FOAM MAT DRYING CHARACTERISTICS OF CUSTARD APPLE PULP

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CERTIFICATE-I

This is to certify that the thesis entitled **"Foam mat drying characteristics of Custard apple pulp"** submitted in partial fulfillment of degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** of Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of *bona fide* research work carried out by **Krishna Deepa** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

The help and information availed during the investigation have been duly acknowledged by her.

Bhubaneswar
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CERTIFICATE-II

This is to certify that the thesis entitled **"Foam mat drying characteristics of Custard apple pulp"** submitted in partial fulfillment of degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** of Orissa University of Agriculture and Technology, Bhubaneswar by **Krishna Deepa** has been approved by the student's advisory committee after an oral examination on the same in collaboration with the external examiner.

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Dedicated to,

My beloved parents

and

My Family...

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ABSTRACT

Foam mat drying study of custard apple pulp was conducted by using Glycerol monostearate (0.5 %, 1.5 %, 2.5 %, 3.5 % and 4.5 %) as foaming agent and 0.5 % methyl cellulose as the stabilising agent with whipping durations of 2, 4, 6, 8 and 10 minutes. Drying was carried out in a cabinet tray dryer at five different drying temperatures (50, 55, 60, 65 and 70 °C) with foam thicknesses of 2, 3, 4, 5 and 6 mm. Optimization of parameters were performed with the help of Design Expert 9 (Stat-Ease, Inc. 2012) software. The expansion of the foams increased with the increase of the GMS concentrations and whipping time of up to 4 to 6 min. The optimum foaming condition providing highest foam expansion (60.89%) and foam stability (99.2 %) values and lower foam density (0.65 gm/cm^3) value was found to be 3.5 % GMS with 0.5 % methyl cellulose whipped for 6 minutes .The drying time of foamed pulp was lower as compared to that of non-foamed pulp but the drying rate was higher in case of foamed pulp as compared to that of non-foamed pulp. Lower thickness and lower temperature dried foam found to have lower drying time compared to higher thickness and higher temperature dried foam. Numerical optimization values of these parameters to get lower drying time and hygroscopicity values and higher ascorbic acid content value was found to be 3.5 % w/w GMS, 4 minutes whipping time, 65 °C drying temperature and 3.02 mm foam thickness.

Keywords: Foam mat drying, custard apple powder, Glycerol monostearate, foam expansion, foam stability, foam density, drying rate, custard apple pulp drying, optimization of parameters etc.

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LIST OF SYMBOLS AND ABBREVIATIONS

m	Meter
g	Gram
PET	Poly ethylene terephthalate
%	Percentage
mg	Milligram
w.b	Wet basis
RTS	Ready to serve
^{o}Bx	Degree Brix
GMS	Glycerol monostearate
MD	Maltodextrin
TCP	Tricalcium phosphate
h	Hour
min	Minute
cm	Centimeter
mm	Millimeter
TSS	Total soluble solid
FE	Foam expansion
CCRD	Central composite rotatable design
D_{eff}	Diffusivity
DT	Drying time
AA	Ascorbic acid
HG	Hygroscopicity
C.V	Coefficient of variance

Chapter I
Introduction

Chapter 1

INTRODUCTION

Custard apple (*Annona squamosa L)* is a tropical fruit coming under the Annonaceae family. It is mainly grown in gardens for its fruits and ornamental value having a round or heart shaped structure. Although, Custard apples are native to West Indies and South America, these are most commonly found in India, China, Philippines, Egypt and Central Africa. In India, The area under custard apple is distributed mostly in the states of Andhra Pradesh, Uttar Pradesh, Bihar, Odisha, Maharashtra and Assam. Maharashtra covers 4,990 hectares of land with an average production of 20,479 tonnes (Hashmi and Pawar, 2011). The custard apple is cultivated in some places of many districts of Odisha like Bolangir, Khordha, Mayurbhang, Phulbani etc. But the data of the area of production of custard apple is not available as the area of production is not so highly remarkable.

Custard apples are highly nutritious fruits as these are packed with vitamin C, antioxidant, vitamin A, magnesium, vitamin B_6, potassium, copper and plenty of dietary fibres. It is beneficial for cardiac disease, diabetes, hyperthyroidism and cancer. The ripe fruits of this plant are applied to malignant tumors to hasten suppuration. The fruit pulp due to its richness in free sugars, minerals and vitamins is known to serve as blood tonic (Rao, 1974). Custard apple pulp has been recognized as a base ingredient in various food products like ice cream, milk shakes, beverages due to its characteristics taste and flavour (Khurdiya, 2001; Hashmi and Pawar, 2011). The flavour components of fresh pulp are due to the volatile compounds of terpenes namely α-pinene, β-pinene, linalool, germacrene-D and spathulenol, Benzyl alcohol etc (Shashirekha *et al.*, 2006).

Custard apples are perishable and cold storage is not promising because of the development of an unattractive brown colour on the skin which decreases the market value (Purohit, 1995). Custard apple gives excessive production during the season, very often perishes owing to inadequate preservation techniques. The pulp when exposed to air undergoes discoloration due to polyphenol oxidase activity. Discolouration occurs during storage in frozen state and continues throughout thawing and causes loss of quality and value (Pardede et al., 1994). Therefore, storage of either fresh custard apple fruit or fruit pulp or concentrate in ambient or refrigeration condition is a limitation due to these mentioned problems.

Drying is an age longed preservation technique which can not only increase the shelf life of the dried product but also makes the product available throughout the year even in the off seasons. Production of dried powder from custard apple pulp by drying is a possible solution for making use of this underutilized and high valued fruit. But, quality aspects are a major concern for selecting any processing or preservation technique for fruit pulps.

Generally, juicy/ pulpy fruits like mango, pineapple, custard apple etc. contain a large amount of sugar content and have a dense physical structure as well as chemical composition. Simply hot air drying is very difficult to achieve the required moisture removal for powder production. The stickiness and caking properties also cause a lot of difficulty in drying. The hot air drying process is also very slow and during drying it may induce colour and flavor change in the final product rejecting its quality for export potential. Fruit pulps are generally spray dried, drum dried or freeze dried. But, in no cases it becomes cheaper for drying by a common farmer. Therefore, drying alternatives could be suggested for fruit pulps for making powder. Foam mat drying by principle can increase the surface area for drying due to foaming. This helps in making the custard apple pulp more porous, thus allowing rapid moisture removal with a higher drying rate. As foaming process provides minimum drying time, with better textured products, we can take foaming in addition to tray drying to get a better textured and good quality custard apple powder.

Foam mat drying is a process in which a liquid or semi solid material is converted into stable foam by incorporating substantial volume of air or other inert gases in the presence of foaming and stabilising agents. The foaming agent works as a foam inducer and/or stabilizer. The foam thus formed is then spread as a thin mat or sheet and allowed to go for drying until it is dried upto the required moisture levels. The dehydrated product is then allowed to go for conditioning and converted into powder form. Many experiments have been done on foam mat drying of different products like mango (Rajkumar *et al.*, 2007; Jaya and Das, 2006), star fruit (Karim and Wai, 1999), banana (Sankat and Castaigne, 2004), tamarind (Eduardo *et al.*, 2001), soymilk (Akintoye and Oguntund, 1991) etc. No works has been suggested till now for foaming of custard apple pulp and then subsequent drying with hot air cabinet tray drying. Therefore the present investigation was carried out with the following specific objectives.

1. To study the foaming behaviour of custard apple pulp for drying.
2. To study the drying characteristics of foamed custard apple pulp after foaming.
3. To optimize the foaming and drying parameters for obtaining a better quality custard apple powder and development of mathematical models.

Chapter II
Review of Literature

Chapter 2

REVIEW OF LITERATURE

2.1 Custard apple Fruit Morphology

Custard apple is a tropical and sub-tropical fruit originated from frost-free valley of Andes at an altitude of between 700-2400 m. Its tree is erect but low branched and somewhat shrubby ranging in height from 5 to 9 m. The leaves are deciduous, alternate, 2-ranked and having minute hairy petioles. The fruit is a compound fruit which is heart shaped and ranges from 150-500 g in weight. The fruit is easily broken or cut open, exposing the snow-white, juicy flesh of pleasing aroma and delicious, sub-acid flavour and brown or black, glossy seeds (Amoo *et al.*, 2008; Morton, 1987).

Custard apple fruit plant grows commonly in India, China, Phillipines, Egypt and Central Africa. In India it is cultivated in Andhra Pradesh, Maharashtra, Karnataka, Bihar, Orissa, Assam and Tamil Nadu states.

Fig. 2.1: Ripe Custard apple fruit

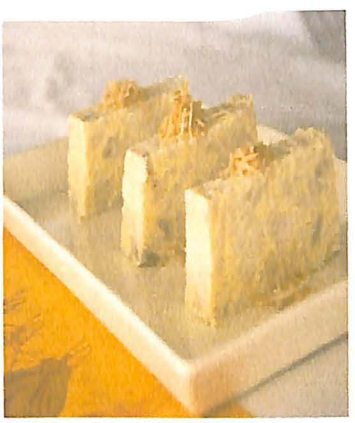
2.2 Uses of custard apple

The fruit of the Custard apple are eaten fresh and the pulp can be used to flavour ice creme or can be blended with orange juice, lime juice and frozen as ice creme (Morton, 1987). Custard apple powder is used for preparation of cakes, ice-creme, puddings etc. Different value added products e.g. squash and RTS were already prepared from custard apple pulp from AICRP on PHT, OUAT. The storage of the above products in glass bottle, PET bottles and poly pouches has been reported earlier (AICRP Annual

report, 2008). A range of processed food products from custard apple has been reported like fresh/frozen fruit pulp (Shasirekha *et al.*, 2003a), jam (Vijaylakshmi *et al.*, 2003), jelly (Shasirekha, 2003b), fruit mix (Revathy et al., 2003), dehydrated (Rjarathnam, 2003a), cereal flakes (Vijaylakshmi, 2003), spray dried powder (Revathy, 2003), nectar (Rajarathnam, 2003b) and RTS beverage (Singh *et al.*, 2002).

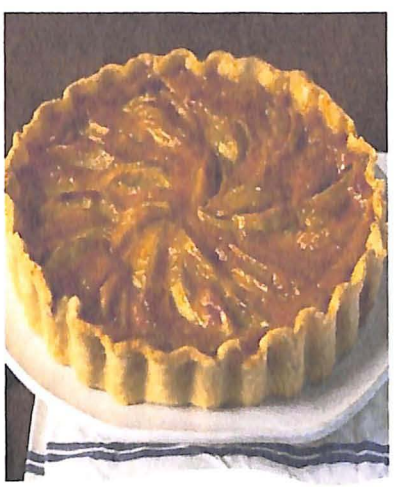
Custard apple ice creme

Custard apple cheese cake



Custard apple parfait

Custard apple Bruschetta



Caramel custard apple tart

Custard apple creme recipe

Fig 2.2: Commercial available products developed from custard apple pulp

Different commercial value added products developed from custard apple pulp are like: custard apple ice crème, parfait, cheese cake, bruschetta, caramel custard apple tart, custard apple crème reciepe etc.

2.3 Food Value of custard apple fruit pulp

Ripe fruits of custard apple are important part of diet which supplies nutrients like vitamin A and vitamin C. The fruit value of 100g of edible portion of ripe fruit

shows moisture of 71.48-78.70 g, protein 1.07-1.40 g, fat 0.4-0.6 g, sodium 4-5 mg, calcium 17 mg, β-carotene 10 mg and ascorbic acid 50 mg (Morton, 1987). These fruits contain small amount of protein and fat when compared with some fruits.

Table 2.1: Chemical compositions of custard apple (per 100g of edible pulp)

Moisture, gm%	76.34±4.12
Protein, gm%	1.62±0.41
Fat, gm%	0.55±0.05
Carbohydrate, gm%	23.52±2.61
Ash, gm%	0.97±0.23
Carotene, mg%	0.012±0.005
Ascorbic acid, mg%	27.42±12.24
Fibre, gm%	2.62±1.33
Calcium, mg%	22.23±3.17
Phosphorus, mg%	15.67±3.14
Iron, mg%	0.81±0.28

2.4 Processing of custard apple pulp

Custard apple fruit is having high initial moisture content of about 72-77 % (w.b). So, there are more chances of the fruit getting spoiled or detoriorated. It has very short shelf life and marketing of fresh fruits to different places is very difficult. Therefore, it is necessary to convert it into value added products which retain colour, flavour and nutrients with longer shelf life. So to increase the shelf life of custard apple, the fruit is converted into various processed products like powder, dried slices, pulp, juice, RTS, beverages, etc.

Process for preparing frozen custard apple pulp or spray dried custard apple powder free from bitterness, discoloration and off-flavor has been reported as patent (Revathy *et al.*, 2005). The process claimed production of fresh custard apple pulp as well as spray dried powder involving the steps mixing custard apple pulp with 0.05 to 0.15% by weight of ascorbic acid and blast freezing the same at temperature in the range of -10 to -50 °C followed by immediately storing the same at -15 to -45 °C to obtain

frozen custard apple pulp. For spray dried powder, the steps followed were the mixing of 50 to 60% of the pulp with 5 to 10 % milk powder, 5 to 10% sugar candy and 3-10% maltodextrin, 0.7 to 3.0% tricalcium phosphate all in w/w basis, honey and the remaining being water to bring the total soluble solids in the range of 35 to 40 °Brix. Spray drying with the mixture at an inlet temperature in the range of 100 to 140 °C and at an outlet temperature of 70 to 110 °C was recommended to obtain good quality custard apple powder.

Custard apple powder by freeze drying is a very interesting alternative to recompose the fruit with practically all the properties of the natural product. Pretreatment of custard apple pulp with Maltodextrin will increase the rate of moisture removal. Freeze drying will give the dried product of the same size and shape as the original frozen material and will be found to have an excellent quality.

2.5 Effect of Foaming agent and optimization of foaming parameters

Numerous workers have reported foam mat drying of fruit pulps using a diversified product ranging from fruits to vegetables, pulses and milk products. They have used a wide range of foaming agents and stabilizing agents. The further discussions are concentrated to the effects of these foaming agents on foaming behaviour of the fruit pulps and subsequent drying process.

Rajkumar *et al.* (2007) studied the foam mat drying of Alphonso mango pulp using various food foaming agents, namely soy protein (0.25, 0.5, 1.0, and 1.5%) with methyl cellulose (0.5%), glycerol monostearate (0.5, 1.0, 2.0 and 3.0%), and egg albumen (2.5, 5.0, 10 and 15%) with methyl cellulose (0.5%). Drying was carried out in a batch type thin layer dryer at four drying temperatures (60, 65, 70, and 75 °C) on 1, 2, or 3-mm thickness foamed samples. The optimum concentrations of each foaming agent were determined to be 1% soy protein, 2% glycerol monostearate, and 10% egg albumen. All were obtained after 25 minutes of whipping time. The drying time was lower for foamed mango pulps as compared to non-foamed pulp at all drying temperatures. Biochemical analysis showed that the foam mat dried powder at 60 °C retained a significantly higher ($P< 0.05$) content of biochemical compounds than at higher temperatures. The treatment of 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 than the other treatments.

Kandasamy *et al.* (2012) conducted experiments to optimize the process parameters for production of papaya powder under foam-mat drying. Papaya pulp was foamed by incorporating methyl cellulose as foaming agent at different concentrations of 0.25, 0.50, 0.75 and 1.00% on w/w basis. The maximum stable foam formation was 83% at 0.75% methyl cellulose with 9 °Brix pulp and whipping time of 15 min. The foam expansion was significantly influenced by pulp concentration and levels of the methyl cellulose at 1% level. The papaya powder obtained from the pulp of 9 °Brix 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 to be the optimum condition for the production of papaya powder.

