Process Development for Dehydration of Fenugreek Leaves and Value Added Product

मेथी की पत्तियों और मूल्य वर्धित उत्पाद के निर्जलीकरण के लिए प्रक्रिया विकास

Shashikumar J N

Thesis

Doctor of Philosophy in Agricultural Engineering

(Processing and Food Engineering)

2021

Department of Processing and Food Engineering

College of Technology and Engineering

Maharana Pratap University of Agriculture & Technology, Udaipur

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Submitted to the

Maharana Pratap University of Agriculture & Technology, Udaipur

In Partial Fulfillment of the Requirement for

The Degree of

Doctor of Philosophy in Agricultural Engineering

(Processing and Food Engineering)

By

Shashikumar J N

2021

CERTIFICATE – I

CERTIFICATE OF ORIGINALITY

The research work embodied in this thesis titled **"Process Development for Dehydration of Fenugreek Leaves and Value Added Product"** submitted for the award of degree of **Doctor of Philosophy** in **Agricultural Engineering** in the subject of **Processing and Food Engineering** to Maharana Pratap University of Agriculture and Technology, Udaipur (Raj.), is original and bonafide record of research work carried out by me under the supervision of **Dr. P. S. Champawat**, Professor, Department of Processing and Food Engineering, CTAE, Udaipur. The contents of thesis, either partially or fully, have not been submitted or will not be submitted to any other Institute or University for the award of any degree or diploma.

The work embodied in the thesis represents my idea in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact source in my submission. I understand that any violation of the above will cause for disciplinary action by the University and can also evoke penal action from the sources, which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Date: **(Shashikumar J N)**

COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR -313 001

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This is to certify that this thesis entitled **"Process Development for Dehydration of Fenugreek Leaves and Value Added Product"** submitted for the degree of **Doctor of Philosophy** in the subject of **Agricultural Engineering** (Processing and Food Engineering), embodies bonafide research work carried out by **Mr. Shashikumar J N** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on date **22/06/2019**.

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(Dr. N. K. Jain)
Head
Department of Processing and
Food Engineering

(Dr. P. S. Champawat)
Major Advisor
Department of Processing and
Food Engineering

(Dr. Ajay Kumar Sharma)
DEAN
CTAE, Udaipur

COLLEGE OF TECHNOLOGY AND ENGINEERING

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY, UDAIPUR

CERTIFICATE – III

Date: 11/02/2021

This is to certify that this thesis entitled **"Process development for dehydration of fenugreek leaves and value added product"** submitted by **Mr. Shashikumar J. N** to Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirement for the degree of **Doctor of Philosophy** in the subject of **Processing and Food Engineering** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination held on 11/02/2021 was found satisfactory; we therefore, recommend that the thesis be approved.

11.2.2021

(Dr. P. S. Champwat)
Major Advisor

(Dr. M. K. Garg)
External Examiner

(Dr. V.D. Mudgal)
Advisor

(Dr. S. K. Jain)
Advisor

(Dr. Deepak Sharma)
Advisor

(Dr. Mahesh Kothari)
DRI Nominee

(Dr. N. K. Jain)
Head, PFE

(Dr. Ajay Kumar Sharma)
Dean
CTAE, Udaipur

Approved
DIRECTOR RESIDENT INSTRUCTION
MPUAT, UDAIPUR

COLLEGE OF TECHNOLOGY AND ENGINEERING

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY, UDAIPUR

CERTIFICATE – IV

Date:

This is to certify that **Mr. Shashikumar J N** student of **Doctor of Philosophy** in **Agricultural Engineering** in the subject of **Processing and Food Engineering,** Department of Processing and Food Engineering has made all the corrections/modifications in the thesis entitled **"Process Development for Dehydration of Fenugreek Leaves and Value Added Product"** which were suggested by the external examiner and the advisory committee in the oral examination held on 11/02/2021. The final corrected and bound copies of the thesis were submitted on 09/03/2021.

(Dr. N. K. Jain)
Head, PFE

(Dr. P. S. Champawat)
Major Advisor

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…any omission in this small manuscript does not mean lack of gratitude.

Place: Udaipur

Date: (**Shashikumar J N**)

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LIST OF SYMBOLS AND ABBREVIATIONS

Adj	Adjusted
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
BIS	Bureau of Indian Standards
CD	Coefficient of Determination
cfu	Colony forming unit
cm	Centimeter
cm^3	Cubic centimeter
CTAE	College of Technology and Engineering
cv.	Cultivated variety
CV	Coefficient of Variance
db	Dry basis
df	Degree of freedom
et al.	et alibi, and others
etc.	et cetra
Equ	Equation
Fig.	Figure
g	Gram
g/s	Gram per second
h	Hour
hg	Mercury
H_2SO_4	Sulphuric acid
i.e.	*ed est*, that is
INR	Indian national rupee
kg	Kilogram
kg/cm^3	Kilogram per cubic centimeter
kg/h	Kilogram per hour
kJ/mol	Kilo joule per mole
LDPE	Low density polyethylene
MC	Moisture content
M_e	Equilibrium moisture content
M_o	Initial moisture content

m/s	Meter per second
m^2/s	Meter square per second
m^3	Cubic meter
mg	Milligram
min	Minute
ml	Millilitre
mm	Millimeter
mm/s	Millimeter per second
MPP	Metalized polypropylene
MPUAT	Maharana Pratp University of Agriculture and Technology
MR	Moisture ratio
No.	Number
NS	Non-significant
PP	Polypropylene
R^2	Coefficient of determination
RMSE	Root mean square error
Pred.	Predicted
PRESS	Predicted residual error sum of squares
rpm	Revolutions per minute
SEM	Standard error mean
S.D.	Standard deviation
SAS	Statistical Analysis Systems. (pronounced "sass")
S. No.	Serial Number
TA	Texture analyzer
var.	Variety
W	Watt
wb	Wet basis
WHO	World Health Organization
viz.	Videlicet, namely
vs	Versus
UV	Ultra- violet
VIS	Visible

β	Beta
μ	Coefficient of friction
μg	Microgram
ρ	Density
^{o}	Degree
^{o}C	Degree Celsius
μm	Micro meter
%	Per cent

CHAPTER I

INTRODUCTION

Vegetable cultivation is an important part of agricultural economy of nation, particularly in the developing countries. India is the second largest producer of vegetables in the world next to China and accounts for about 15 per cent of the world production of vegetables. In India, the area under vegetable production is 92.05 lakh ha with 162187 MT production and 17.62 MT/ha productivity in year 2014-15. In world, the area under vegetable production is 572.65 lakh ha with 646758 MT production and 11.3 MT/ha productivity in year 2014-15 (Anonymous, 2014).

Vegetables hold significant position in balanced diet. Green leafy vegetables are being used since ancient period as source of food as they contain many nutrients and minerals which are helpful in maintaining human health. Leafy vegetables play important role in alleviating food security and they are very important in the diet of many people. They contribute protein, mineral, vitamins, fiber and other nutrients which are usually in short supply in daily diets (Solanke and Awonorin, 2002). These vegetables also provide little dietary energy, making them valuable in energy limited diets. Some of the green leafy vegetables are mint, drumstick, fenugreek, curry, spinach, amaranth, mustard and coriander leaves.

