9880	0.0014	0.0000	0.0058	-3.9986	4.844
		180	-0.005	0.037	-62.61			63.576	0.9800	0.0014	-0.0001	0.0043	0.0015	1.847
		360	-0.008	0.030	-65.83			66.808	0.9858	0.0013	0.0000	0.0045	0.0013	5.653
		540	0.155	0.160	1.611			-0.518	0.9887	0.0012	0.0000	0.0050	0.0010	2.253
De mir et al	2	720	-0.015	0.026	-78.78			79.750	0.9695	0.0031	-0.0001	0.0093	-3.9970	15.110
		900	-0.092	-0.09	4.972			-3.936	0.9952	0.0005	0.0000	0.0037	-3.9995	0.589
		180	-0.006	0.030	-61.18			62.137	0.9886	0.0008	0.0000	0.0031	0.0008	1.178
	4	360	-0.006	0.037	-68.37			69.347	0.9812	0.0018	-0.0001	0.0050	0.0001	7.928

	540	-0.008	0.036	-69.93	70.891	0.9729	0.0026	-0.0001	0.0069	0.0027	10.428
	720	0.186	0.166	1.501	-0.417	0.9861	0.0015	0.0000	0.0058	-3.9986	4.698
	900	-0.153	-0.16	1.842	-0.784	0.9943	0.0006	0.0000	0.0038	-3.9994	3.242
	180	-0.006	0.031	-64.47	65.410	0.9700	0.0022	-0.0001	0.0051	0.0023	2.536
	360	-0.006	0.032	-70.61	71.586	0.9689	0.0029	-0.0010	0.0062	0.0031	6.056
6	540	-0.007	0.037	-76.97	77.899	0.9343	0.0060	-0.0002	0.0097	0.0064	14.014
	720	-0.010	0.036	-63.23	64.227	0.9791	0.0022	0.0000	0.0067	0.0013	2.949
	900	-0.183	-0.20	1.502	-0.386	0.9749	0.0030	0.0000	0.0083	-3.9971	7.307

APPENDIX F

Energy consumption during microwave drying of artificial foamed mandarin juice

Microwave Power W	Drying bed thickness Mm	Energy consumption kWh	Specific energy consumption MJ/kgH ₂ O	Drying Efficiency, %
660	2	198.0000	0.1523	24.698
530	2	212.0000	0.1845	23.082
400	2	173.3400	0.2008	28.105
270	2	144.0000	0.2530	33.045
130	2	93.1700	0.3263	53.205
660	4	220.0000	0.1693	22.217
530	4	229.6700	0.1997	21.325
400	4	193.3300	0.2232	25.281
270	4	184.5000	0.3237	25.825
130	4	108.3300	0.3910	44.404
660	6	264.0000	0.2037	18.464
530	6	256.1700	0.2203	19.327
400	6	206.6700	0.2385	23.656
270	6	207.0000	0.3632	23.018
130	6	125.6700	0.4579	37.916

APPENDIX G

Sensory Evaluation

Evaluation chart for fuzzy logic five point scale

Name:

Date:

Product: Cookies

Time:

Instruction: Give tick (✓) mark to appropriate respective fuzzy scale factor for each of the quality attributes of the sample after evaluating the samples.

Table 1. Sensory scores for quality attributes of samples

Sensory quality attributes of samples	Sensory scale factors				
	Not satisfactory	Fair	Medium	Good	Excellent
Color					
1					
2					
3					
Flavor					
1					
2					
3					
Texture					
1					
2					
3					
OAA					
1					
2					
3					

Table 2. Individual preferences to the importance of quality attributes of samples in general.

Sensory quality attributes of samples in general	Sensory scale factors				
	Not at all important	Somewhat important	Important	Highly important	Extremely important
Color					
Flavor					
Texture					
OAA					

Signature

VITA

1. Name of student : **Bhagyashree Nivrutti Patil**
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6. Research papers : 30
published (if any)
7. Field of Interest (in which : Teaching, Research and Extension
you desire to work)

Place : Akola

Signature of Student

Date :

(Bhagyashree N. Patil)