Mango powder produced by vacuum drying of mango pulp(Jaya and Das, 2006) at various levels of maltodextrin (MD) ranging between 0.25 and 0.65 kg per kg of mango solid, Glycerol monostearate (GMS) and tricalcium phosphate (TCP) varying between 0.01 and 0.02 kg per kg of mango solid. MD was used to eliminate the stickiness of the mango powder and to get less hygroscopic powder. GMS was used as foam stabilizer and TCP as anticaking agents respectively. Based on the quality properties of mango powder like hygroscopicity, degree of caking, dispersibility, flowability, sticky point temperature and overall color difference at 5% (d.b) moisture an optimum feed mix composition of 0.43–0.57 kg MD per kg of mango solids was obtained. The optimum requirement for the TCP and GMS were 0.015 kg per kg of mango solid.

Bag *et al.* (2011) optimized the process parameters for foaming of bael (Aeglemarmelos L.) fruit pulp. Foams were prepared from various pulp concentrations (PC) by adding different concentration of glycerol monostearate (GMS) and methyl cellulose (MC) at different whipping time (WT). Foam expansion and foam stability of the bael (Aeglemarmelos L.) fruit pulp foam was studied. Response surface methodology was used for prediction of foam stability and foam expansion. The optimum conditions reported after the numerical and graphical optimization for maximum foam expansion and stability was: GMS (3.10 g/100 g pulp), MC (0.32 g/100 g pulp), PC (13.2 °Bx), and WT (2 min). The predicted and experimental values of foam density and foam drainage volume at optimum point were 0.658 gcm^{-3} and 1.75 mL, and 0.635± 0.02 gcm^{-3} and 1.75±0.12 mL, respectively.

Krasaekoopt and Bhatia (2012) produced yogurt powders by using foam-mat drying method. Two types of foaming agents as methylcellulose and egg albumen at different concentrations of 0.5, 1.0, 1.5 and 2.0% for methylcellulose and 1, 2, 3 and 4% for egg albumen, respectively were used. Characteristics of yoghurt foam like density, foam stability and foam expansion were better at 3.0% of egg albumen with the mixing time of 12 min.

Widyastuti and Srianta (2011) developed functional drink based on foam-mat dried papaya. Papaya slurry was foamed by adding egg white of 10%, 15% and 20% w/w. The foamed papaya slurry was dried by using hot air drying method at 60 °C for 5 hours. Drying yield increased with increasing of egg white concentration. Moisture content, reconstitution and water holding capacity of the products were in the range from 2.91 to 3.09%, from 81.34 to 83.42% and from 6.19 to 6.34 g/g, respectively.

Dattatreya *et al.* (2011) developed dried tomato powder by foam mat drying by taking different levels of egg albumen(0, 5, 10, 15 and 20%, w/w) as foaming agent using tomato juice (4 °Brix total soluble solids). Incorporation of 10% egg albumen with 5 min of whipping time was found optimum for stable foam formation. The increase in foaming agent level enhanced the drying process (up to 15% egg albumen) and thereafter followed a decreasing trend.

2.6 Drying Study of Foamed and Non-foamed Fruit Pulp

Many studies have been reported on the drying of foamed and non-foamed fruit juices. Jayaraman *et al.,* (1974) dried mango pulp foam by spreading it as a thin sheet on plain aluminum trays at a rate of 0.25 kg per tray (40-80 cm) in a cross flow drier, initially at 80 °C for 30 min and subsequently at 65–70 °C for 30–90 min to reduce the drying time. Baldry *et al.,* (1976) prepared Alphonso mango powder using 1.5% poly glyceryl stearate as a foaming agent by spreading in a 2-mm-thick layer and drying in the temperature range of 50 to 80 °C for 20 min to the final moisture content of 3%. Although increasing the airflow rate (58–95 cm/s) at temperatures between 50 and 70 °C increased the initial drying rates, a moisture content of less than 5% was not achieved at 50 °C, a level normally required for safe storage. Furthermore, they noted that the drying rate increases as the foam dries in contrast to the usual drying behavior.

Akintoye and Oguntunde (1991) reported that a temperature of 65 °C for 90 min was found to be more suitable for foam-mat drying of soymilk. They also concluded that

the foam drying at 65 °C occurred in the falling rate period and that the drying rate is dependent on the foam density. Beristain *et al.* (1976) found that the best quality pineapple powder was obtained at 60 °C with 5mm foam thickness by using maltodextrin as the surfactant mixture. Foam-mat drying of star fruit by foaming with different concentrations of methyl cellulose and drying at a 5-mm thick layer in a mini kiln smoker at temperatures between 70 and 90 °C and with an airflow rate of 0.12m/s showed that obvious color and flavor changes were observed in the product dried at 90 °C. Similar foam-mat drying studies were reported for mango pulp, (Srivastava, 1998) apple pulp (Mishra, *et al.*, 2002) cowpea paste (Falade, 2003) and lemon juice (Sharma and Sharma, 2004). The transient drying behavior of banana pulp in terms of capillary model [ln $(M=M0)^{1/4}$-Kt] showed that the drying time (t) was directly related to the thickness of the foam mat (Sankat and Castaigne, 2004). They also reported that the drying rate constant increased with an increase in drying temperature.

Rajkumar *et al.* (2007) conducted preliminary trials for foam mat drying of alphonso mango pulp using batch type cabinet dryer. The foamed mango pulp was dried at 60 °C with 1 mm foam thickness and was found to be the best. The drying study showed that the time required to dry the fresh (non-foamed) and foamed mango pulps were 75 and 35 min, respectively. The overall moisture diffusion in fresh and foam dried mango flakes were 5.3 and 9.7 x 10-9 m^2/s, respectively. It was observed that the changes were comparatively lower in foamed dried flakes than in non-foamed dried flakes using continuous type foam mat dryer.

The drying time required for foamed papaya pulp (Kandasamy *et al.* 2012) was lower than the non-foamed pulp at all selected temperatures of 65 and 70 °C) and foam thickness of 2, 4, 6 and 8 mm in a batch type cabinet dryer. A significant reduction in ascorbic acid, β-carotene and total sugars was found in the foamed papaya dried product at higher foam thickness (6 and 8 mm) and temperature due to destruction at higher drying temperature and increasing time. There was no significant change in other biochemical constituents such as pH and acidity. The sensory evaluation of the quality attributes of papaya powder juice showed significant reduction in colour, taste, flavour and overall acceptability at 65 and 70 °C.

. Mango pulp from Dussehri variety was foam mat dried using (Robin *et al.*, 2012) 0, 3, 5, 7 and 9% egg white as foaming agent and then dried at air drying

temperature of 65, 75 and 85 °C. Change in moisture ratio with respect to time and effective diffusivity were fitted with seven thin layer drying models to get the best fit model, which was selected on the basis of various statistical parameters. Wang and Singh model was found to be best in almost all cases.

Dattatreya *et al.* (2011) studied on foam mat drying of tomato juice at different drying air temperature of 60, 65 and 70 °C and foaming agent (egg albumen) for production of tomato powder. They suggested that foamed tomato juice can be dried in 510 and 450 min at 60 and 70 °C drying air temperature respectively, with best acceptability. Effective moisture diffusivity of tomato juice ranged from 2.026×10^{-8} to 3.039×10^{-8} m^2/s.

Solar-augmented foam-mat drying of fruits (1994) like orange, lemon, grapes, tomatoes, strawberry, guava and apple by Aghareed M. Tayeb suggested that, foaming decreased the time of drying by 30.8-41.5% in the case of direct sun drying and by 47.1-73.2% in the case of solar drying compared to the drying time of non-foamed syrup. The solar-augmented foam-mat drying technique proved to be of sufficient efficiency and acceptability to replace spray drying which is known to be a highly complicated and energy consuming technique.

Microwave assisted foam mat drying characteristics of black currant pulp was investigated (Zheng et al., 2011) to optimize the microwave power, pulp load, drying time and pulp thickness. The qualitative evaluation of black currant pulp like anthocyanin content and vitamin C content were evaluated. Microwave power of 560 W, pulp load 65 g, drying time 8 minute and pulp thickness of 4.46 mm were found to be optimum for microwave foam mat drying of black-currant pulp.

2.7 Quality parameters of foam mat dried end product

Dried yoghurt produced by foam drying of yoghurt (Krasaekoopt and Bhatia, 2012) using methyl cellulose and egg albumen for foaming and dried at 50, 60 and 70 °C for 3 h. Characteristic of yogurt powder as moisture content, water activity (aw) and glass transition temperature (Tg) showed water activity of 0.348, moisture content 8.5%,Tg of 25.51 °C. Yoghurt powder (15%) mixed with orange flavor (0.1 g) and color (0.1 g) was preferred by the sensory panellists with sensory values of 6.7, 6.8, 6.6 and 6.7 for appearance, flavour, texture and overall acceptability respectively. The yoghurt powder dried at 60 °C had lactic acid bacteria count of 5.6×10^7 cfu g^{-1}.

Foam-mat dried papaya powder blended with skim milk powder of ratio 6:4; 5:5; 4:6 w/w to produce a soft drink affected the physio-chemical properties (moisture content, reconstitution, viscosity, turbidity, water holding capacity and stability) and sensory properties (colour, viscosity, aroma and taste) of the product (Widyastuti and Srianta, 2011).

Foam-mat freeze drying is one of the promising methods of drying, which utilizes advantages of both freeze drying and foam-mat drying. Arunmuthukumaran (2007) studied on foam-mat freeze drying of egg white along with Xantham Gum (XG) at 0.125% concentration which was used as stabilizer for foaming. The results showed that the addition of Xantham gum during foaming has a positive impact in reducing the total drying time and also produces excellent quality egg white powder. The addition of stabilizer also played an important role in improving drying.

Kadam *et al.* (2012) studied on Physicochemical and microbial quality evaluation of foam-mat-dried pineapple powder. In this case, pineapple pulp was foamed using two foaming agents like tricalcium phosphate (TCP) (0%, 0.25%, 0.50%, 0.75%, and 1.0%) and egg white (EW) (0%, 0.50%, 1.0%, 1.50%, and 2.0%). Carboxy methyl cellulose (0.25%) was used as foam stabiliser and drying was carried out at 65, 75, and 85 °C in tray drier followed by pulverising the dried foam mats in to fine powder. Powdered samples were analyzed for various physicochemical quality parameters viz. total sugars, reducing sugars, ascorbic acid, total acid, pH, iron, phosphorus and calcium content and bacterial and fungal load. Statistical analysis using LSD revealed that sample dried using 1% TCP at 65 °C was the best with 4.60% total sugars, 2.71% reducing sugars, 4.05 mg per 100 g ascorbic acid, 0.35% total acid, 0.29 mg per 100 g Iron, 2.24 mg per 100 g phosphorous and 6.58 g per 100 g of calcium and zero bacterial and fungal growth.

Kadam *et al.* (2011) studied on quality of fresh and stored foam mat dried Mandarin powder. Foam mat drying is a lucrative process of mandarin (kinnow) pulp preservation in the form of powder. Foam mat drying of mandarin pulp experiments were carried out at 65, 75 and 85 °C drying air temperatures using carboxy methyl cellulose, milk and egg white as foaming agents at different concentrations levels to get dried mandarin powder. Quality of the reconstituted dried Mandarin pulp-powder was evaluated for 6 month storage studies at an interval of 2 months for total sugars (%), ascorbic acid (mg 100 mL^{-1}), total acid (%), pH and microbial load (fungal and bacterial)

using standard procedures. It was reported that total sugars, ascorbic acid and total acid were decreased whereas pH was slightly higher than the fresh pulp. There was minor bacterial growth noticed in all the treatments, which is within the permissible limit, furthermore no fungal growth was noticed during storage period.

From the literature scanned, it is evident that very little work has been reported on custard apple pulp drying to produce powder. Although the foam mat drying is very popular for drying fruit pulps, the custard apple fruit pulp has not been yet dried using foam mat technique. Therefore, there is a scope for the foam mat drying of custard apple pulp concentrating on optimization of foaming and stabilizing ingredients and study of drying behaviour and qualitative aspects.

Chapter III
Materials and Methods

Chapter 3

MATERIALS AND METHODS

This chapter deals with different experimental processes, procedures and analytical methods followed in the foaming and drying study of the custard apple pulp. The steps followed for custard apple pulp preparation and its foaming behaviour by adding different compositions of foaming and stabilizing agents were studied. The procedures followed for drying of foamed pulp at different drying conditions were described. The optimization technique used for determination of the optimum level of parameters was discussed and the analytical procedures followed for determination of different qualitative parameters were also covered in this chapter.

3.1 Raw Material Preparation

Fresh Custard apples of uniform sizes and maturity were brought from the local market of Bhubaneswar. Then pulp was separated out from the fruit part manually using a steel spoon. The percentage of pulp and seed were calculated. Then whole pulp was allowed for grinding using a laboratory available grinder for foaming and drying studies. Initial readings of the pulp like moisture content, bulk density, total soluble solids and ascorbic acid content were recorded.

Moisture content of the custard apple pulp was determined with the help of hot air oven method following the standard procedure (AOAC, 1990). About 10 g of pulp sample were taken for drying in hot air oven set at temperature of 105 ^{o}C for 6 hours to determine moisture content in three replications.

3.2 Foaming Experiments

The grinded custard apple pulp was taken for the foaming studies. Foaming of custard apple samples were carried out using a domestic hand blender (ORPAT, HHB-100E). For the foaming experiments, Glycerol monostearate (GMS) at five different levels of 0.5, 1.5, 2.5, 3.5 and 4.5% (w/w) was used as the foaming agent and 0.5% methyl cellulose was used as the stabilising agent. Calculated amount of the custard apple pulp, GMS and methyl cellulose were taken in measuring beaker. This mixture of fruit pulp, foaming and stabilizing agent was then blended with a commercial blender available in the market with the specifications provided in Appendix A1. Foaming was

done for five different whipping times of 2, 4, 6, 8 and 10 minutes. The different foaming parameters studied were foam expansion, foam stability and foam density following the procedures which were followed in other types of fruit pulps like mango (Jaya and Das, 2006) and malta (Khan Chand and Pandey, 2012). The foaming of the custard apple pulp was presented in figure 3.1.

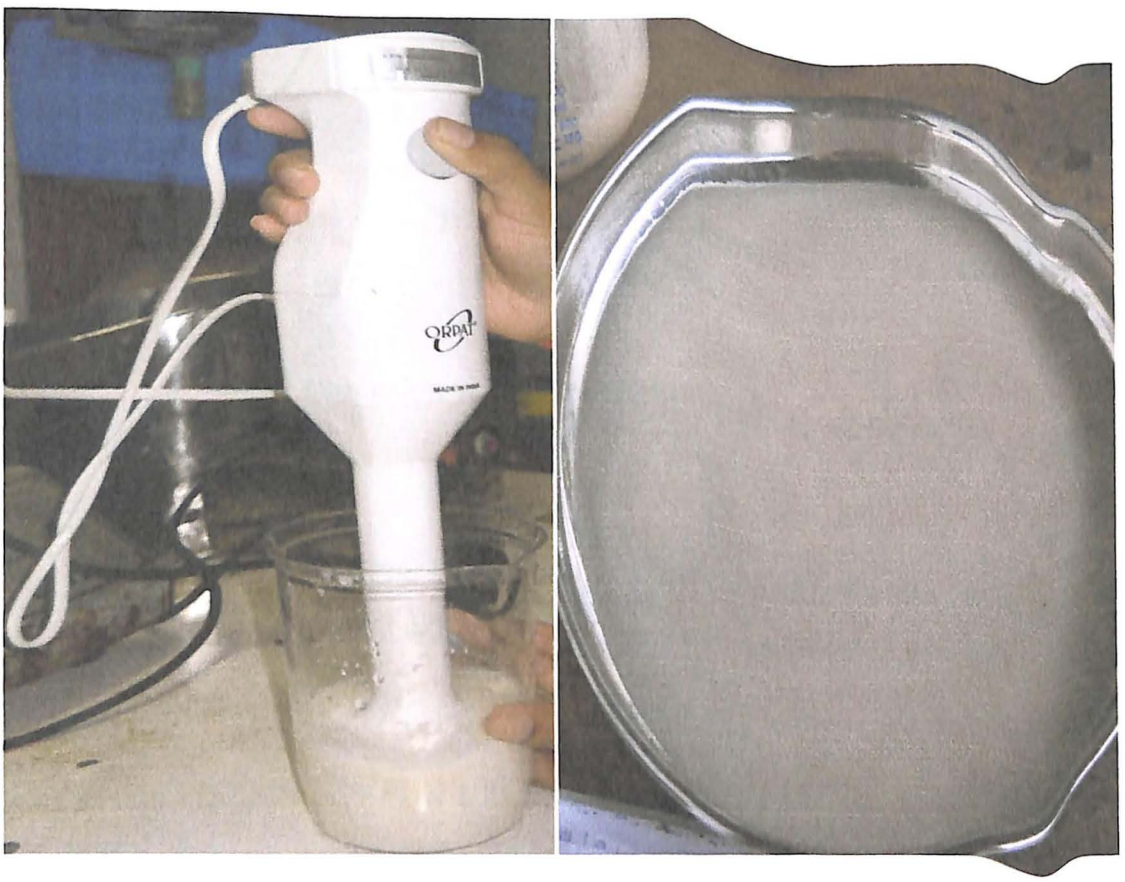


Fig 3.1: Foaming of the pulp

From the preliminary study, it was found that, due to high TSS content of custard apple pulp (23 °Brix) foaming was not at all achieved with the available blender and specified levels of GMS and methyl cellulose content. Therefore, pulp was diluted with water at 1:1, 1:2, 1:3 and 1:4 pulp/water ratio by weight. The amount of foam expansion (3.2.1) at different pulp to water ratio observations were recorded (Figure 3.2). It was finally standardized to take 1:2 ratio of pulp to water, as it gave maximum expansion of foam compared to that of the other ratios. At this point, the final TSS content of the pulp was 6.8 °Brix. Subsequently, all the experiments were conducted with the above procedure maintaining TSS of 6.8 °Brix.