Quercetin, a bioflavonoid found in green leafy vegetables has antioxidant and anti-inflammatory activity, thus displays unique anticancer properties. The high level of vitamin K in greens plays an important role for the production of osteocalcin, a protein essential for bone health. Lutein, lycopene zeaxanthin, and carotenoids found in dark green leafy vegetables are concentrated in the eye lens and macular region of retina and play a protective role in the eye by preventing both cataract and age related macular degeneration (Craig, 2010).

The shelf life of vegetables is further limited due to loss of chlorophyll, which is accelerated by water loss during harvest season. A huge loss is observed mainly due to lack of adequate storage facilities (Ben, 1987).

Fenugreek (*Trigonella foenum-graecum*) constitutes a self-pollinated annual herbaceous legume, belongs to Fabaceae family and popularly known as Greek hay,

bird's foot (Petropoulos, 2002) and methi. It is one of the well documented and most ancient recorded medicinal herbs used as major culinary ingredient since ancient in India. Fenugreek is supposed to be originated from southeastern Europe and western Asia. Presently, it is extensively cultivated in many parts of the world, including India, northern Africa and United States. Fenugreek leaves and seeds have been used extensively to prepare powders and extracts for medicinal uses (Basch *et al.,* 2003).

Fresh or dried forms of fenugreek leaves are very popular kitchen herb due to its associated properties of pleasant flavor, powerful antioxidant properties, health promoting effects and antimicrobial activities. Application of fenugreek has been found to be lethal against hazardous bacteria, specifically coli forms, *Pseudomonas* spp., *Shigella dysentiriae* and *Salmonella typhi*. These properties probably make fenugreek a valuable ingredient in food and pharmaceutical applications (Meghwal and Goswami, 2012).

Vitamins, flavonoids, terpenoids, carotenoids, cumarins, curcumins, lignin, saponin and sterol are the active phytochemicals responsible for the antioxidant properties. High protein and fibre content with the presence of many bioactive compounds make fenugreek a naturally available unique and health promoting major herb (Meghwal and Goswami, 2012).

It is a rich source of β-carotene, a precursor of vitamin A. It is also a good source of vitamin C, riboflavin, folic acid and minerals like calcium, iron and phosphorus and fair source of protein containing about 2-7 per cent (Narasingh *et al.*, 1989).

In India, Fenugreek is grown in an area of 134 ('000 hectares) producing about 180.8 ('000 MT), where as in Rajasthan grown in an area of 81.70 ('000 hectares) with a production of 84.20 ('000 MT) in 2014-15 (Anonymous, 2017). It is exported to Saudi Arabia, Japan, Korea, Srilanka and United Kingdom. The major states growing in India are Rajasthan, Madhya Pradesh, Gujarat, Uttar Pradesh, Maharashtra, Karnataka and Punjab.

Drying is the oldest method of preserving food. The main aim of drying agricultural products is to reduce water content to certain level at which the microbial spoilage and the deterioration by chemical reaction are greatly minimized (Krokida and Kouris, 2003).

Among the techniques used to maintain post-harvest quality of herbs, drying is used as conservation method to prevent deterioration and loss in commercial value. The technique causes the transformation of the product, adding value to it and originating a new option in the market. Drying has the advantage of facilitating the conservation of foods, prolonging shelf-life and reducing the volume of the product, which facilitates and reduces costs of transportation, promoting physico-chemical stability and adding economic value to the final product (Akpinar 2006). Drying of vegetable can be done by two methods - one is natural drying that is sun or solar drying and another one is mechanical drying. Mechanical drying method includes tray drying, oven drying, fluidized bed drying, freeze drying and micro-wave drying.

Preservation and product diversification of vegetables can prevent huge wastage as well as make them available for consumption in the lean season. Owing to high moisture content, green leafy vegetables are highly perishable and are sold at throw away prices in the peak season resulting in heavy losses to the growers due to non-availability of sufficient storage, transport and proper processing facilities at the production point. Drying is the oldest method of preserving food. The main aim in drying agricultural products is to reduce water content to certain level, at which, microbial spoilage and deterioration by chemical reaction are greatly minimized (Krokida and Kouris, 2003).

Dehydrated leafy vegetables have the potential to become an important product because of relatively inexpensive, quickly cookable and rich in several nutrients which are essential for human health. Besides, dehydrated leafy vegetables have the great potential to use throughout the year.

Dehydration facilitates the utilization of the dried product in areas where it is unavailable. In addition to increasing variety in the menu, reducing wastage, labour and storage space, dehydrated vegetables are simple to use and have longer shelf life than fresh vegetables (Chauhan and Sharma, 1993). There is a great demand in overseas countries for the fenugreek dried material, among the large number of Non-resident Indian citizens. Drying of leafy vegetables and making them use for future opens up new vistas in the field of food technology, since they are rich in antioxidants and could be added as the natural antioxidants to develop new commercial products.

Baked goods are ready to eat, contains nutritional quality and are easy to use. Several researchers have revealed that the rural market implies greater growth in bakery products, particularly bread and biscuits, as in the urban area, which has finally increased the growth of this sector. The bakery sector has great market potential and a wide range of untapped markets that can be explored through various promotional activities and also by providing quality bakery products. India has a larger bakery industry in the food industries with annual sales of around Rs. 32,000 million and got 3rd place in the food sector after the United States, India is the second largest producer of biscuits. The unorganized sector of the bakery industry has about 67 per cent and 80 per cent of the total biscuit production estimated at 1.3 million tons and the estimated production of bread at 1.5 million tons respectively. About ninety percent of the other baked goods approached 0.6 million tons, including biscuits, buns, cakes and other products (Nemat, 2012).

Because consumers today are more concerned about their health, they focus on consuming products that strengthen their immune system. Foods rich in protein and fiber are now preferred primarily by consumers to maintain their health and keep them away from many types of diseases such as cardiovascular disease, diabetes, weight gain, etc. Therefore, there is a new trend in the market to develop a product that combines health benefits with good sensory properties. Many health benefits, such as lowering cholesterol, reducing the level of the glycemic index, colon cancer, intestinal disorders and improving metabolism through the use of foods rich in dietary fiber. There is a current fashion in the bakery sector that includes the use of cereals or more cereals, oilseeds and legumes, and as it provides numerous health benefits and a better taste, taste, consistency and appearance. Previously, many authors have declared the use of protein and fiber-rich materials to improve the nutritional composition of biscuits. The mixed combination of cereals, legumes and oil seeds will have the same effect as high quality protein and dietary fiber in the required product (Kumar *et al*., 2015).

Hence, a research studies is taking up to study the drying, storage and packaging of fenugreek leafy vegetable. The present research work was carried out with following specific objectives.

1. To study the physico-chemical properties of fenugreek leaves
2. To study the drying characteristics of fenugreek leaves
3. To develop fenugreek supplemented biscuits
4. To study the quality of dried fenugreek leaves and fenugreek supplemented biscuits
5. To study the storage life of dried fenugreek leaves

CHAPTER II

REVIEW OF LITERATURE

A comprehensive review is mandatory in any research endeavour. This requires thorough efforts on the part of investigator to select relevant subject matter, to organize and to report it systematically. This chapter deals with brief account of literature, which has direct and indirect bearing on the specific objectives of the investigation.