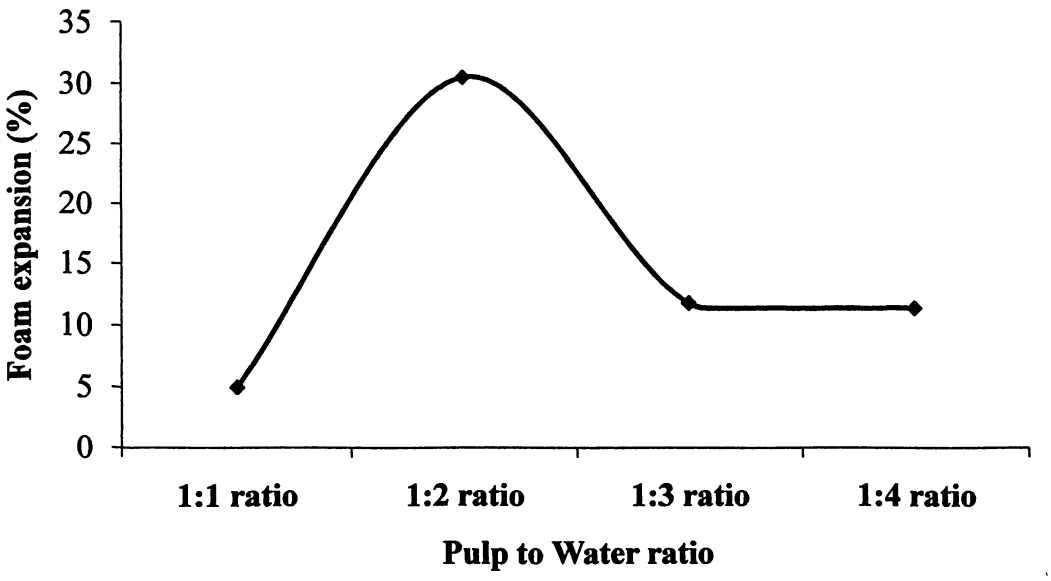


Fig 3.2: Foam expansion values at different pulp to water ratios

3.2.1 Foam Expansion

It is the percentage increase of the volume of the pulp after foaming with required amount of the foaming agent and whipping. The foam expansion value was calculated by the given expression,

$$\text{Foam Expansion (FE)} = \left[\frac{V_1 - V_0}{V_0}\right] \times 100 \quad \text{.....(3.1)}$$

Where, FE is expressed in percentage (%), V_0 is the initial volume of the custard apple pulp before foaming (cm^3) and V_1 is the final volume of the custard apple pulp after foaming (cm^3).

3.2.2 Foam Stability

Foamed pulp of 50 ml was taken in a 50 ml glass tube and was kept in normal atmosphere for 3 hours. Then the decrease of the foam volume was noted in every 30 min time interval. The reduction of the foam volume was noted to be used as an index for the determination of the foam stability for every 30 minutes by using the following relationship.

$$\text{Foam stability} = V_0 \frac{\Delta t}{\Delta V} \quad \text{.....(3.2)}$$

dimension (27.8 x 27.8 x 5 cm) kept over the dryer tray. The air was circulated by a variable speed fan and heated by electricity.

3.3.2 Drying experiments

After foaming, the foamed samples were taken for the drying studies. The detailed process flow chart of preparation of custard apple powder from custard apple pulp was given in Appendix A2. For the drying experiments, Different levels of drying temperatures taken were 50, 55, 60, 65 and 70 °C. The different levels of foam thicknesses were maintained at 2, 4, 6, 8 and 10 mm. The various pulp thicknesses were maintained by dividing the plate volume to the plate area. The weighted foamed pulp was taken in the stainless steel plate and allowed to spread in the required thickness. Then the metallic plate alongwith the sample was kept inside the cabinet tray dryer and the loss of weight values were noted for every 30 minutes of time intervals. Drying was carried out up to three consecutive constant weight of the sample was recorded. The moisture content, drying rate, mass diffusivity values were then calculated. Drying data was expressed as moisture content versus drying time and drying rate versus moisture content (dry basis). Drying rate was calculated as the amount of water removed per amount of dry matter per unit time (h). Different pictures of the dried samples were presented in Figure 3.4.

Fig 3.4: Figures of Dried samples

3.3.3 Moisture diffusivity

Moisture diffusivity is an internal transport property of the sample in which food dehydration generally occurs during falling rate period of the drying. During falling rate period of drying, moisture movement of the sample occurs to the surface by the principal moisture transport mechanism of diffusion. The most widely studied theoretical model in

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thin layer drying of various foods is given by the solution of Fick's second law. The solution of Fick's second law for diffusion of infinite slab may be used to fit the experimental drying data (Crank, 1975):

For infinite slab,

$$\text{Moisture ratio, } \frac{M\text{-}Me}{M0\text{-}Me} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left[-\frac{(2n+1)^2+\pi^2X^2}{4}\right] \quad \text{..... (3.4)}$$

$$\text{Where, } X = \frac{Dw \times t}{0.5L} \quad \text{..... (3.5)}$$

When drying time is large, the equation of moisture ratio reduces to the following expression.

$$\frac{M-Me}{M0-Me} = \frac{8}{\pi^2} \exp\left[\frac{-\pi^2 Deff \times t}{L^2}\right] \quad \text{..... (3.6)}$$

$$MR = \frac{8}{\pi^2} \exp\left[\frac{-\pi^2 Deff \times t}{L^2}\right] \quad \text{..... (3.7)}$$

$$MR = \frac{8}{\pi^2} \exp^{(-\pi^2 \times F_0)} \quad \text{..... (3.8)}$$

$$F_0 = \frac{-1}{\pi^2} \ln\left(\frac{MR \times \pi^2}{8}\right) \quad \text{.....(3.9)}$$

$$\text{Where , Fourier number } F_0 = \frac{D_{eff} \times t}{L^2} \quad \text{.....(3.10)}$$

$$F_0 = -0.1013 \ln MR - 0.02128 \quad \text{..... (3.11)}$$

$$Deff = \frac{F_0 L^2}{t} \quad \text{..... (3.12)}$$

$$\text{Also } \frac{\pi^2}{8}(MR) = \exp^{(-\pi^2 \times F_0)} \quad \text{.....(3.13)}$$

$$Ln\left(\frac{\pi^2}{8}\right) + \ln MR = -\pi^2 \times F_0 \quad \text{..... (3.14)}$$

$$F_0 = \frac{-1}{\pi^2} \ln\left(\frac{\pi^2}{8}\right) - \frac{1}{\pi^2} \ln MR \quad \text{.....(3.15)}$$

A linear relation of equation 3.11 was followed for determination of Fourier's number (F_0) from the drying data. Considering the entire positive signed F_0 values, the effective moisture diffusivity (D_{eff}) values were calculated. The average of all the D_{eff}

values for a particular set of drying experiment gave the value of average effective moisture diffusivity.

3.4 Quality Analysis

Quality analysis of the different samples included the determinations of the ascorbic acid and hygroscopicity.

3.4.1 Ascorbic acid

Ascorbic acid content was determined by titration method with 2,6-dichlorophenol-indophenol dye technique. The reagents used were 3% metaphosphoric acid (HPO_3), ascorbic acid standard and dye solution. For standardization of dye, 5ml of standard ascorbic acid solution and 5 ml of HPO_3 were taken in a burette. Then this solution was titrated with dye solution to a pink color which persisted for 15 seconds. Then dye factor was calculated.

$$\text{Dye factor} = \frac{0.5}{\text{Titre}} \qquad \text{..... (3.16)}$$

Five grams of dried custard apple samples were blended with HPO_3 and make up to 100ml in a volumetric flask.100 ml solution found was filtered out to a conical flask. Out of the total extract 5ml of filtered extract sample was titrated with dye solution to a pink end point persisted at least for 15 seconds.

Ascorbic acid content of the sample was then calculated from the following formula:

mg of ascorbic acid per 100gm of fresh sample =

$$\frac{\text{Titre x dye factor x volume made up x 100}}{\text{aliquot of extract taken for estimation x wt or vol of sample taken}} \qquad \text{.....(3.17)}$$

3.4.2 Hygroscopicity

About 2 grams of foam mat dried custard apple powder was kept inside a desiccator containing NaCl saturated solutions (75.5% humidity) and stored at 25 °C for 7 days. Then hygroscopicity value was found out with the following formula.

$$\text{Hygroscopicity} = \frac{\Delta m(M+M_i)}{1+\frac{\Delta m}{M}} \qquad \text{..... (3.18)}$$

Where, Δm = Increase in weight of powder after equilibrium.

M = initial mass of powder.

M_i = Free water contents (% wet basis) of powder before exposing to humid air environment.

Determination of the hygroscopicity of the custard apple powder was presented in figure 3.5.

Fig 3.5: Determination of Hygroscopicity of custard apple powder produced after foam drying.

3.5 Optimization of Process Parameters

3.5.1 Design of Experiments

Foam mat drying characteristics of the custard apple pulp was evaluated by taking five levels of GMS concentrations (0.5-4.5% w/w) along with 0.5% methyl cellulose, five levels of whipping time (2-10 minutes), five levels of drying temperatures (50-70 °C) and five levels of foam thicknesses (2-6 mm). The five levels central composite rotatable design (CCRD) of experiments was applied to optimize the drying and foaming parameters of the study. The coded and actual values of input parameters (i.e. GMS concentration, whipping time, drying temperature and foam thickness) are presented in Table 3.1.

Table 3.1: Coded and actual values of input parameters used in optimization process

Input parameters	Coded value	Actual value
1. GMS concentrations (%)	-2	0.5
	-1	1.5
	0	2.5
	1	3.5
	2	4.5
2. Whipping time (min)	-2	2
	-1	4
	0	6
	1	8
	2	10
3. Drying temperatures (°C)	-2	50
	-1	55
	0	60
	1	65
	2	70
4.Foam thickness (mm)	-2	2
	-1	3
	0	4
	1	5
	2	6

The analysis was conducted taking 30 combinations of experiments from which six were based at the centre points. The dependent (or response) variables (Y_k) and the independent (or process) variables (X_k) were assumed to correlate with a second order polynomial (equation no. 3.19).

The equation is of the following form,

$$Y_k = \beta_{ko} + \sum_{i=1}^{n} \beta_{ki} X_{ki} + \sum_{i=1}^{n} \beta_{kii} X_{ki}^{2} + \sum_{i=1}^{n} \sum_{j=i+1}^{n} \beta_{kij} X_{ki} X_{kj} \quad \text{.....(3.19)}$$

Optimization of the input parameters like GMS concentration (A), time of whipping (B), drying temperature (C) and the foam thickness (D) with respect to minimization of the responses i.e drying time (R_1) and hygroscopicity (R_3) and maximization of response like ascorbic acid (R_2) was carried out using Design Expert 9 software (Stat-Ease, Inc. 2012 East Hennepin Ave., Suite 480, Minneapolis, MN 55413). Selection of optimum conditions was accomplished through the accepted desirability levels in numerical optimization. It was followed with graphical solution method to find out optimized range of the parameters by the overlaid contour plot given by the software.

3.5.2 T- paired test

The paired t-test was employed for making pair comparisons between different treatments as the case had arisen. The calculated t- value was tested to be greater than the tabulated t-value, at a prescribed level of significance, which served as the boundary between significant and non-significant differences between any pair of treatment means (Gomez and Gomez, 1984).

Where t_α is the tabular t value at α level of significance and t-cal is the calculated t value from paired t-test.

Chapter IV
Results and Discussion

Chapter 4

RESULTS AND DISCUSSIONS

Foaming and Drying behaviour of custard apple pulp for production of powder was carried out with five levels of GMS concentration, whipping time, drying temperature and thickness levels of the pulp using 0.5% methyl cellulose as stabilizing agent. Foaming studies were carried out by finding foam expansion, foam density and foam stability at different levels of foaming agents and whipping time.

The initial moisture content, pulp percentage, TSS and bulk density of the custard apple pulp were found to be 74-76% (w.b), 35-45% (w/w), 23 ^{o}Brix and 1.090 g/cm^{3} respectively.

4.1 Foaming behaviour of Custard apple pulp

4.1.1 Effect of GMS concentration and whipping time on foam expansion

The effect of time of whipping on foam expansion of foamed custard apple pulp at different concentrations of GMS is shown in Figure 4.1. It was observed that, in 0.5% GMS treated sample, there was no increase of the foaming volume resulting into no foam expansion. In all other GMS treatments, the foam expansion values were increased with the increase of the whipping time. The foam expansion also increased with whipping duration up to a time period of 4-6 minute but after that, there was a stable trend up to 10 minutes of foaming. This type of phenomena was observed may be due to the present mixer condition which operated at a fixed rpm of 18000. Some amount of foaming may be collapsed due to overheating, caused by the over-rated operation of the blender.

Glycerol monostearate at 0.5% level recorded the lowest foam expansion value of 11% (Table 4.1) in all of its foaming durations, suggesting that this much amount of GMS (0.5%) was not sufficient to induce foaming in the pulp. With increasing GMS concentrations from 1.5 to 4.5% by weight the foam expansion value increased. Glycerol monostearate level at 3.5% and 4.5% by weight recorded higher foam expansion values of 60.89% and 72.22% respectively for whipping duration of 6 minute respectively. The increase in Foam expansion from 1.5 to 2.5% and 2.5 to 3.5% GMS for different whipping time gave significant ($p<0.05$ or $p<0.10$) different values, but the rise from 3.5 to 4.5% GMS was not significant ($P>0.108$). It was therefore evident that maintaining

3.5% GMS level with 6 minute whipping time will be optimum for obtaining foaming in custard apple pulp for subsequent drying experiments.