In the present investigation, an attempt has been made to summarize the detailed "Process development for dehydration of fenugreek leaves and value added product". The literature pertaining to present investigation is reviewed under the following sub headings:

2.1 Fenugreek and its importance
2.2 Physico-chemical properties of leafy vegetables
2.3 Drying of leafy vegetables
2.4 Development of leafy vegetable supplemented food products
2.5 Packaging and storage of leafy vegetables

2.1 Fenugreek and its Importance

Khosla *et al.* (1995) reported that fenugreek (*Trigenoella foenum-gracum* L.) belongs to the Leguminosae family, it is an annual aromatic herbaceous plant, widely cultivated in Mediterranean countries and in Asia.

Petropoulos (2002) stated that fenugreek contains a myriad of phytochemicals such as steroids, flavonoids and alkaloids, which have been identified, isolated and extracted from the pharmaceutical industry to serve as a raw material for the production of hormonal and therapeutic medicines. The polysaccharides form the mucilage (galactomannan) present in the plant and are finding wider applications in the food, pharmaceutical, cosmetic, painting and paper industries, following the most common carobs and guar gums, all with neutral and high viscosity properties. However, fenugreek is most commonly used in everyday life as a spice and seasoning in soups and curry. It is also reported that the oil extracted from fenugreek seeds is strongly scented, which is used as an insect repellent for cereals and fabrics. In cosmetics traces of oil are used in perfumes.

Basch *et al.* (2003) reported that fenugreek leaves were widely used to prepare extracts and powders for medicinal uses. Fenugreek has been reported to have antidiabetic, antifertility, anticancer, antimicrobial, pesticide and hypocholesterolemic effects.

Srichamroen *et al.* (2005) reviewed that fenugreek contains three important chemical constituents with medicinal value; i.e., steroidal sapogenins, galactomannans and isoleucine. These constituents have placed fenugreek among the most commonly recognized "Nutraceutical" or health food products.

Laila *et al.* (2013) investigated that fenugreek is consumed in various parts of the world in different forms and has been regarded as a treatment for many ailments known to man. Recent advances in nutraceutical and phyto-chemical research stimulated a renewed interest in fenugreek to be used as a functional food.

Patil and Jain (2014) isolated common phenolic compounds from fenugreek such as scopoletin, coumarin, chlorogenic, caffeic p-coumaric acids and quercetin. Among these flavonoids present in fenugreek, quercetin being a strong antioxidant has been reported to possess antiinflammatory, antitumor, immunomodulatory, antiulcer, anticancer, antidiabetic, antiangiogenic activities and many other properties including the improvement of mental and physical performance.

Buba *et al.* (2015) revealed that fenugreek (*Trigonella foenum-graecum*) is one of the most promising medicinal herbs known from long times having nutritional value. A wide range of uses were found for fenugreek in ancient times. The leaves and seeds of the plant are widely consumed as spice in food preparations and as ingredient in traditional medicine. The aqueous extract of fenugreek (*Trigonella foenum-graecum*) contains bioactive constituents that may be beneficial as a spice in food and management of diseases. This supports the traditional use of the plant as food supplement and in the management of diseases.

Rehab *et al.* (2015) reported that fenugreek (*Trigonella foenum-graecum*) is an annual herb which has widely been consumed throughout the world as a food, a food additive and in the traditional remedies science civilizations. Fenugreek, being rich in phytochemicals, has traditionally been used as a food, forage and medicinal plant.

2.1.1 Anticarcinogenic activities and complementary cancer therapy

Raju and Bird (2006) reported that fenugreek powder in the diet due to the presence of fiber, flavonoids and saponins decreased the activity of β glucuronidase significantly and prevented the free carcinogens from acting on colonocytes whereas mucinase helped in hydrolysing the protective mucin. Diosgenin in fenugreek prevented cell growth and induced apoptosis in the H-29 human colon cancer cell line and fenugreek seed was found to have hepatoprotective properties.

Kaviarasan and Anuradha (2007) concluded that polyphenolic extract of fenugreek seed acts as a protective agent against ethanol induced abnormalities in the liver having similar affects as that of silymarin, that of silymarin, a known hepatoprotective agent.

2.1.2 Hypocholesterolemic activities

Zia *et al.* (2001) investigated an abnormal deficiency of cholesterol level in the blood is known as hypocholesterolemic problem and oral administration of methanolic and aqueous extracts of fenugreek seeds at a dose of one gram per kilogram body weight resulted in hypoglycaemic effect in mice.

Basch *et al.* (2003) reported that fenugreek seeds have lowered serum cholesterol, triglyceride and low-density lipoprotein in hypercholesterolemia suffering patients and experimental models. Fenugreek consumption in diet reduced triglyceride accumulation in the liver but do not interfered with the plasma insulin or glucose levels obesity suffering rat.

2.1.3 Hypoglycemic activities

Sameh *et al.* (2003) demonstrated the usefulness of fenugreek as a dietary supplement of therapeutic and nutritive value in the management of Type II diabetes and evaluated the effect of fenugreek seed diet supplementation on blood glucose and lipid profile in Type II diabetic patients. He showed that fenugreek seeds significantly reduced postprandial blood glucose level in all groups that received the fenugreek seed supplement. The hypoglycemic effect is believed to result from single or combined mechanisms, such as soluble dietary fiber content, insulinotropic action of amino acids or increased peripheral

utilization of glucose. The lipid lowering effect may result from the steroid saponin content that inhibits cholesterol absorption from the intestine.

Singh and Garg (2006) studied the fenugreek has hypoglycemic and hypocholesterolemic effect as supported by findings during the experiment on animals. It improves peripheral glucose utilization contributing to improvement in glucose tolerance and exerts its hypoglycemic effect by acting at the insulin receptor level as well as at the gastrointestinal level.

Sampath *et al.* (2011) reported that the hypoglycemic property of fenugreek seeds, a commonly used condiment in Indian homes, due to its high dietary fiber content. Fenugreek has a lowering effect on glycemic index when added to rice and wheat diets, due to delayed gastric emptying and increased intestinal transit time. In addition, fenugreek decreases glucose absorption and inhibits starch digestion due to presence of soluble fiber and galactomannans. Adding fenugreek to the diet of diabetes patients 15 min before the meal causes a significant reduction in glycemic index.

2.1.4 Antioxidant and antimicrobial activity

Grover *et al.* (2002) reported that fenugreek shows hypoglycemic and antihyperglycemic activity in diabetic mice and it has attributed to the health benefits due to the presence of antioxidant carotenoids in those spices.

Dixit *et al.* (2005) studied the fenugreek seed contains phenolic and flavonoid compounds which help to enhance its antioxidant capacity.

Sulieman *et al.* (2008) demonstrated the importance of fenugreek seed and its oil as an antimicrobial agent to be used as a food preservative or in medical industries. The inhibitory effect of fenugreek oil was tested against micro-organisms and found the highest antimicrobial activity against all tested organisms was found against *Aspergillus niger* where a complete inhibition (100 per cent) was recorded.