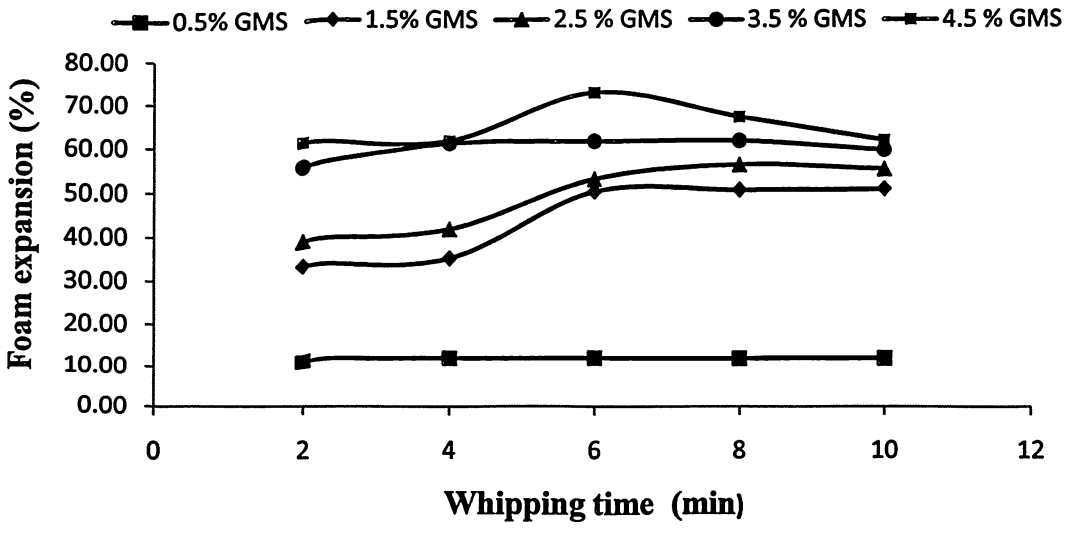

Fig. 4.1: Effect of GMS concentration and whipping time on foam expansion

Table 4.1: Effect of GMS concentration (%) and whipping time (min) on foam expansion (FE)

Whipping Time (min)	Foam Expansion (%)				
	GMS (0.5%) (a)	GMS (1.5%) (b)	GMS (2.5%) (c)	GMS (3.5%) (d)	GMS (4.5%) (e)
2	11	33.33	38.89	55.56	61.11
4	11	34.44	41.11	60.56	61.11
6	11	49.44	52.22	60.89	72.22
8	11	49.89	55.56	61.11	66.67
10	11	50.00	54.44	58.89	61.11
Paired T-value	-	3.80ab	4.06bc	2.48cd	2.06de
p-value		0.019**	0.015**	0.054*	0.108ns

Similar findings were also observed by Jaya and Das (2004) for mango powder preparation with optimum requirement of TCP and GMS as 0.015 kg per kg mango solid for foaming. The optimum concentrations of foaming agent for alphonso mango pulp were determined to be 1% soy protein, 2% glycerol monostearate, and 10% egg albumen

after 25 minutes of whipping time (Rajkumar et al. 2007). Optimum level of GMS (3.10 g/100 g pulp), methyl cellulose (0.32 g/100 g pulp), pulp concentration (13.2 ^{o}Bx) and whipping time of 2 min was found for bael powder (Bag et al., 2011). In many works like papaya powder, tomato powder, egg albumin/egg white with 10-15% concentration was used as foaming agent. In the present study, in order to prevent some consumer's non-preference for non-vegetative diet the addition of egg white was not considered and only GMS with 0.5% methyl cellulose could act here as foaming as well as stabilizing agent.

4.1.2 Effect of GMS concentration and whipping time on foam density

The density of the custard apple pulp foam was ranged between 0.60 to 0.94 g/cm^3. The highest foam density value of 0.94 gm/cm^{3}was recorded for GMS at a level of 0.5% w/w. The lowest foam density value of 0.60 gm/cm^3 was recorded for GMS at level of 4.5% for a whipping duration of 6 min. The next lowest density of the foam was observed at 3.5% GMS and 4 to 6 minutes of whipping duration. Therefore, as per desired low density foam were obtained between 3.5 to 4.5% GMS.

Table 4.2: Variation of foam density with GMS concentration and whipping time

Whipping time (min)	Foam density (g/cm^3)				
	0.5% GMS	1.5% GMS	2.5% GMS	3.5% GMS	4.5% GMS
2	0.94	0.78	0.75	0.67	0.65
4	0.94	0.77	0.74	0.65	0.65
6	0.94	0.69	0.68	0.65	0.60
8	0.94	0.69	0.67	0.65	0.62
10	0.94	0.69	0.67	0.65	0.65

4.1.3 Effect of GMS concentration and whipping time on foam stability

Foam stability studies of foamed custard apple pulp at different GMS level and whipping time were conducted for a maximum holding time period of 3 hour i.e. 180 minute. The results were presented in figures 4.2 to 4.4 for whipping time of 2 minute, 4 minute and 6 minute respectively. It was observed that, with the increase of the standing time foam stability value decreased. After 180 minute, the foam stability values were found to be 94.2, 95.8, 97 and 98% respectively for 2 minutes whipped pulp.

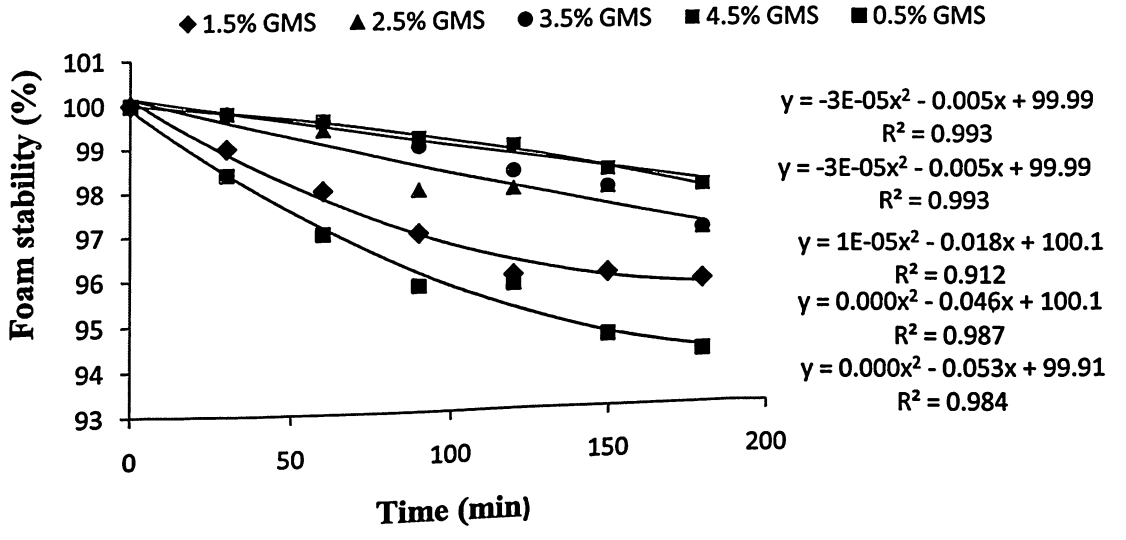

Fig 4.2: Foam stability of custard apple foam at different GMS concentration (after 2 minute of whipping time)

It was evident from figure 4.3 that, foam stability values of 0.5, 1.5 and 2.5% GMS treated samples after 180 minute were reduced. But, for 2.5% and 3.5% GMS treated sample, it gave a relatively stable behaviour. The foam stability value of 3.5% GMS treated sample was found out to be 1.64% more than that of the 2.5% GMS treated samples after 180 min of standing time.

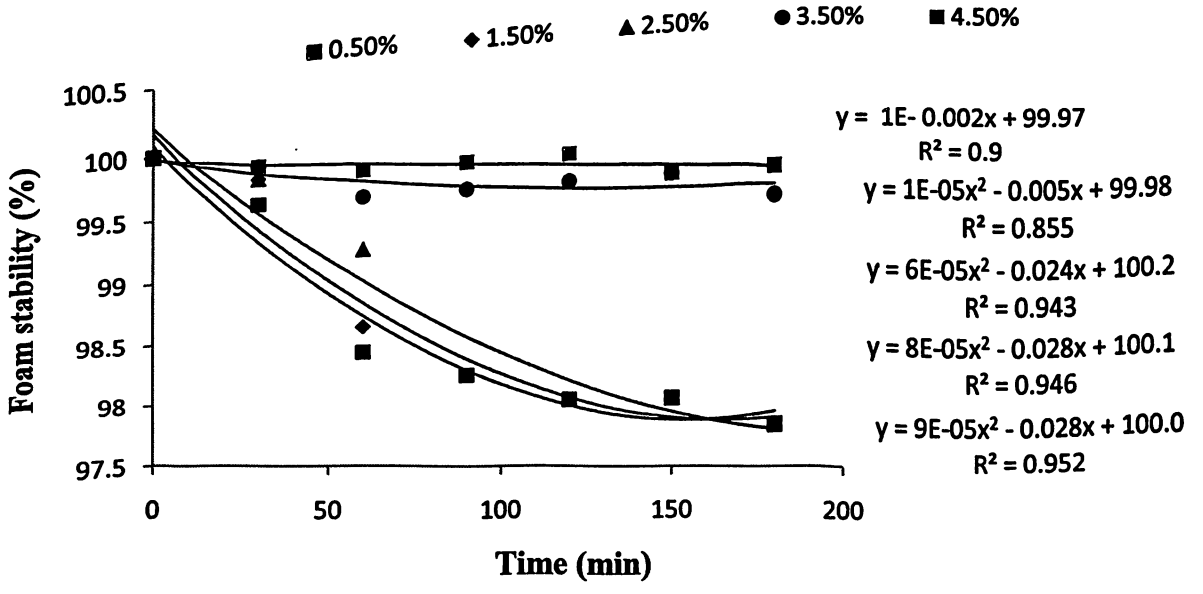

Fig. 4.3: Foam stability of custard apple foam at different GMS concentration (after 4 minutes whipping time)

Between 3.5% and 4.5 % GMS treated samples, the difference was only 0.2%. That is why it was decided to take 3.5% GMS treated sample whipped for 6 min as the best sample considering foam stability as well as foam expansion values. Similar research result was found for papaya pulp foaming by incorporating methyl cellulose as foaming agent at different levels of 0.25, 0.50, 0.75 and 1.00% on w/w basis. Here, the most stable foam formation was 83% at 0.75% methyl cellulose with 9 °Brix pulp and whipping time of 15 min (Kandasamy et al., 2012). Similar types of results were also found for six minute of whipping duration (Fig 4.4).

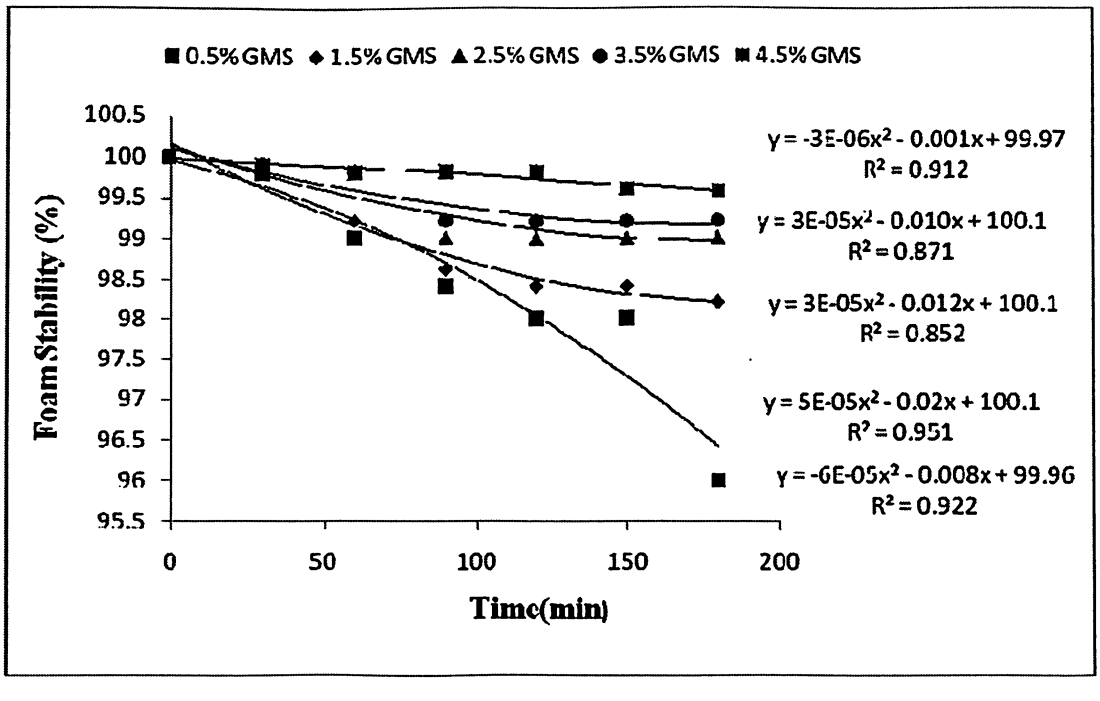

Fig. 4.4: Foam stability of custard apple pulp at different GMS concentrations (after 6 minutes of whipping time)

4.2 Drying characteristics of Custard apple pulp

4.2.1 Effect of drying air temperature and foam thickness on drying time

The variations of the moisture content of foamed custard apple pulp (with GMS and 0.5 % methyl cellulose) with drying time at different air temperature(50, 60, 70°C) and foam thickness (2, 4, 6 mm) were presented in Figures 4.5 and 4.6 respectively. Moisture content of the samples decreased with the drying time. The total drying time required to achieve up to a constant moisture level was found to be 720 min, 600 min and 330 min for 50, 60 and 70 °C drying air temperature respectively. So to get nearly the same amount of the moisture removal, the time differences between 50 and 60 °C, 60

and 70 °C and 50 and 70 °C dried sample were found to be 120 min, 270 min and 390 min respectively. At higher drying temperature i.e 70 °C the drying time was less as compared to lower temperature levels. It is in accordance with other related research findings (Rajkumar et al. 2007; Kandasamy et al., 2012) for other type of fruit pulps like mango or papaya.

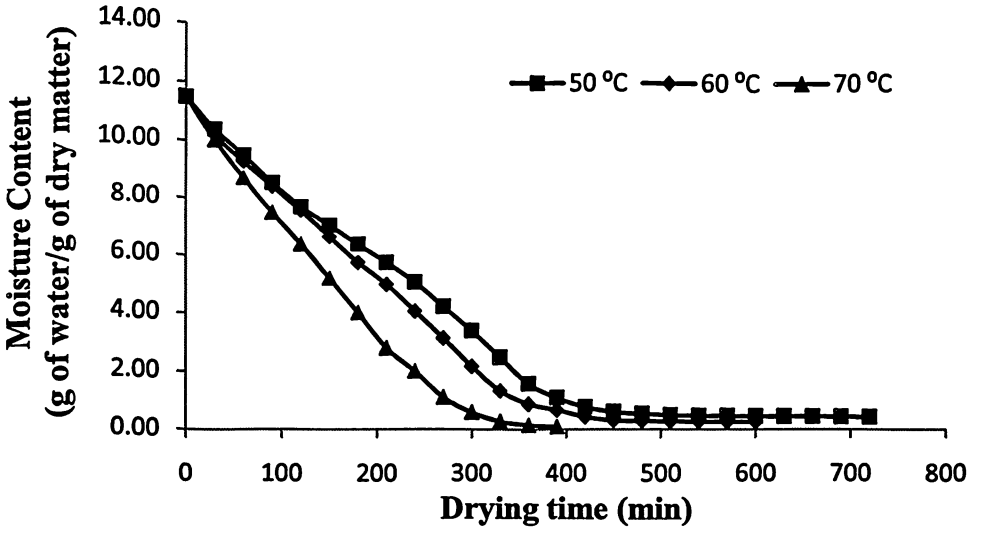

Fig.4.5: Drying curve of foamed custard apple pulp at different drying air temperature

The relationship between the moisture content and drying time for various foam thicknesses (2 mm, 4 mm, 6 mm) at 2.5 % GMS treated 4 minute whipped and 55 °C dried sample values was presented in Fig. 4.6. It showed with the increase of the foam thickness from 2 to 6 mm, there was an increase of the drying time.