Norziah *et al.* (2015) investigated the efficacy of fenugreek seeds as a potential natural source of antioxidants and antimicrobials. The various fenugreek seed extracts from different solvents obtained in this study exhibited antioxidant and antimicrobial activity.

However, water extract of germinated fenugreek seed shows the highest antioxidant and antimicrobial activities compared to the other extracts. It is concluded that strong antioxidant potential with significant antimicrobial activity in germinated fenugreek seeds which may be due partly to the presence of flavonoids and polyphenols. Water extract of germinated fenugreek seeds shows great potential to be used as a natural antioxidant and antimicrobial source and to be further explored for use in the food industry.

Rehab *et al.* (2015) evaluated antimicrobial activities of fenugreek seeds against gram-negative and gram-positive bacteria and other microorganisms using two different methods: agar disc diffusion and agar-well diffusion method. The obtained results indicated that only the boiling water extract contains the antimicrobial active ingredients of fenugreek seeds, while both cold water extract and methanol extract were not suitable for such purposes.

2.1.5 Diabetes management

Kochhar and Nagi (2005) concluded that to lower blood glucose level in diabetics, 2 g of a powdered assortment of bitter gourd, jamun seed and fenugreek seed, either raw or cooked, can be used successfully.

Srinivasan (2006) reported that aqueous extract and a gel fraction, isolated from fenugreek seeds has significant ulcer protective effects. It has soothing effect on gastric and gastritis ulcer. He also proposed that the unsaponifiable portion of the oil (3.9 per cent) extracted from fenugreek seeds contains a lactation-stimulation factor. Cooked and defatted fenugreek seeds (containing soluble fiber) prevented a rise in blood glucose levels in these patients. This was attributed to hypoglycaemic properties of fenugreek gum present in the seeds which were not lost during the cooking process.

Jiang *et al.* (2007) demonstrated that fenugreek seed contains 26.80 per cent fenugreek galactomannan or gum. The effect of the gum on the blood glucose level of the normal and diabetic rats has been determined after treatment with supplemented diets. Fenugreek seed gum produces a significant drop in blood glucose both in normal and diabetic rats when they are fed with 0.9 and 4.5 g/kg dose.

Das *et al.* (2011) recommended that the inclusion of fenugreek recipes in daily diet to provide at least 25 g fenugreek seeds that helps in diabetes management. Water extract of fenugreek seeds has higher hypoglycemic and anti-hyperglycemic potential and for this reason it may be used as a supplementary medicine to treat the diabetic population by significantly reducing the dose of standard drugs. Since fenugreek seeds are a source of protein, they can replace pulses in the diets of diabetics.

Omi and Imtiyaz (2015) reviewed that one of the most promising vegetable providing treasures of secondary metabolites is fenugreek. The herb have an enormous potential to prevent or cure diabetes more than other plant species especially due to the presence of unique chemical constituents including quercetin, diosgenin, trignolline, galactomannan and unusual amino acid 4-hydroxy isolucine.

Gupta and Verma (2015) demonstrated that fenugreek supplement with usual medical care for Type II Diabetes Mellitus is more effective than the usual medical care alone. Therefore, it is recommended that fenugreek supplementation is safe and may be considered in diabetic patients as a potential means to lower the serum lipid profile level.

2.2 Physico-Chemical Properties of Leafy Vegetables

Gupta *et al.* (1989) showed the presence of macro and micro elements fenugreek leaves, where calcium varied from 0.9- 2.9 per cent, phosphorus from 0.6-1.1 per cent whereas copper, iron, zinc and manganese ranged from 37.5-62.5 ppm, respectively.

Padmavathi and Rao (1990) studied the nutritional profile of *Sauropus androgynus* and reported that 100 g of fresh leaves had crude fiber 1.8 per cent ether extractive 1.1 per cent and protein 7.4 per cent. *Sauropus androgyus* is a perennial shrub found growing wild in South East Asia. The dark green leaves also called as ‘multivitamin’ leaves are commonly used for human consumption.

Heaney *et al.* (1993) reported the fractional calcium absorption from broccoli, bok choy stems, bok choy leaves and kale to be 0.478, 0.519, 0.520 and 0.527 respectively. They have reported the mean calcium absorbability to be 0.463, thus showing that Brassica vegetable sources exhibit excellent calcium bioavailability.

Yadav and Sehgal (1997) examined the ascorbic acid and β-carotene content of bathua and cholai. They reported that the β-carotene content of bathua (*Chenopodium album*) and cholai (*Amaranthus tricolour*) varied from 0.68 to 9.62 and 1.14 to 14.52 mg/100g, respectively on dry weight basis. According to Rajyalakshmi *et al.* (2001) per cent losses of total carotenoids and β-carotene content due to boiling in thirty two edible forest green leafy vegetables usually consumed by the tribals of Andra Pradesh ranged from 5.67 to 84.14 and 2.66 to 92.344 mg/100g, respectively.

Yadav and Sehgal (1997) showed the oxalic acid, phytic acid and polyphenol content of amaranth, bathua, fenugreek and spinach leaves ranged from 0.91 to 14.92 g and 129.67 to 234.50 mg/100g, 11.96 to 22.88 mg tannic acid equivalent/g, respectively on dry matter basis.

Nambiar and Sheshadri (1998) investigated the moisture content of sixteen green leafy vegetables consumed in western region of India ranged from 78.4-92.1 per cent. Moisture content of bengal gram and spinach leaves were found to be 75.09 per cent and 94.17 per cent respectively on fresh matter basis and crude protein content was found to be 26.18 per cent and 26.53 per cent respectively.

Khanum *et al.* (2000) studied the dietary fiber content of cabbage, cauliflower and fenugreek leaves to be 3.0, 4.2 and 4.9 g/100g edible portions, respectively.

Singh *et al*. (2001) selected six green leafy vegetables and herbs – spinach, amaranth, bengal gram, cauliflower, mint, coriander and carrots – were analyzed for moisture, protein, ascorbic acid, β-carotene, total iron, ionizable iron (as per cent of total iron) in vitro iron (per cent of total iron), copper, manganese and zinc. Moisture content of the leaves and carrots varied from 75.1 percent (bengal gram) to 95.4 per cent (carrot) and protein from 9.83 per cent (carrots) to 30.9 (mint) per cent. Ascorbic acid, β-carotene, total iron and ionizable iron contents were at a maximum in case of bengal gram leaves whereas level of ionizable iron and in vitro iron as a per cent of total iron was highest in carrots. Copper, manganese and zinc contents were maximum in spinach.

Chandrasekhar and Kowsalya (2002) analyzed ten green leafy vegetables, five other vegetables, five fruits in raw form and cooked greens for their total carotene contents

by spectrophotometry and β-carotene or pro-vitamin A content by HPLC. Dark green leafy vegetables were found to be richest source of pro-vitamin A. Drumstick showed a maximum β-carotene content. Further 81.0 per cent of total carotenes in fenugreek were β-carotene.