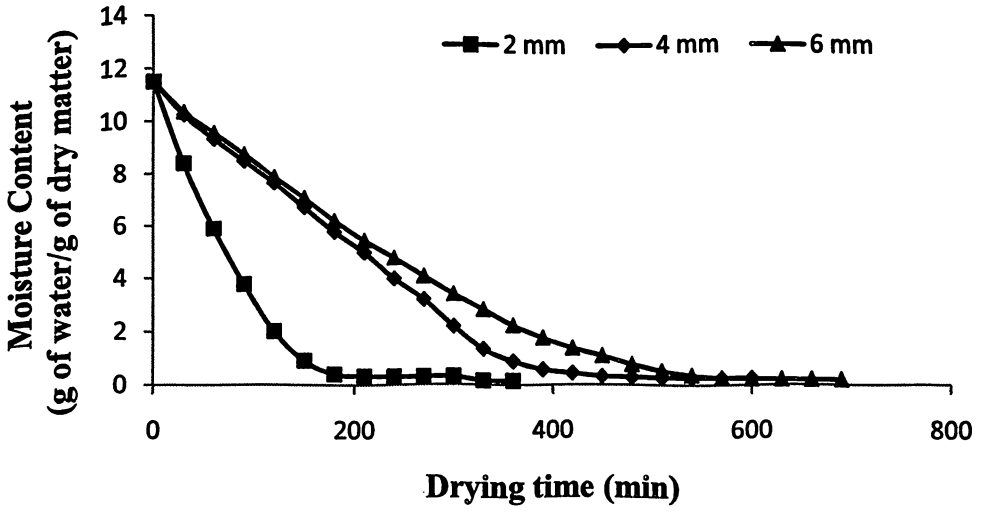

Fig. 4.6: Drying curve of foamed custard apple pulp at different foam thickness

The drying time required to get desired final moisture content for 2 mm pulp thickness was 360 minute, whereas it was 600 min for 4 mm pulp and 690 minutes for 6 mm thickness of pulp. As expected the more thickness foamed sample took more drying time than the lower thickness samples. Similar findings were also reported by (Rajkumar et al., 2007).

4.2.2 Effect of Drying temperature and foam thickness on variation of drying rate

The drying rate curves for custard apple pulp as a function of moisture content at different drying air temperatures and drying foam thickness were shown in figures 4.7 and 4.8 respectively. The drying rate was calculated from the drying data by estimating the change in the moisture content, which occurred in each time interval and was expressed as g of water/ g of dry matter/h. The drying rates were higher at the beginning of the drying process because the moisture was present in abundance at the surface of the product. The drying rates decreased as drying progressed further. The increased drying air temperature also affected drying rate in all drying conditions. Increase in drying air temperature increased the drying rates, reducing drying time. Such trends have also been reported for mango (Rajkumar *et al.*, 2007) and grapes (Tulsidas *et al.*, 1993).

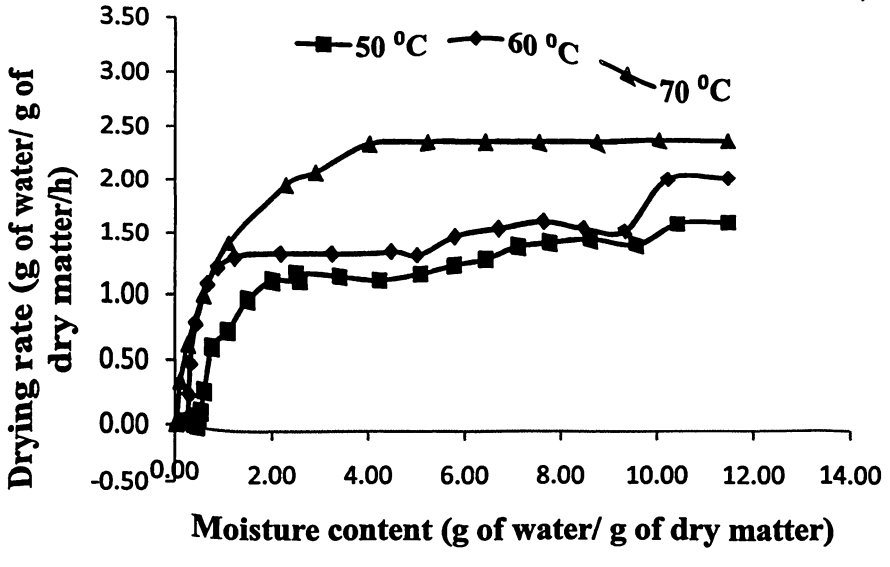

Fig. 4.7: Drying rate curve of foamed custard apple pulp at different drying air temperature

For instance, drying rate curve for custard apple sample treated with 2.5 % GMS whipped for 4 minute of 3 mm of pulp thickness at different drying air temperatures showed that the drying rates values were 2.09, 2.5 and 2.85 g of water/g of dry matter/h at 50, 60 and 70 °C respectively with a moisture content value of 11.50 g of water/g of

dry matter. But with the decrease of the moisture content value the corresponding drying rates values also decreased.

Similar types of results were also found for drying rate at different foam thickness. The drying rate curve of 2.5% GMS treated sample whipped for 4 min at 55 °C drying temperature was presented in Figure 4.8. The initial drying rates values were 6.18, 2.5, 2.27 g of water/g of dry matter/h with an initial moisture level of 11.5 g of water/g of dry matter for 2mm, 4 mm and 6 mm drying thicknesses values respectively. But with the decrease of the moisture values, there was a decrease of the drying rate values was observed.

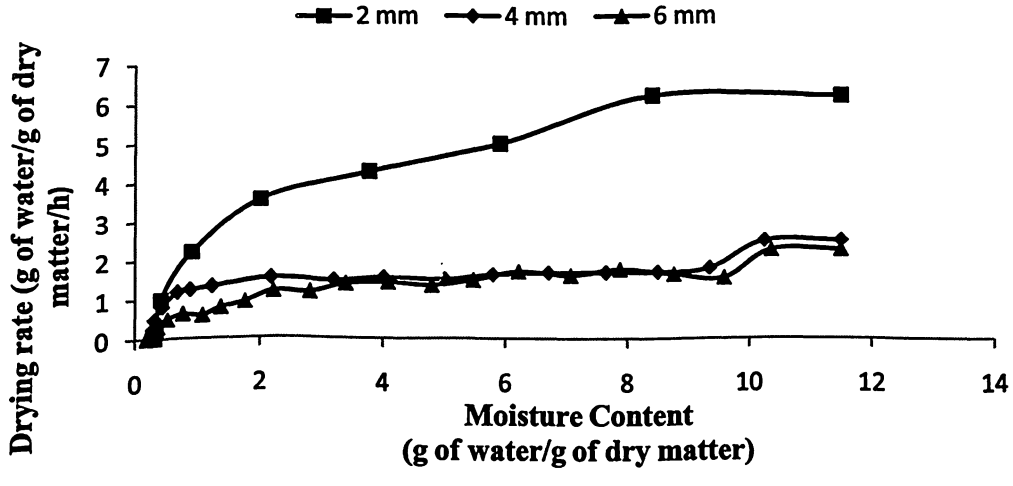

Fig. 4.8: Drying rate curve of foamed custard apple pulp at different foam thickness

Increasing the drying air temperature in foam mat drying of custard apple pulp from 50 to 70 °C, drying time reduced from 720 minutes to 420 minutes saving around 300 minutes drying time. The foam thickness has similar effects showing less time (360 min) for 2 mm thickness than 6 mm thickness (690 min).

4.2.3 Effect of Drying temperatures and thickness in the moisture diffusivity values

The moisture diffusivity value increased with increasing drying air temperature giving range of 1.53×10^{-8}-7.62×10^{-7} for 70°C with average D_{eff} as 2.225×10^{-7}. Similarly with reducing the foam layer thickness from 6 to 2 mm the average D_{eff} value increased from 2.8×10^{-8} to 3.71×10^{-6}.

Table 4.3: Moisture diffusivity, average moisture diffusivity and drying time at different temperature and foam thickness

Variables		Drying time (min)	Moisture diffusivity (m^2/s)	Average Diffusivity(m^2/s)
Temperature (°C)	50	720	5.61×10^{-9}-7.46×10^{-9}	1.6×10^{-9}
	60	600	1.81×10^{-8}-8.10×10^{-8}	2.30×10^{-8}
	70	420	1.53×10^{-8}-7.62×10^{-7}	2.225×10^{-7}
Foam thickness (mm)	2	360	3.36×10^{-7}-7.96×10^{-6}	3.71×10^{-6}
	4	600	1.81×10^{-8}-8.10×10^{-8}	2.30×10^{-8}
	6	690	6.07×10^{-8}-8.85×10^{-8}	2.8×10^{-8}

4.2.4 Effect of foaming and non-foaming on drying time and drying rate of custard apple pulp

The time taken by the non-foamed pulp from a moisture content of 3.17 to 0.16 g of water/g of dry matter was found to be 900 minutes and the time taken by that of the foamed pulp was found to be 570 minutes (Fig. 4.9). So, the extra time taken by the non foamed pulp was found to be 330 minute.

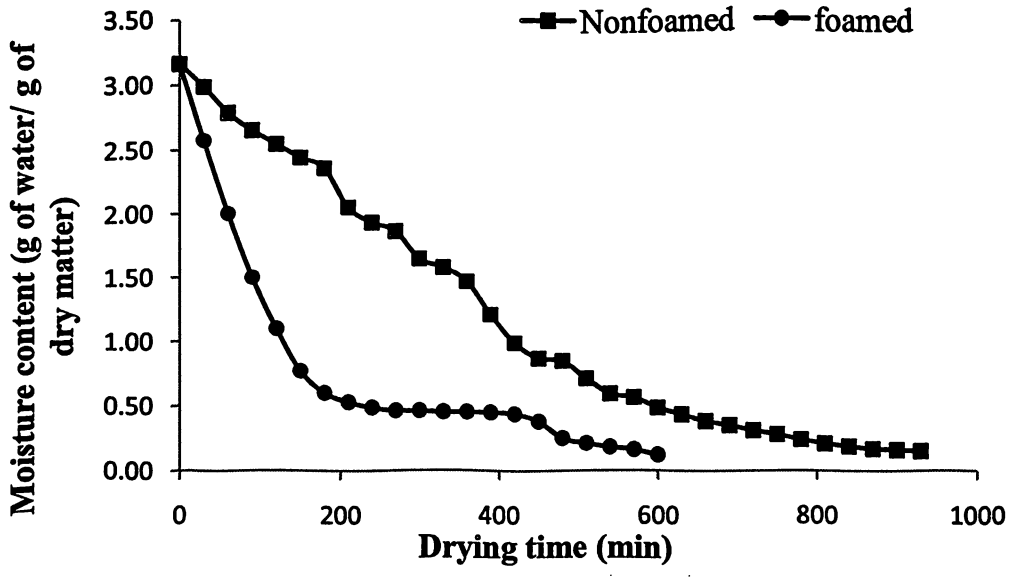

Fig 4.9: Drying curve of foamed and non-foamed custard apple pulp at 50 °C

There was a decreasing trends of the drying rate was observed in both of the foamed and non foamed pulp with the decrease of the moisture content (Fig.4.10). After 420 minutes of drying, the drying rate value decreased from 1.75 to 0.75 in non foamed pulp and 2.09 to 1.01 g of water/ g of dry matter/ h in foamed pulp. So, the drying rate values were lower for non-foamed than that of the foamed pulp.

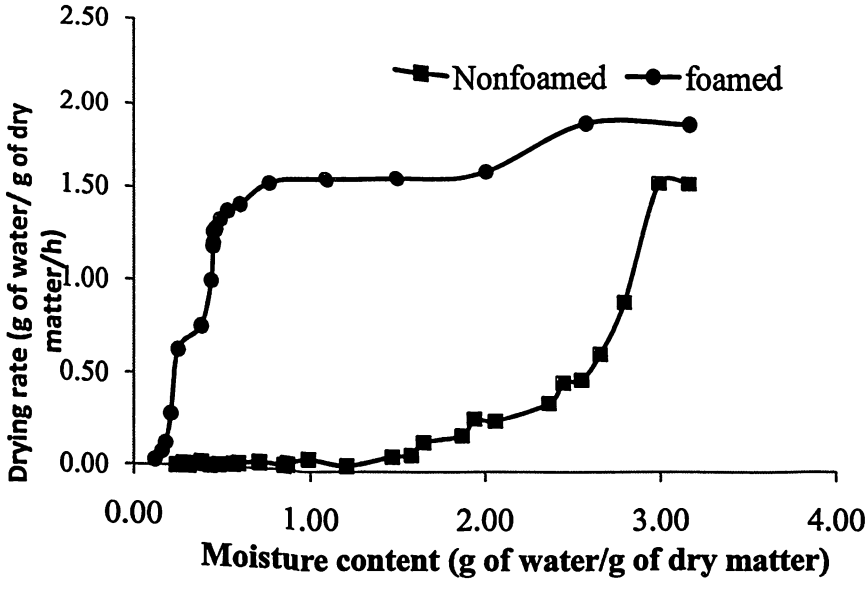

Fig 4.10: Drying rate curve of foamed and non foamed pulp at 50 °C

4.3 Optimization of Process Parameters

4.3.1 Correlation of drying time, ascorbic acid content, hygroscopicity with process parametrs

The variation of total drying time (R1) at different GMS concentration (A), whipping time (B), drying temperature(C) and foam layer thickness (D) in coded forms was fitted with a second order polynomial equation (equation 4.1).

DT=605.25+5.00*A+5.00*B68.13*C+58.12*D+4.69*AB+12.19*AC+4.69AD+44.0
6*AD+44.06*BC-12.19*BD-19.69*CD-16.47*A^2-29.59B^2-17.41*C^2-38.03*D^2

.....(4.1)

Table 4.4 showed the analysis of variance of drying time (DT), ascorbic acid content (AA) and hygroscopicity (HG) of custard apple powder at different process parameters. It revealed that the model is significant ($P<0.01$) to predict the DT.

Table 4.4: ANOVA for drying time, ascorbic acid content and hygroscopicity of custard apple powder at different process parameters

Response	Drying Time		AA Content		Hygroscopicity	
Source	F Value	p-value Prob>F	F Value	p-value Prob>F	F Value	p-value Prob>F
Model	4.37	0.0037***	3.88	0.0359*	3.46	0.04373*
A-GMS	0.12	0.7296	1.59	0.2476	1.042E-003	0.9747
B-Whipping Time	23.03	0.7296	0.64	0.4509	1.13	0.3044
C-Drying Temp	16.76	0.0002***	15.25	0.0059**	11.69	0.0038**
D-Layer thickness	0.073	0.0010***	6.58	0.0372*	0.20	0.6603
AB	0.49	0.7911	1.60	0.2465	1.373E-005	0.9971
AC	0.073	0.4941	5.04	0.0597	1.151E-003	0.9734
AD	6.42	0.7911	1.51	0.2585	7.514E-005	0.9932
BC	0.49	0.0229**	1.79	0.2230	0.13	0.7276
BD	1.28	0.4941	0.00903	0.9269	0.025	0.8 34
CD	1.54	0.0275**	1.20	0.3095	0.015	0.9040
A^2	4.97	0.2340	0.21	0.6574	3.52	0.0802
B^2	1.72	0.0416**	0.013	0.9123	4.72	0.0462*
C^2	8.20	0.2096	21.87	0.0023**	0.099	0.7575
D^2		0.0118**	0.00309	0.9572	0.29	0.6000
Lack of fit	0.442	0.4683ns	0.35	0.7209ns	0.54	0.8092ns
R^2	0.8032		0.9243		0.7780	
R^2 adj.	0.6195		0.8863		0.6821	
$R^{\wedge 2}$ Pred.	0.1236		0.4322		0.5586	
CV (%)	13.24		14.26		15.97	
Adeq.	7.727		9.354		6.595	

Coefficient of determination R^2 = 0.80, R^2 (adj)= 0.62, non-significant lack of fit, C.V.= 13.24, positive R^2 pred. value, adeq precision >4.0 suggest adequacy of the model to predict the experimental data. The drying temperature, layer thickness significantly affects the DT. The interaction terms of whipping time-drying temperature and drying temperature-layer thickness and square terms of whipping time and layer thickness in the equation significantly affected the variation of drying time.