Akindahunsi and Salawu (2005) studied the phytochemical screening and nutrient-antinutrient composition of 14 commonly consumed tropical green leafy vegetables in Southwestern Nigeria. They found that the crude protein, fat, fibre and ash ranged from 20.59 to 38.18, 5.90 to 12.73, 6.20 to 7.20 and 8.00 to 25.49 per cent, respectively.

Akubugwo *et al*. (2007) investigated the nutritional and chemical value of Amaranthus hybridus were observed using standard analytical methods in order to assess the numerous potential of the plant leaves. The Proximate analysis showed the percentage moisture content, ash content, crude protein, crude lipid, crude fibre and carbohydrate of the leaves as 84.48, 13.80, 17.92, 4.62, 8.61 and 52.18 per cent, respectively while its calorific value is 268.92 Kcal/100 g. Elemental analysis in mg/100 g (DW) indicated that the leaves contained sodium (7.43), potassium (54.20), calcium (44.15), Magnesium (231.22), Iron (13.58), Zinc (3.80) and phosphorus (34.91). The vitamin composition of the leaves in mg/100 g (DW) was β-carotene (3.29), thiamine (2.75), riboflavin (4.24), niacin (1.54), pyridoxine (2.33), ascorbic acids (25.40) and α-tocopherol (0.50). The chemical composition in mg/100 g (DW) for alkaloid, flavonoid, saponin, tannins, phenols, hydrocyanic acid and phytic acid were 3.54, 0.83, 1.68, 0.49, 0.35, 16.99 and 1.32, respectively.

Mahesh *et al*. (2008) determined the phytochemical, nutritional and medical properties of some leafy vegetables. Twelve commonest ones out of the twenty nine green leafy vegetables come across with frequency ≥ 1.5 per cent were selected for further evaluation. The vegetables were a major source of ascorbic acid and the mean values ranged from 100 to 421.6 mg/100 g with the Amaranthus (408 mg/100 g) and Celosia (421 mg/100 g) species containing higher quantities. Amaranthus and Talinum recorded high mineral contents. The crude protein ranged from 3.8 to 27.7 g/100 g and carbohydrate contents ranged from 2.9 to 47.9 g/100 g. The analysis further showed presence of

alkaloids, inulins, saponins and tannins which are known components of herbs used in traditional medicine.

Sheetal and Jamuna (2009) identified the potential of green leafy vegetables (GLV) as antioxidants, methanolic extracts of *Amaranthus sp*., *Centella asiatica*, *Murraya koenigii* and *Trigonella foenum graecum* were studied for their antioxidant activity in different systems at multiple concentrations. The GLV were analyzed for ascorbic acid, total and β-carotene and total polyphenol contents. The ascorbic acid, total carotene, β-carotene and total phenolic content (tannic acid equivalents) of the GLV ranged between 15.18–101.36, 34.78–64.51, 4.23–8.84 and 150.0–387.50 mg/100g GLV, respectively. The extracts were found to have significantly different levels of antioxidant activities in the systems tested. The total antioxidant activity was highest in *Murraya koenigii* (2,691.78 μmol of ascorbic acid/g sample) and least in *Centella asiatica* (623.78 μmol of ascorbic acid/g sample).

Vani and Rajinder (2014) investigated that dried samples of methi leaves. The methi leaves and kasuri methi showed to be good sources of protein. While both the samples are excellent sources of calcium, magnesium, potassium, phosphorus and moderate sources of zinc, kasuri methi has a slightly richer amount of iron as compared to methi leaves. The samples revealed good amounts of alkaloids followed by moderate amounts of saponins. Total phenolics and flavonoids contents were obtained for methanolic and aqueous solvent extracts for each of the samples.

Saha *et al.* (2015) analyzed the nutritional, antinutritional and mineral compositions of eight green leafy vegetables. Moisture and ash content of the green leafy vegetables were in the range of 71.74-98.20 g/100g and 8.23-26.01 g/100g respectively. Fiber was higher in *Basella rubra* (8.61 g/100g) and lower in *Moringa oleifera* and *Amaranthus viridis* (0.25 g/100g). Protein content largely varied from 2.29-18.56 g/100g, whereas carbohydrate ranged from 5.45-11.16g/100g respectively. Ascorbic acid was higher in *Diplazium esculentum* (23.59 mg/100g) and lower in Brassica nigra (8.50 mg/100g), β-carotenoid ranged between 4.65-18.90 mg/100g in all the green leafy vegetables.

2.3 Drying of Leafy Vegetables

Singh *et al*. (1997) studied the dehydration characteristics of four commonly consumed green leafy vegetables. The vegetables were cut into shreds and blanched in hot water at 90 °C for two minutes and immersed in 0.2 per cent potassium metabisulphate solution. The blanched leaves when dried at 60 ± 2 °C with 55-60 per cent relative humidity, required four hours for complete dehydration in cabinet drier and two days for drying under sun (25 °C), to reach desired moisture level (9-10 per cent). Drying rate was fast in spinach and lower in fenugreek leaves.

Lakshmi and Vimala (2000) determined the drying characteristics of green leafy vegetables. Amaranth, curry leaves, gogu and mint leaves were dried under sun and cabinet drier at 30-45 °C and 60-70 °C respectively. Sun drying required 5 to 10 folds longer time compared to cabinet drying to bring down the moisture to 9-11 per cent. Amaranth, curry leaves, gogu and mint respectively required 2.5, 1.0, 3.0, and 2.5 h for drying in cabinet drier. Low dehydration ratio resulted in high yield of cabinet dried product.

Nagi and Roy (2000) analyzed the leaves of savoy beet (*Beta vulgaris var bengalensis*), amaranth (*Amaranthus tricolor*) and fenugreek (*Trigonella foenum graecum*) which were subjected to different blanching and drying treatments to establish the retention of β-carotene, ascorbic acid and chlorophyll. The vegetables were blanched at 95 ± 3 °C in water, water followed by potassium metabisulphite (KMS) dip, salt solution, salt solution followed by KMS dip, and mixture of sodium bicarbonate, magnesium oxide and KMS and dried in sun, shade, solar drier, cabinet drier, and low temperature drier. Water followed by potassium metabisulphite was found most suitable for blanching and selected for subsequent drying and method low temperature had least drastic effect on β-carotene, ascorbic acid and chlorophyll content of the processed product.

Coriander and fenugreek leaves were dried in solar drier by Pande and coworkers (2000). A forced circulation solar hot-air-dryer was used, where the leaves were loaded at the rate of 3.3 kg/m^2 tray area and 3.7 kg/m^2 respectively in perforated trays. The results indicated that, coriander could be dried within 3.5, 3.0, 2.5 h at 40, 45 and 50 °C

respectively, while fenugreek required 4.5, 3.5, 3.0 and 2.5 h at 40, 45, 50 and 60 °C, respectively. The drying rate was higher in the first 30 minutes where temperature had a significant influence on moisture reduction.

Singh *et al*. (2006) investigated the effect of drying conditions on the drying rate of five leafy vegetables. The leaves were dried under cabinet drier (58-60 °C), low temperature drier (40 ± 2 °C and 25-40 per cent RH) and solar drier (40-50 °C, 60-80 per cent RH) to a moisture content of four to five per cent. The drying rate was faster in cabinet drier followed by low-temperature drier and solar drier. Drumstick leaves took seven hours for drying in cabinet drier whereas amaranth, curry leaves, and fenugreek required six hours in the same drying condition.

Agasimani *et al*. (2008) studied the value addition to the coriander through drying and dehydration. The cleaned coriander leaves were dried under three different drying methods *viz.*, shade drying (28 °C, 32.5 per cent RH), sun drying (7 h) and conventional drying (40, 100 and 140 °C). The results indicated that, coriander leaves dried by conventional method of drying showed a uniform physiological loss in weight and color at lower levels of air temperature. In case of sun drying physiological loss in weight was more rapid at initial period of drying followed by gradual decrease in moisture content in the later part of drying. The weight of leaves dried at 40 °C reduced from 25 g to 6 g at the end of drying period. Similarly, the weight was reduced to 4.2 g at the conventional drying temperature of 140 °C.

Manchekar *et al*. (2008) studied the drying of curry leaves under shade (24-28°C), sun (29.7 °C) and conventional method 40, 100, 140 and 180 °C. Time taken for drying and physiological loss in weight (PLW) was recorded. The results depicted that, conventional drying method was faster (8 h) compared to sun drying (20 h) and ambient drying (34 h). Higher the temperature in conventional drying lower was the time taken for drying to a constant weight.

Suchismita *et al.* (2012) investigated the effect of drying methods on quality characteristics of medicinal indian borage (*Coleus aromaticus*) leaves. The drying methods considered were hot air drying (50-80 °C), fluidized bed drying (50-80 °C), and microwave drying (180-900 W). Effect of power level and temperature on quality characteristics of

dried products has been analyzed to determine the optimum drying conditions. Considering the total drying time, therapeutic and sensory attributes of the dried leaves, it is proposed to dry the leaves at 60 °C and 540 W in hot air dryer and microwave dryer respectively to obtain an acceptable product.

Upadhyaya *et al.* (2012) worked to develop a model for drying characteristic curve for spinach in universal hot air oven. The experiments were conducted using a constant air velocity 2.2 m/s and three drying air temperature of 55, 65, and 75ºC with two pre-treatment conditions (blanched and unblanched). They showed that the drying rate increased with increase in temperature and decreased with increase in time.

Satwase et *al.* (2013) studied the drying characteristic of drumstick leaves by using sun, shadow, cabinet and oven drying methods. The drying was done at 60 °C to minimize the drying losses. The results obtained from cabinet dried sample were better than other and it had highest nutrient retention followed by shadow, sun drying and oven dried sample. The rehydration ratio calculated at 55, 65 and 75 °C temperature for 60, 45 and 30 minutes respectively. The rehydration ratio of cabinet dried sample was more than other samples. The study revealed that the cabinet tray drying method was observed suitable for dehydration of drumstick leaves.

Shahi *et al*. (2014) studied the drying of basil leaves to determine the effect of drying methods and drying air temperature on activation energy. The results showed that the increase in drying air temperature decreased the drying time in both the drying methods. Logarithmic thin layer drying equation represented the thin layer drying behavior of basil leaves. Effective moisture diffusivity of basil leaves was higher in solar dryer as compared to that of vacuum dryer irrespective of drying air temperature. Activation energy was 38.54 and 20.32 kJ/mol for drying of basil leaves sample in solar and vacuum dryer respectively.

Sweta *et al.* (2017) studied the effect of drying condition and rehydration characteristics. It was found that total drying time considerably reduced with the increase in drying air temperature. Major drying took place in the falling rate period. The average drying rate increased with increase in temperature and decrease with time and loading density. Chemically treated samples dried under cabinet tray dryer (CT, CB and UT) took lesser time than blanched and untreated samples. It was observed that total moisture loss

increased with increase in drying temperature and decreased with a decrease in drying temperature. The study revealed that the chemically treated samples had higher rehydration ratio values than that of chemically blanched and untreated samples.

Tasirin *et al*. (2014) investigated the drying of kaffir lime leaves in a fluidized bed dryer with inert particles: kinetics and quality determination under different superficial air velocities (0.6, 0.7 and 0.8 m/s) and mass ratios of kaffir lime leaves to sand (without inert, 0.04, 0.02 and 0.01) at a constant temperature of 50 °C. Effects of air velocity and mass ratio of kaffir lime leaves to sand were studied. The results showed that the rate of drying increased with increasing superficial air velocity. It was found that the presence of inert particles enhanced the drying rate. However, the rates of drying decreased when higher ratios of kaffir lime leaves to sand were used.

2.3.1 Effect of drying on nutritional content of leafy vegetables

Shivhare *et al.* (1997) investigated the effect of drying of arvi in a cabinet dryer at 57 °C. The treatment prior to drying included blanching of arvi in boiling water for two minutes followed by cooling and dipping the sample in 0.5 per cent KMS solution at room temperature for two minutes. The results indicated the overall acceptability was higher for samples blanched in hot water followed by dipping in KMS solution and subsequent drying at 57 °C in cabinet dryer.

Singh *et al.* (1997) conducted a comparative study to develop dehydrated green leafy vegetables by mechanical and sun drying. The chlorophyll retention and rehydration studies were also conducted on the final products. According to the panel of judges, the overall acceptability of mechanically dried product was superior to sun dried products.

Ramanna *et al.* (1998) investigated the effect of different dehydration methods on colour of dehydrated fenugreek and mustard leaves. Sun dried samples showed considerable change in the hue and chlorophyll content when compared to solar cabinet dried and tray dried samples. Reconstituted products showed significant difference ($P \leq 0.01$) when subjected to sensory evaluation for colour attributes.

Laxmi and Vimla (2000) nutritionally evaluated green leafy vegetable powders prepared by using dehydration technology. Drying was done by sun drying and cabinet

drying and the nutritive value of the powders was determined. It was found that insipte of considerable losses in vitamins, green leafy vegetables powders retained good amount of protein, fiber, minerals (Ca, Mg and Fe) and fair amount of ascorbic acid and β-carotene.

The effect of blanching and dehydration on colour and vitamins on seven green leafy vegetables was studied by Premavalli *et al.* (2001) and reported that the total chlorophyll reduced during dehydration, retention of ascorbic acid during blanching and dehydration was found to be from 32 to 97 per cent and 28 to 74 per cent, respectively. β-carotene showed better retention (36 to 94 per cent). Amongst the vegetable studied fenugreek leaves showed better retention of colour and vitamins.

Patricia *et al.* (2015) evaluated the impact of sun drying on nutritional value and antioxidant properties of five leafy vegetables (*Hibiscus sabdariffa, Amaranthus hybridus, Adansonia digitata, Vigna unguiculata* and *Ceiba pentandra*) consumed in Northern Côte d'Ivoire. The selected leafy vegetables were subjected to sun drying for 1, 2 and 3 days (8 h/day) and the physicochemical properties were determined using standard methods. The proximate analysis showed the following results after 3 days of sun-drying: moisture (4.62 ± 1.53-8.36 ± 2.77 per cent), ash (8.69 ± 0.28-24.85 ± 0.19 per cent), proteins (7.62 ± 0.02-11.51 ± 0.03 per cent) and crude fiber (13.11 ± 3.11-32.19 ± 0.45 per cent). It was also observed that there was a decrease in vitamin C and carotenoids contents with calculated losses estimated to 89.37-97.50 per cent and 69.82-89.03 per cent, respectively after 3 days of sun drying.