The polynomial equation fitting well to the experimental data of ascorbic acid content (AA) and hygroscopicity (HG) at different process parameters in coded forms were given in equation 4.2 and 4.3 as follows.

AA=0.11+8.087E-003*A+5.119E-003*B-0.025*C+0.016*D-5.733E 003*AB+0.010*AC+5.733E-003*AD+6.062E-003*BC+4.310E-004*BD-4.968E-003*CD+1.604E-003*A^2+3.953E-004*B^2+0.016*C^2-1.926E-004*D^2 .....(4.2)

HG = 11.78 + 0.002*A+0.72*B-2.33*C+0.31 * D + 3.094E-003*AB+0.028*AC - 7.237E-003*AD – 0.30 *BC – 0.13 * BD + 0.10 * CD – 1.20*A^2-1.39*B^2-0.20*C^2-0.34*D^2 .....(4.3)

From the ANOVA table (Table 4.4) it was evident that the model F value 3.88 and 3.46 implies the models were fitting well to the experimental data. It was further supported by R^2, R^2 (adj), non-significant lack of fit, Low C.V, positive R^2 pred. Values and Adeq. Precision>4.0 (Table 4.3) suggesting adequacy of the model to predict well the experimental data. The drying temperature and thickness of layer in linear and square terms are significantly ($P<0.05$) affecting the model values in case of AA content and the drying temperature and square term of whipping time in case of hygroscopicity values.

The figures of normal plot of residuals and predicted vs. actual plot (Fig. 4.11 – 4.12) for R_1, R_2 and R_3 i.e. (DT, AA , HG) show the data points are concentrated along the center line and scattered uniformly on both side of the center line revealing the good fit of the models.

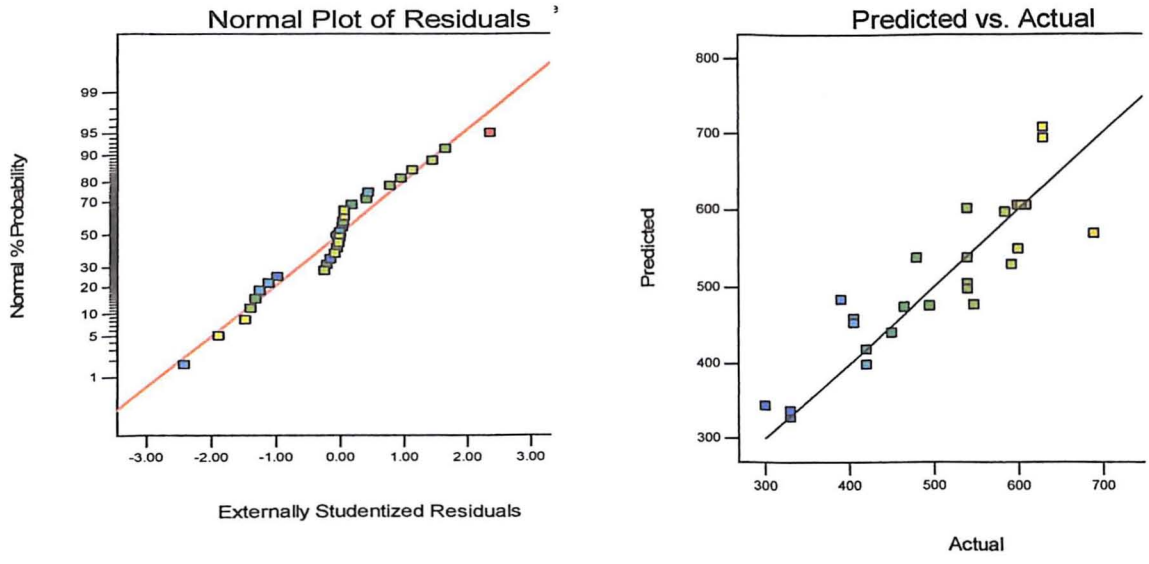

Fig 4.11: Normal plot of residuals and predicted Vs. actual values of DT.

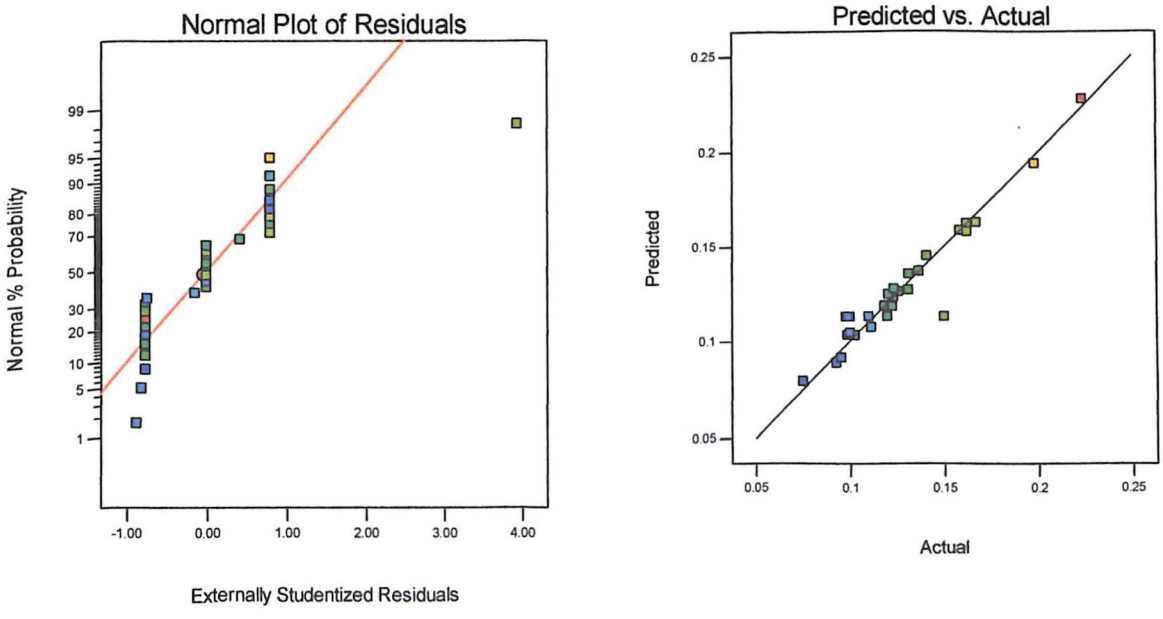

Fig 4.12: Normal plot of residuals and predicted Vs. actual values of AA.

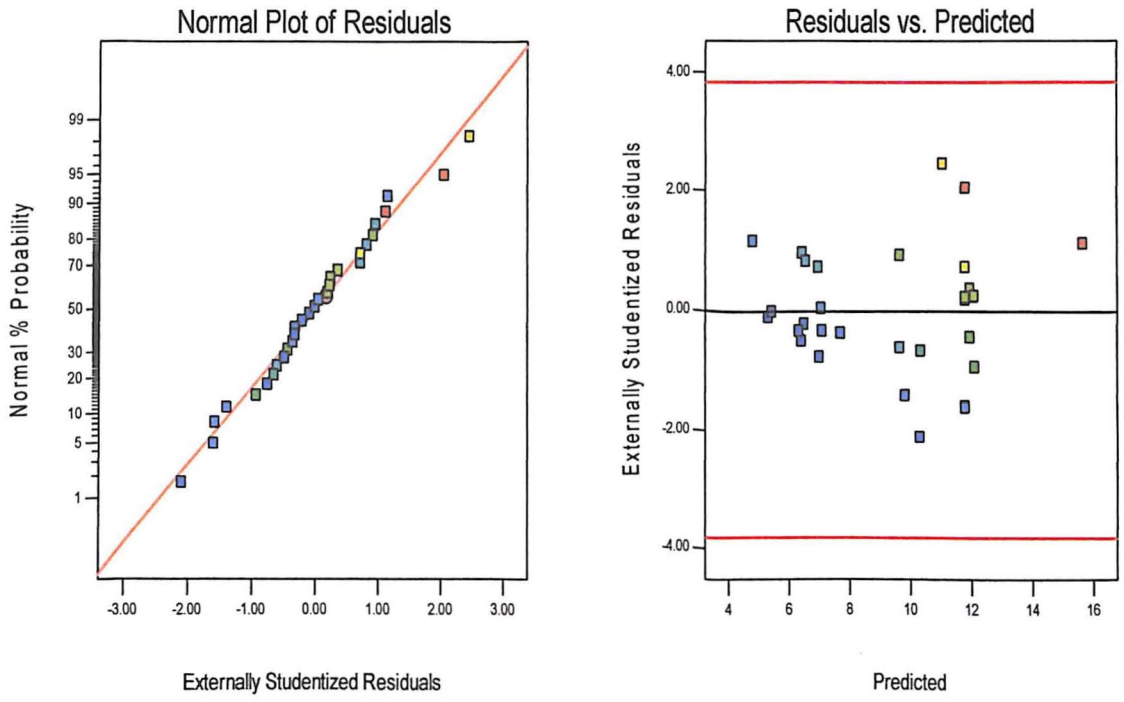

Fig 4.13: Normal plot of residuals and predicted Vs. actual values of HG.

4.3.2 Response surface plots

The response surface plots of DT, AA and HG (Fig. 4.12) were developed by design software (Design Expert software 9, Stat-Ease Inc., 2013, USA) with respect to two variables, keeping the other two parameters fixed at the central point.

The 3D surface plots of individual responses can be categorised into two forms: one showing the effects of foaming parameters i.e. GMS concentration (%) and whipping time on the each response and the other showing the effects of drying parameters i.e. drying temperature (^{o}C) and thickness of product layer (mm) with the response.

With increasing GMS concentration the drying time gradually decreased, ascorbic acid content steadily increased and hygroscopicity increased first and then steadily decreased. With increasing whipping time the drying time, ascorbic acid content remained almost static and hygroscopicity first increased and then almost static.

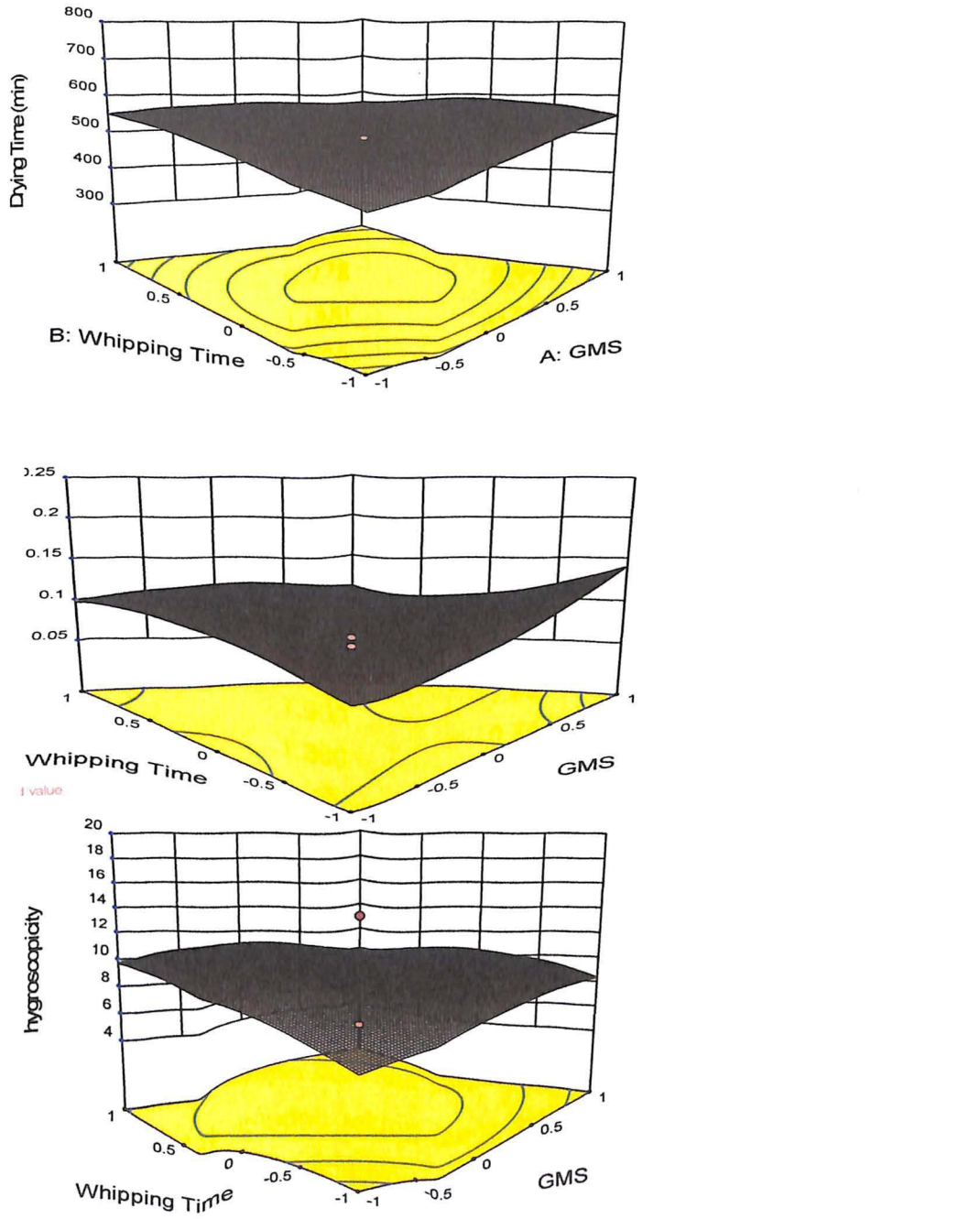

Fig 4.14: Response surface plots of drying time, ascorbic acid content and Hygroscopicity vs. GMS and whipping time.

Numerical optimization technique was followed in the standard Design Expert software 9 to obtain the optimized process parameters. The criteria set were minimizing drying time, hygroscopicity and maximizing ascorbic acid content. Table 4.5 showed 19 optimum solutions with varying level of desirability from 0.935 to 0.903. The optimized parameters in coded form selected were 1.000 (GMS), -1.000 whipping time, 1.000 drying temperature and -0.983 layer thickness of sample with desirability value of 0.935.

Table 4.5: Numerical solution of optimized parameters

Sl. No.	GMS	Whipping time	Drying temperature	Layer thickness	Drying time	Desirability
1	1.000	-1.000	1.000	-0.983	330.242	0.935 (S)
2	-0.935	-1.000	1.000	-1.000	330.718	0.934
3	-0.926	-1.000	1.000	-1.000	331.061	0.933
4	-1.000	-0.993	0.978	-0.998	332.215	0.931
5	-1.000	-0.994	1.000	-0.965	333.099	0.929
6	-0.884	-1.000	1.000	-0.994	333.404	0.928
7	-1.000	-0.943	1.000	-1.000	334.650	0.925
8	-0.999	-1.000	0.949	-0.997	335.547	0.924
9	-0.765	-1.000	1.000	-1.000	336.823	0.921
10	-0.900	-1.000	1.000	-0.955	337.461	0.919
11	-0.750	-0.999	0.982	-1.000	339.868	0.914
12	-0.608	-1.000	1.000	-1.000	341.557	0.911
13	-1.000	-0.999	0.994	-0.893	341.685	0.910
14	1.000	-1.000	1.000	-1.000	343.750	0.906
15	-1.000	-1.000	1.000	-0.866	343.814	0.906
16	0.989	-0.999	0.999	-1.000	344.213	0.905
17	-0.677	-1.000	0.963	-1.000	344.482	0.904
18	0.970	-1.000	1.000	-1.000	344.485	0.904
19	0.961	-1.000	0.995	-1.000	345.239	0.903

(S: selected)

The uncoded or actual values of these parameters are 3.5 % w/w GMS, 4 minutes whipping time, 65 °C drying temperature and 3.02 mm layer thickness of sample. It was followed with the graphical solution taking the criteria of drying time within range between 300-750 minutes, ascorbic acid from 0.1-0.2 and hygroscopicity less than 10% for obtaining the best quality custard apple powder.