Sheetal *et al.* (2013) studied the influence of dehydration on the nutrient composition of *Amaranthus gangeticus, Chenopodium album, Centella asiatica, Amaranthus tricolor and Trigonella foenum graecum*. The leafy green vegetables (GLV) were steamed for 5 minutes after pretreatment and dried in an oven at 60°C for 10-12 h. The fresh and dehydrated samples were analyzed in search of selected proximal components, minerals, vitamins, antinutrients and dialyzable minerals. Among the vitamins, the retention of ascorbic acid was 1-14 per cent, total carotene 49-73 per cent, thiamine 22-71 per cent and β-carotene 20-69 per cent individually, from its initial content. Dehydration seems to be the simplest and most convenient technology to preserve these sources of micronutrients, especially when they are available in abundance.

2.4 Development of Leafy Vegetable Supplemented Biscuits

Bakery products have become popular in India, as evidenced by increase in their production. Among these, biscuit forms the most popular item. Some of the reasons for such wide popularity are low cost among other processed foods, varied taste and textured profiles, easy availability in attractive packaged form and longer shelf life to suit easy marketing.

Singh *et al.* (1993) prepared biscuit from wheat flour supplemented with green gram, bengal gram and black gram and reported that biscuits made with higher levels of bengal gram (more than 15 per cent were hard). The biscuits made from 15 per cent green gram scored highest for flavour. Thickness, width and spread ratio decreased progressively with increase in pulse flours. Acceptable biscuits could be prepared from wheat flour supplemented with pulse flours at a level of 15 per cent.

Singh *et al.* (1993) examined the effect of supplementation of wheat flour with pulse flours (green gram, bengal gram and black gram) at the rate of 5, 10, 15, 20, 25 and 30 per cent on biscuits and concluded that. The protein content of biscuits increased significantly as the level of the pulse flour increased.

Patel and Rao (1996) examined the biscuit baking properties of composite flours containing varying levels of 0, 5, 10, 15, 20 and 25 per cent of untreated; heat treated and germinated bengal gram flour. The organoleptic studies inferred that 10 per cent of untreated, 15 per cent of heat treated and 10 per cent of germinated were the optimum acceptable level.

Onweluzo and Iwenu (1998) prepared biscuits from different blends of wheat-soy and cassava soy flours and found that the control wheat flour biscuits showed a higher spread ratio of 1.8 and lower break strength of 1.8 kg. The cassava soybean biscuits showed comparable crispness, measured as break strength (1.7 kg), with the control, but had half the spread ratio of the control. The wheat-soybean biscuits had low spread ratio (1.0) and high average break strength of 2.6 kg.

Sharma *et al.* (1999) prepared biscuit from cow pea flour and revealed that there was significant increase in cookie spread factor with increase in the level of cow pea flour

in blends. Overall acceptability scores increased significantly upto 15 per cent cowpea flour addition. Colour became darker and taste was unacceptable beyond 15 per cent of cowpea flour supplementation.

Gupta (2001) reported that legume supplemented biscuits moisture, protein, fat and ash content increased while total carbohydrate and crude fiber content decreased significantly. Total soluble sugar and non-reducing sugar content increased at 20 per cent and 30 per cent supplementation.

Shalini and Sudesh (2005) studied the organoleptic and nutritional evaluation of wheat biscuits supplemented with untreated and treated fenugreek flour. The thickness of fenugreek supplemented biscuits increased, whereas width and spread ratio of biscuits decreased with the increasing level of fenugreek flour. The sensory results showed that a maximum of 10 per cent fenugreek flour can be incorporated to prepare acceptable quality biscuits. Addition of raw, soaked and germinated fenugreek flour to wheat flour increased the contents of protein (10.5, 10.4 and 11.0 per cent), dietary fiber (12.7, 11.3 and 10.9 per cent), total Ca (58.3, 57.1, 57.7 mg/100g) and total iron (7.40, 7.26 and 7.36 mg/100g), respectively, at 10 per cent level of substitution. These biscuits can be safely stored in polypropylene bags upto 1 month without altering their organoleptic properties.

Tyagi *et al.* (2007) studied the effect of mustard flour incorporation of nutritional, textural and organoleptic characteristics of biscuits. The wheat flour was replaced by defatted mustard flour at 5, 10, 15 and 20 per cent incorporation levels in biscuit preparation. The protein content of mustard flour biscuit increased nearly 2.5 times as a result of mustard flour incorporation, coupled with reduction in fat and an increase in fiber content. Sensory evaluation results revealed that the sample containing 15 per cent defatted mustard flour scored highest in most of the attributes including overall acceptability. The study reveals that incorporation of 15 per cent defatted mustard flour gave desirable results in terms of nutritional, sensory and textural attributes of mustard fortified biscuits.

Dachana *et al.* (2010) studied the effect of replacement of wheat flour with 5, 10 and 15 per cent dried moringa leaves (*Moringa oleifera Lam*) powder (DML) on the rheological, microstructural, nutritional and quality characteristics of cookies. Sensory evaluation showed that cookies incorporated with 10 per cent DML powder were

acceptable. Microstructure studies showed calcium oxalate crystals in both DML powder and cookies with DML. The starch granules appeared wrapped in cookies with 10 and 15 per cent DML. Protein, iron, calcium, β-carotene and dietary fiber contents increased with increasing amount of DML from 0 to 15 per cent. The results showed the possibility of utilizing DML to improve the nutritional characteristics of cookies.

Pankaj *et al.* (2013) studied the effect of dried guduchi (*Tinospora cordifolia*) leaf powder on rheological, organoleptic and nutritional characteristics of cookies. Used dried *Tinospora* leaf powder (DTLP) at the levels of 2.5, 5.0 and 7.5 per cent. Incorporation of increasing amount of DTLP from 0 to 7.5 per cent increased farinograph water absorption, decreased dough stability; increased amylograph gelatinization temperature, decreased peak viscosity; increased hardness, decreased cohesiveness and springiness of cookie dough; decreased spread ratio and increased breaking strength of the cookies. Sensory evaluation showed that cookies incorporated with 5 per cent DTLP were acceptable. Addition of DTLP increased the protein, dietary fiber, iron, calcium, radical scavenging activity and β-carotene contents of the cookies. The results showed the possibility of utilizing DTLP to improve the nutritional properties of cookies.

Drisya *et al.* (2015) evaluated the rheological, physical, sensory and nutritional properties of dried *Murraya koenigii* leaves powder (DMKLP) was incorporated at different levels (5, 10 and 15 per cent) in cookies. The results revealed that the contents of protein, dietary fiber, minerals, β-carotene and radical scavenging activity (RSA) in cookies increased with incorporation of increasing levels of DMKLP. Sensory evaluation showed that cookies with acceptable quality and typical curry leaf flavor could be obtained by incorporating DMKLP up to 10 per cent. Thus, the nutritional quality of cookies could be enhanced by incorporating DMKLP in a dose dependent manner.