4.3.3 Overlaying of contour plots of responses

Figures 4.15 to 4.17 showed the contour plots of DT, AA and HG with all possible input parameters (assuming GMS and whipping time optimized as per numerical solution i.e. 3.5% GMS and 4 minutes). Overlaying of all the contour plots (Fig. 4.18) were made to select optimum range of process parameters by graphical optimization technique. The bright yellow coloured portion in the plot shows the optimum range of parameters with drying temperature range between -1 to +1 in coded unit i.e. 55-65 °C and layer thickness between -1.5 to 1.0 in coded unit i.e. 2.5-5.0 mm.

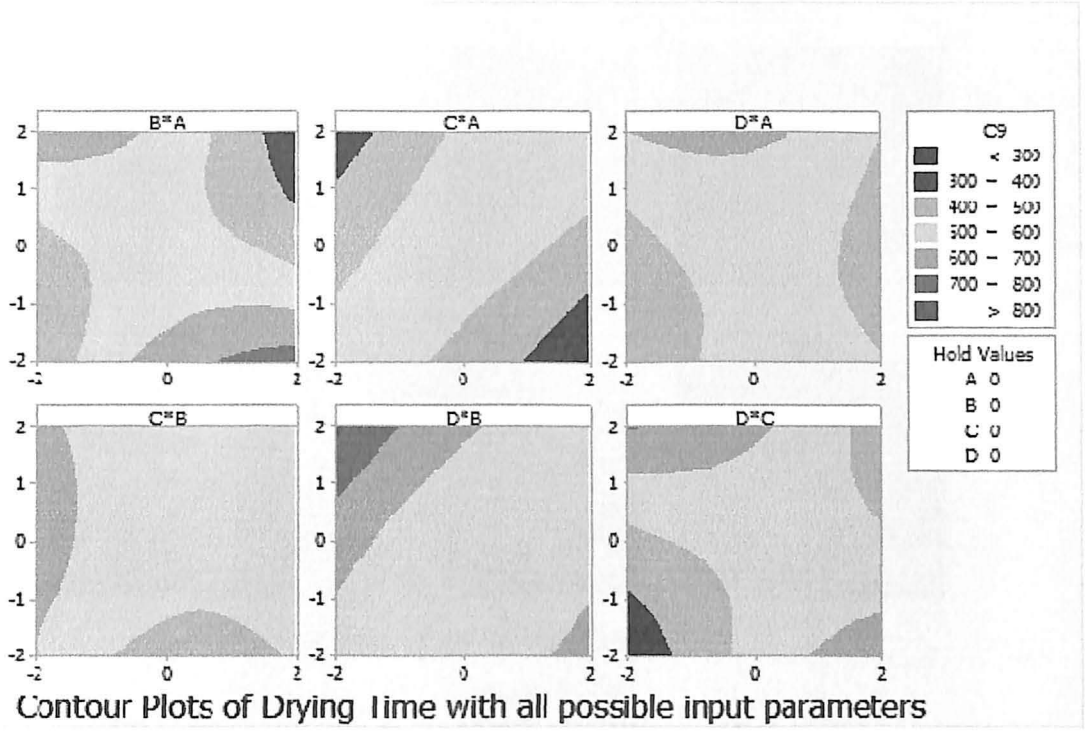

Fig 4.15 Contour plots of DT with all possible input parameters

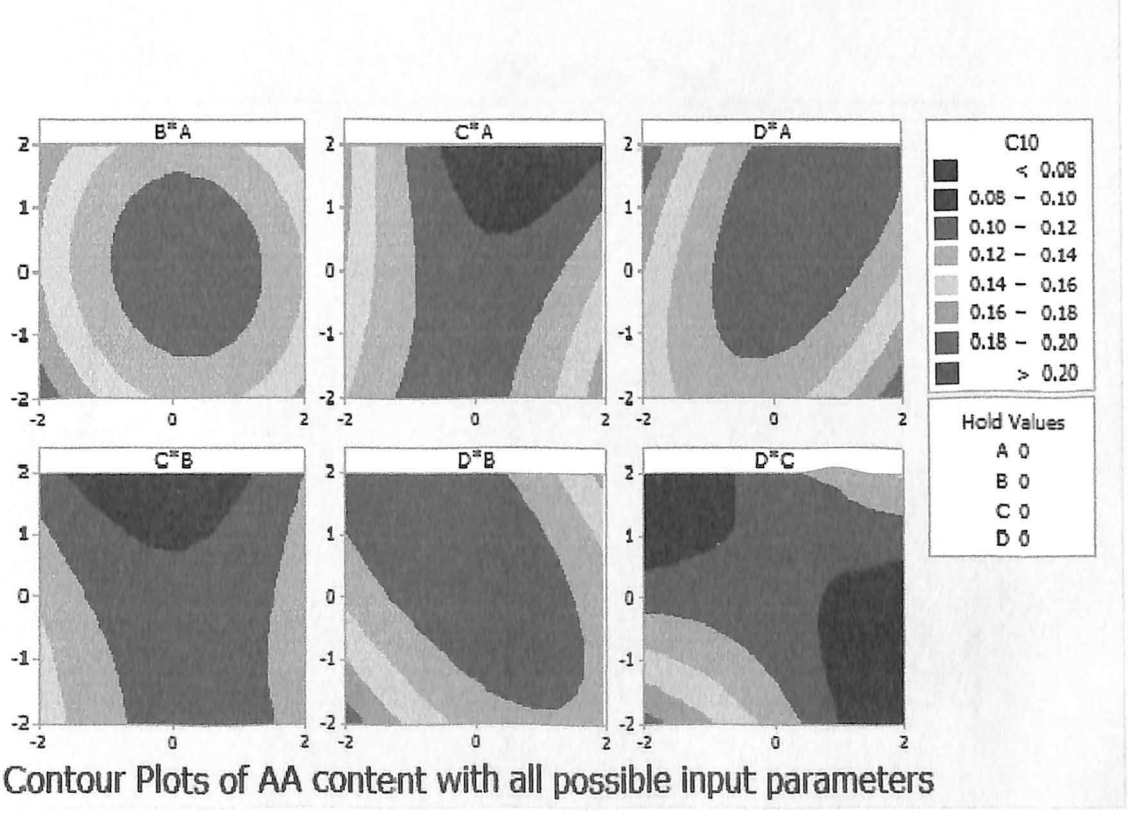

Fig 4.16 Contour plots of AA with all possible input parameters

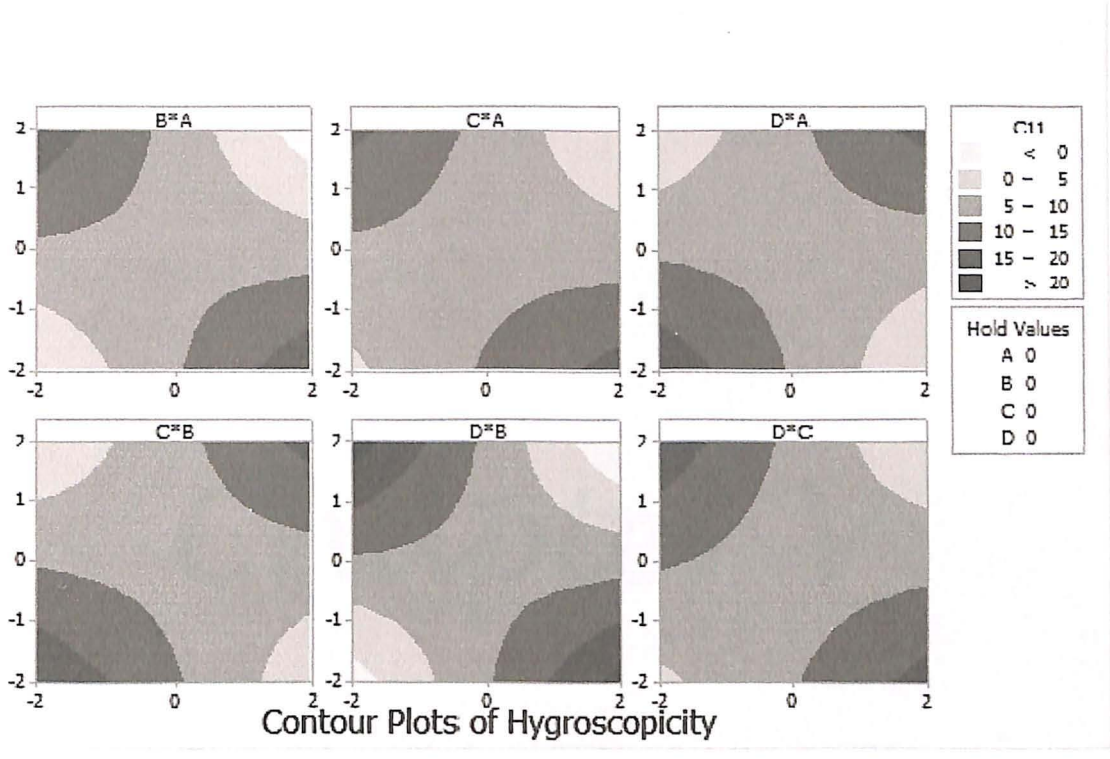

Fig 4.17 Contour plots of HG with all possible input parameters

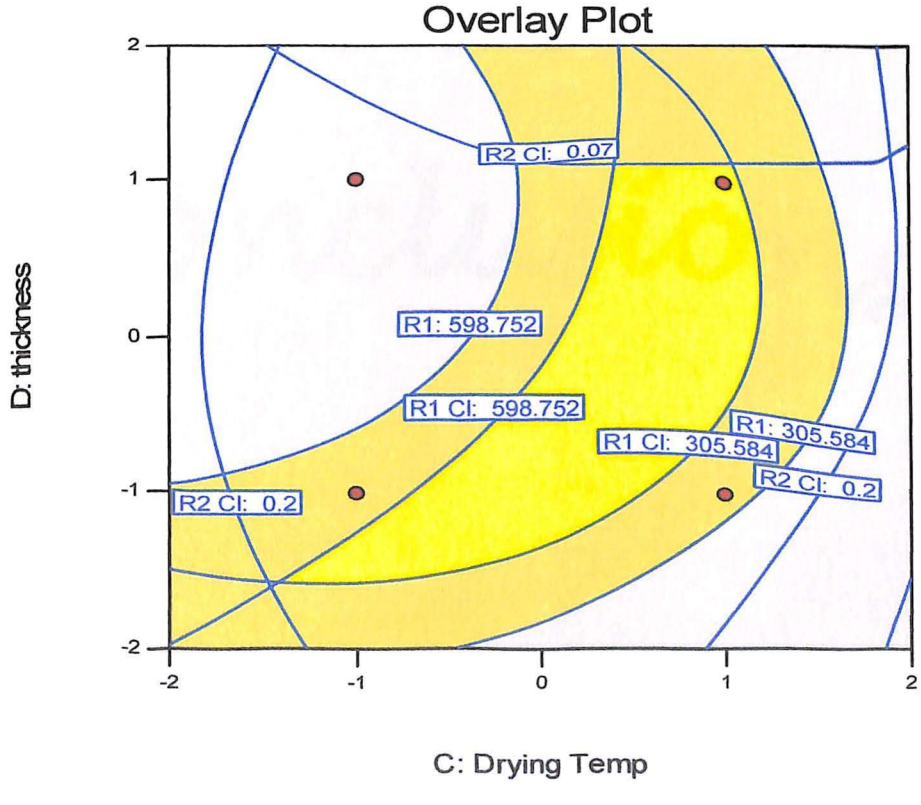

Fig. 4.18: Overlaid contour plots of all responses

Chapter V
Summary and Conclusions

Chapter 5

SUMMARY AND CONCLUSION

Custard apple (*Annona squamosa L)* is a tropical fruit coming under the Annonaceae family. It contains upto 72-78% of moisture content, proteins, carbohydrates, vitamins, minerals, dietary fibres etc. It is beneficial for cardiac disease, diabetes, hyperthyroidism and cancer. The ripe fruits of this plant are applied to malignant tumors to hasten suppuration. Its pulp is most popularly used in ice cream, milk shake, dessert foods, cakes, beverages etc. in powder form. The flavor component of the custard apple is mainly responsible for the volatile components like σ-pinene, ß-pinene, Linalool etc.

Foam mat drying is a process in which a liquid or semi solid material is converted into stable foam by incorporating substantial volume of air or other inert gases in the presence of foaming and stabilising agents. The foaming agent works as a foam inducer and/or stabilizer. The foam thus formed is then spread as a thin mat or sheet and allowed to go for drying until it is dried upto the required moisture levels. The dehydrated product is then allowed to go for conditioning and converted into powder form.

Generally, pulpy fruit like custard apple contain a large amount of sugar content and have a dense physical structure as well as chemical composition. Simply hot air drying is very difficult to achieve the required moisture removal for powder production. The stickiness and caking properties also cause a lot of difficulty in drying. The hot air drying process is also very slow and during drying it may induce colour and flavor change in the final product rejecting its quality for export potential. Fruit pulps are generally spray dried, drum dried or freeze dried. But, in no cases it becomes cheaper for drying by a common farmer. Therefore, drying alternatives could be suggested for fruit pulps for making powder. Foam mat drying by principle can increase the surface area for drying due to foaming. This helps in making the custard apple pulp more porous, thus allowing rapid moisture removal with a higher drying rate. As foaming process provides minimum drying time, with better textured products, we can take foaming in addition to tray drying to get a better textured and good quality custard apple powder.Keeping the above facts in view, the present research work has been undertaken to study the foam mat drying characteristics of custard apple pulp with the following specific objectives:

1. To study the foaming behaviour of custard apple pulp for drying.
2. To study the drying characteristics of foamed custard apple pulp after foaming.
3. To optimize the foaming and drying parameters for obtaining a better quality custard apple powder and development of mathematical models.

The Foam mat drying study of the Custard apple pulp was conducted by using Glycerol monostearate (0.5%, 1.5%, 2.5%, 3.5% and 4. %) as foaming agent and 0.5 % methyl cellulose as the stabilising agent with whipping durations of 2, 4, 6, 8 and 10 minutes. Drying was carried out in a cabinet tray dryer at five different drying temperatures (50, 55, 60, 65 and 70 °C) with foam thicknesses of 2, 3, 4, 5 and 6 mm. The five levels central composite rotatable design (CCRD) of experiments was applied to optimize the drying and foaming parameters of the study. Design Expert 9 software (Stat-Ease, Inc. 2012 East Hennepin Ave.) was used to analyze the foaming and drying parameters by numerical and graphical analysis. The following findings were found from the experiments.

1. It was observed that, in 0.5% GMS treated sample there was no increase of the foaming volume resulting into no foam expansion. In all other GMS treatments, the foam expansion values were increased with the increase of the whipping time.
2. The foam expansion values increased with whipping duration up to a time period of 4-6 minute but after that, it was a stable or reduced trend up to 10 minutes of foaming, which may be due to the overheating of the product due to the over-rated operations of the blender.
3. Glycerol monostearate at 0.5% level recorded the lowest foam expansion value of 11% in all of its foaming durations, suggesting that this much amount of GMS (0.5 %) was not sufficient to induce foaming in the pulp.
4. With increasing GMS concentration from 1.5 to 4.5% by weight the foam expansion value increased. Glycerol monostearate level at 3.5% and 4.5 % by weight recorded higher foam expansion values of 60.89% and 72.22% respectively for whipping duration of 6 minute.
5. The increase in FE from 1.5 to 2.5%, 2.5 to 3.5% GMS for different whipping time gives significant ($p<0.05$ or $p<0.10$) different values, but the rise from 3.5 to 4.5% GMS is not significant ($P>0.108$). It is therefore evident that maintaining 3.5% GMS level with 6 minute whipping time will be optimum for obtaining foaming in custard apple pulp for subsequent drying experiments.

6. The density of the custard apple pulp foam was ranged between 0.60 to 0.94 g/cm^3. The foam density value for GMS at 3.5% level with a whipping duration of 6 min was found to be 0.65 gm/cm^3.
7. The foam stability value of 3.5% GMS treated sample was found out to be 1.64 % more than that of the 2.5% GMS treated samples after 180 min. But between 3.5% and 4.5% samples, the difference was only 0.2%. Therefore, it was decided to take 3.5% GMS treated sample whipped for 6 min as the best sample considering foam stability value
8. The drying time taken by the non foamed pulp was found to be 350 minutes more than that of the foamed pulp. Drying rate was also lower in non foamed pulp than that of the foamed pulp.
9. Increase in drying air temperature increased the drying rates, reducing drying time. So, more drying rates were found in more drying temperatures like 70 ^{0}C and lower in lower drying temperatures like 50 ^{0}C.
10. The foam thickness has similar effects showing less drying time (360 min) for 2 mm thickness than 6 mm thickness (690 min).
11. The moisture diffusivity value increased with increasing drying air temperature giving range of 1.53×10^{-8}-$7.62 \times 10^{-7}$for 70^{0}C with average D_{eff} as 2.225×10^{-7}. Similarly with reduction of the foam layer thickness from 6 to 2 mm the average D_{eff} value increased from 2.8×10^{-8} to 3.71×10^{-6}.
12. The variation of total drying time (DT), ascorbic acid content (AA) and hygroscopicity (HG) at different GMS concentration (A), whipping time (B), drying temperature(C) and layer thickness (D) in coded forms were fitted with second order polynomial equations as given below.

DT=605.25+5.00*A+5.00*B68.13*C+58.12*D+4.69*AB+12.19*AC+4.69AD+4
4.06*AD+44.06*BC-12.19*BD-19.69*CD-16.47*A^2-29.59B^2-
17.41*C^2-38.03*D^2

AA=0.11+8.087E-003*A+5.119E-003*B-0.025*C+0.016*D-5.733E-
003*AB+0.010*AC+5.733E-003*AD+6.062E-003*BC+4.310E-
004*BD-4.968E-003*CD+1.604E-003*A^2+3.953E-
004*B^2+0.016*C^2-1.926E-004*D^2

$$HG = 11.78 + 0.002*A+0.72*B-2.33*C+0.31 * D + 3.094E-003*AB+0.028*AC - 7.237E-003*AD - 0.30 *BC - 0.13 * BD + 0.10 * CD - 1.20*A^2 - 1.39*B^2-0.20*C^2-0.34*D^2$$

13. The ANOVA table revealed that the model is significant ($P<0.01$) to predict the drying time (DT). Coefficient of determination $R^2 = 0.80$, R^2 (adj)= 0.62, non-significant lack of fit, C.V.= 13.24, positive R^2 pred. value, adeq precision >4.0 suggest adequacy of the model to predict the experimental data. The drying temperature, layer thickness significantly affects the DT.
14. The interaction terms of whipping time-drying temperature and drying temperature-layer thickness and square terms of whipping time and layer thickness in the equation significantly affect the variation of drying time.
15. The drying temperature and thickness of layer in linear and square terms are significantly ($P<0.05$) affecting the model values in case of ascorbic acid content and the drying temperature and square term of whipping time in case of hygroscopicity values.
16. The figures of normal plot of residuals and predicted vs. actual plot for drying time, ascorbic acid and hygroscopicity showed the data points are concentrated along the centre line and scattered uniformly on both side of the centre line revealing the good fit of the models.
17. The response surface plots of DT, AA and HG were developed by design software (Design Expert software 9, Stat-Ease Inc., 2013, USA) with respect to two variables, keeping the other two parameters fixed at the central point.
18. With increasing GMS concentration the drying time gradually decreased, ascorbic acid content steadily increased and hygroscopicity increased first and then steadily decreased. With increasing whipping time the drying time, ascorbic acid content remained almost static and hygroscopicity first increased and then almost static.
19. Numerical optimization technique suggested that the optimised parameters in actual values were 3.5% w/w GMS, 4 minutes whipping time, 65 °C drying temperature and 3.02 mm layer thickness of sample.

20. The graphical optimization through overlaying of contour plots suggested optimum range of drying temperature between 55-65 °C and layer thickness between 2.5-5.0 mm to obtain dried custard apple powder with less drying time, higher ascorbic acid content and less hygroscopicity.

Chapter 6

SUGGESTIONS FOR FUTURE WORK

1. The present blender may not be sufficient to induce much of foam expansion. This can be modified with fabrication of a foaming device with suitable rotating arrangements and facility for incorporation of air inside the foam through attachment of air compressor.
2. Other quality aspects of custard apple powder such as solubility or reconstitution, total acidity, sugar content and minerals like Ca, Mg and Fe can be estimated and the effect of foaming and non-foaming of pulp on these quality aspects may be determined.
3. Some pre-treatment methods must be standardized to counter the discolouration of powder during drying. Low temperature slow drying or spray drying with grits removal or vacuum drying may be tried for achievement of better quality custard apple powder.
4. Other types of foaming and stabilising agent e.g. soya protein isolate, egg albumin etc. may be tried for investigating their effects on foaming behaviour of custard apple pulp.
5. The process of powder formation from the flakes obtained after drying of custard apple pulp need to be standardized properly.

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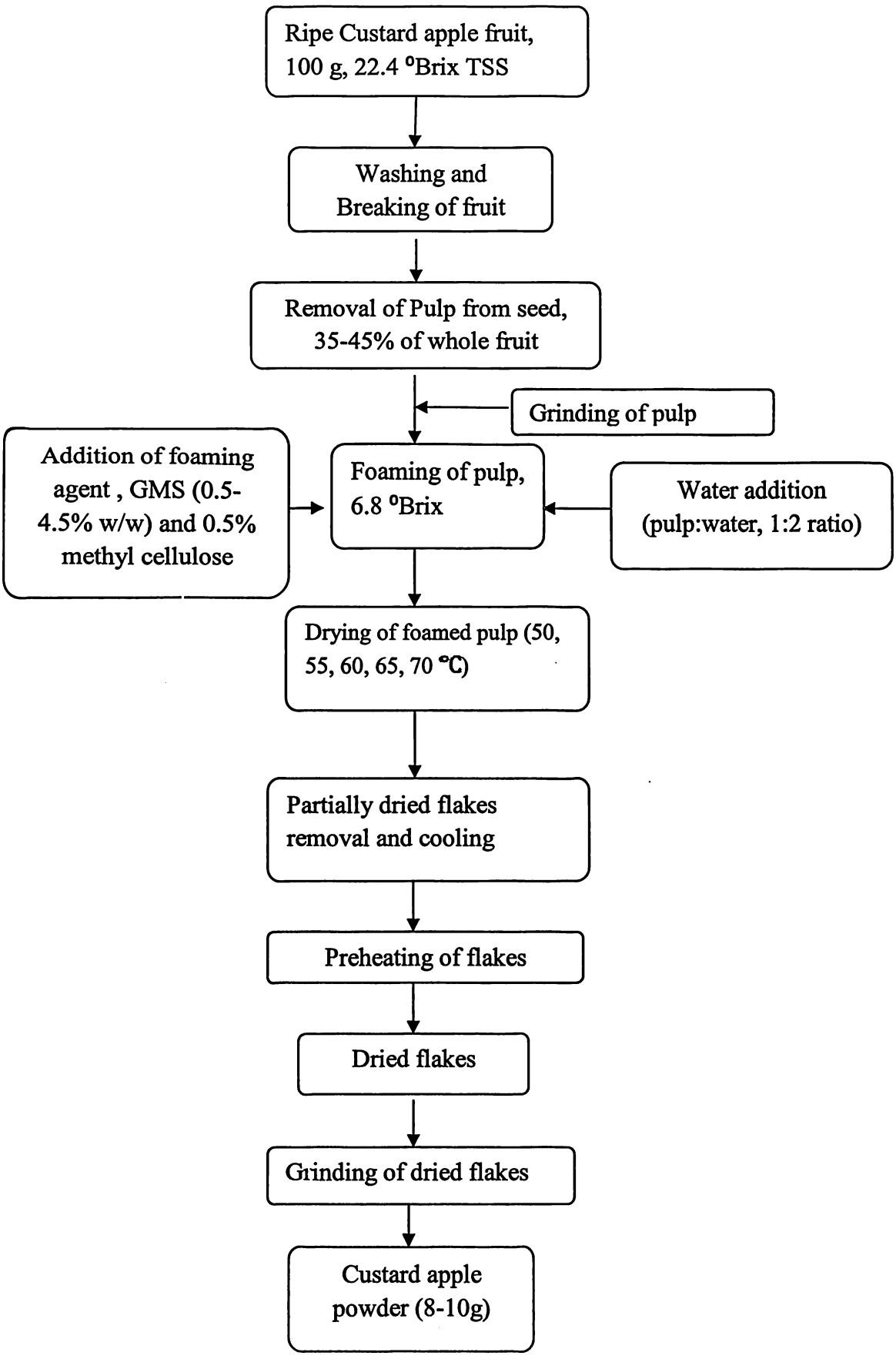
Appendices

APPENDIX-A

Appendix A1: Model specification of ORPAT hand Blender

Product	Hand blender
Model	HHB-100E
Volts	230 V/50 Hz/1Ø/250 Watt
Speed	18000 RPM
Weight	900 g, Including Acessories
Rating	6 min on-3 min off
Accessories	Wall Bracket,2 meter Electric cord, Bowl with cover (HHB-100E), Gripper and Screw

Appendix A2 : Flow diagram of foam mat drying process of custard apple pulp



APPENDIX-B

Appendix B1: Moisture content and drying rate datas of Replication-1 of Experiment no. 25

Time (min)	Sample wt (g)	Weight of water removed (g)	Weight of water (g)	Dry weight (g)	M.C (g water/g dry matter)	DR (g water/g dry matter/h)
0	199.1	0	183.172	15.928	11.5	2.66
30	177.9	21.2	161.972	15.928	10.17	2.6
60	163.3	35.8	147.372	15.928	9.25	1.83
90	149.3	49.8	133.372	15.928	8.37	1.76
120	135.8	63.3	119.872	15.928	7.53	1.70
150	122.4	76.7	106.472	15.928	6.68	1.68
180	109.2	89.9	93.272	15.928	5.86	1.66
210	97.6	101.5	81.672	15.928	5.13	1.46
240	85.9	113.2	69.972	15.928	4.40	1.47
270	75	124.1	59.072	15.928	3.71	1.37
300	63.7	135.4	47.772	15.928	2.9	1.42
390	33.2	165.9	17.272	15.928	1.08	1.23
420	27.3	171.8	11.372	15.928	0.713	0.74
450	23.1	176	7.172	15.928	0.45	0.53
480	21	178.1	5.072	15.928	0.32	0.26
510	20.3	178.8	4.372	15.928	0.27	0.09
540	20.1	179	4.172	15.928	0.26	0.03
570	20	179.1	4.072	15.928	0.26	0.01
600	20	179.1	4.072	15.928	0.26	0

Appendix B2: Moisture content and Drying rate datas of Replication-2 of Experiment no. 25

Time (min)	Sample wt (g)	Weight of water removed (g)	Weight of water (g)	Dry weight (g)	M.C (g water/g dry matter)	Drying rate (g water/g dry matter/h)
0	207.5	0	190.9	16.6	11.5	2.3
30	188	19.5	171.4	16.6	10.33	2.35
60	173.3	34.2	156.7	16.6	9.446	1.78
90	159.6	47.9	143	16.6	8.61	1.65
120	145.6	61.9	129	16.6	7.77	1.698
150	131.7	75.8	115.1	16.6	6.934	1.68
180	118.45	89.05	101.85	16.6	6.13	1.59
210	105.6	101.9	89	16.6	5.361	1.55
240	92.2	115.3	75.6	16.6	4.55	1.62
270	79.3	128.2	62.7	16.6	3.78	1.55
300	65.8	141.7	49.2	16.6	2.96	1.63
390	34.1	173.4	17.5	16.6	1.05	1.14
420	27.1	180.4	10.5	16.6	0.63	0.84
450	23.5	184	6.9	16.6	0.42	0.43
480	21.8	185.7	5.2	16.6	0.31	0.20
510	21.6	185.9	5	16.6	0.30	0.02
540	21.3	186.2	4.7	16.6	0.28	0.03
570	21.2	186.3	4.6	16.6	0.278	0.01
600	21.1	186.4	4.5	16.6	0.27	0.01

Appendix B3: Diffusivity datas of both the replications of Expt. No. 25

Time (min)	Replication-1 (D_{eff}) (m^2/s)	Replication-2 (D_{eff}) (m^2/s)
0	-	-
30	-	-
60	1.81×10^{-9}	-
90	1.32×10^{-9}	1.00×10^{-9}
120	2.54×10^{-9}	2.18×10^{-9}
150	3.90×10^{-9}	3.49×10^{-9}
180	5.42×10^{-9}	4.90×10^{-9}
210	6.96×10^{-9}	6.46×10^{-9}
240	8.77×10^{-9}	8.37×10^{-9}
270	1.08×10^{-8}	1.06×10^{-8}
300	1.3×10^{-8}	1.35×10^{-8}
330	2.65×10^{-8}	2.72×10^{-8}
360	3.31×10^{-8}	3.57×10^{-8}
390	4.26×10^{-8}	4.58×10^{-8}
420	5.51×10^{-8}	5.95×10^{-8}
450	6.84×10^{-8}	6.32×10^{-8}
480	8.05×10^{-8}	7.33×10^{-8}
510	-	8.10×10^{-8}

Appendix B4: Moisture content values with drying time of Experiment no. 21, 27 and 22

Moisture content			
Drying time (min)	**Expt. 21 (50 ^{0}C)**	**Expt. 27(60 ^{0}C)**	**Expt. 22(70 ^{0}C)**
0	11.50	11.5	11.5
30	10.44	10.24715588	10.07088785
60	9.58	9.346072386	8.781365254
90	8.62	8.493944134	7.568102229
120	7.78	7.648475368	6.441646167
150	7.12	6.709157776	5.238638463
180	6.44	5.79569675	4.033797105
210	5.78	5.014509933	2.810781668
240	5.09	4.173617726	2.00862502
270	4.24	3.242898767	1.107293143
300	3.40	2.181551016	0.596813476
330	2.01	1.069298288	0.047376368
360	1.50	0.88	0.042657607
390	1.09	0.673246477	0.037938845
420	0.77	0.432969447	0.037938845
450	0.60	0.31584298	-
480	0.53	0.287845001	-
510	0.49	0.272530605	-
540	0.46	0.26637943	-
570	0.46	0.263367382	-
600	0.45	0.263367382	-
630	0.45	-	-
660	0.45	-	-
690	0.44	-	-
720	0.23	-	-

Appendix B5: Moisture content values with drying time of Experiment no. 23, 27 and 24

Drying time (min)	Expt. 23 (2 mm)	Expt. 27 (4 mm)	Expt. 24 (6 mm)
0	11.50	11.50	11.50
30	8.41	10.25	10.36
60	5.91	9.35	9.59
90	3.78	8.49	8.76
120	2.01	7.65	7.88
150	0.91	6.71	7.07
180	0.41	5.80	6.22
210	0.34	5.01	5.48
240	0.32	4.01	4.80
270	0.31	3.20	4.09
300	0.32	2.18	3.40
330	0.16	1.23	2.82
360	0.15	0.88	2.23
390	-	0.67	1.76
420	-	0.43	1.37
450	-	0.32	1.08
480	-	0.29	0.77
510	-	0.27	0.52
540	-	0.27	0.37
570	-	0.26	0.27
600	-	0.26	0.23
630	-	-	0.21
660	-	-	0.20
690	-	-	0.20