Karad *et al.* (2016) studied the quality characteristics of crackers made from kasuri methi and different flours. The proximate analysis was determined using standard methods. From the result of proximate analysis, the moisture content ranged in values from 3.7-4 per cent. Also the other components of ash, fat, protein and carbohydrate were in the ranges of 0.35-0.45, 29.2-32.5, 6.1-9.81 and 50.4-55.2 per cent respectively. Sensory evaluation was done to know the acceptability of methi crackers.

Narsing *et al.* (2017) studied nutritional, textural and sensory quality of biscuits supplemented with spinach (*Spinacia oleracea L.*). Biscuits were prepared using 5, 10 and 15 per cent SP and evaluated for their nutritional, textural, sensory quality and sorption behavior. Moisture sorption isotherm of SP indicated non-hygroscopic nature with an initial moisture content (IMC) of 8.6 per cent, which equilibrated at 64 per cent relative humidity (RH), whereas, biscuits were observed to be hygroscopic with an IMC of 0.94-1.26 per cent, which equilibrated between 5-30 per cent RH for control sample (CB), 5, 10 and 15 per cent RH for SP supplemented biscuits respectively. Textural quality revealed that hardness and breaking strengths increased with increased addition of SP. Sensory studies of biscuits showed that 5 per cent supplementation of spinach powder was more acceptable.

Parvinder *et al.* (2017) estimated quantitative changes in nutraceutical properties of cookies. Refined wheat flour and raw/roasted flaxseed flour blends (100:00, 90:10, 80:20, and 70:30) were prepared and subjected for baking to prepare cookies. Refined wheat flour was found to have 4.26 per cent protein and 0.04 per cent fiber which were further increased to about 9.25 per cent and 2.37 per cent respectively after addition of raw flaxseed flour in 70:30 proportions. Baking process at higher temperature resulted in decrease in TPC and TFC while increase in antioxidant capacity. Hardness, resilience, chewiness and springiness of cookies decreased and cohesiveness, gumminess and fracturability increased with increasing amount of flaxseed flour in cookies.

2.5 Packaging and Storage of Leafy Vegetables

Negi and Roy (2001) studied the retention of quality characteristics of dehydrated green leaves during storage. Two green leafy vegetables, savoy beets (*Beta vulgaris var. bengalensis*) and fenugreek (*Trigonella foenum graecum*) were dehydrated in a low temperature drier and stored for 9 months under ambient and cold stored conditions after packaging in single or double layers of high density polyethylene film (200 gauge). The quality was determined on the basis of retention of β-carotene, ascorbic acid and chlorophyll, and the extent of browning during storage. Double packed and cold stored samples of fenugreek retained 67 per cent β-carotene, whereas savoy beet leaves retained only 57 per cent of the initial β-carotene under similar conditions. Similarly, higher

retention of ascorbic acid and chlorophyll, and lower browning was observed in double packed, cold stored samples. Results indicated the efficacy of double packed and cold stored samples over other combinations.

Sagar and Neelavathi (2005) studied the influence of different packaging materials (200 gauge LDPE, 400 gauge LDPE, 200 gauge HDPE) on the quality of ready-to-eat dehydrated carrot shreds. HDPE 200 gauge pouch was suitable in retaining higher quality of total carotenoids and β-carotene as well as high sensory score during storage of ready-to-eat dehydrated carrot shreds.

Jasleen *et al.* (2013) assessed the potential of macro-perforated modified atmosphere packaging (M.A.P) for storage of fenugreek leaves. Packages (bag area: 0.075 m^2) made from polypropylene (PP) film (Thickness: 35 μmm) were selected for the storage studies. The leaves were packaged in macroperforated (2 perforations, perforation diameter: 0.3 mm each, with and without mustard seeds as natural absorbents) as well as in non-perforated PP film packages with and without mustard seeds. 10 g of mustard seeds were placed inside the packages to check water accumulation. The packaged samples were stored for 6 days at 75 per cent relative humidity (RH) at 15 °C to check water accumulation. Results of the study suggested that among all the treatments, packaging of fenugreek in two perforation packets with mustard seeds resulted in best maintenance of chlorophyll, ascorbic acid, phenols and aroma.

Rohit *et al.* (2016) extended the shelf-life of fresh fenugreek in different forms (leaves and bunch), using different packaging material *viz.*, polypropylene, cling film, paper with an unpacked control sample. The packed fresh fenugreek was stored under refrigerated conditions (temperature 6 ± 1°C and RH 95 ± 2 per cent). Polypropylene package and bunch form of sample were the best for enhancement of shelf-life of fenugreek up to 7 weeks. Lower PLW was observed to be 2.11 and 2.85 per cent of initial weight in polypropylene material for leaves and bunch, respectively. Chlorophyll content decreased as much as by 91 per cent for leaf and 90 per cent for a bunch with respect to fresh (220 mg/100g) in polypropylene packaging. It was observed that packaging of fenugreek in polypropylene package in bunch form resulted in best maintenance of chlorophyll, colour, weight loss, aroma and visual appearance. Overall it can be concluded that the fresh

fenugreek in the form of bunch can be stored safely up to 48 days when packed in polypropylene package and stored under refrigerated conditions.

Pragalyaashree *et al.* (2017) studied the impact of gas composition, temperature and pre-treatments on mint leaves quality under modified atmosphere packaging. The low density poly ethylene (LDPE) bags with a thickness of 152 µ which recorded the lowest permeability to oxygen (1067 ml/m^2/day) was selected and used for packaging mint leaves. The harvested mint leaves were cleaned and subjected to pre-chilling and pre-cooling treatment and packaged (LDPE) bags with a product volume ratios *Viz.*, 1:18, 1:11 and 1:8 to assess the respiration rate under ambient and refrigerated condition using the permeable system. Based on the respiration rate, a gas composition of 5 per cent O_2, 5 per cent CO_2 and 90 per cent N_2 was found to be the best in the product volume ratio of 1:8 which recorded the lowest respiration rate, and a slight changes in the physico-chemical parameters, was recorded during the storage period of 30 days. The MA packaged mint leaves kept under refrigerated condition had more shelf-life than at ambient condition.

CHAPTER III

MATERIALS AND METHODOLOGY

The present investigation entitled "Process development for dehydration of fenugreek leaves and value added product" was undertaken in the Department of Processing and Food Engineering, College of Technology and Engineering, Maharana Pratap University of Agricultural Technology, Udaipur, Rajasthan during 2016-19. The study was undertaken to study the suitable drying technology for drying of fenugreek leaves and for development fenugreek supplemented biscuits.

3.1 Procurement of Fenugreek Leaves

The fresh fenugreek leaves (local variety) were procured from local market of Naguar, Rajasthan, and brought to the Department of Processing and Food Engineering, CTAE, MPUAT, Udaipur, Rajasthan to carry out the experiments.

3.2 Process Technology for Dehydration of Fenugreek Leaves and Value Added Product

The fresh fenugreek leaves were sorted and separated from main branches and separated leaves were washed thoroughly with tap water to remove foreign matter such as dust, dirt and chaff. After washing, leaves were spread on muslin cloth to remove surface moisture as depicted in Plate 3.1. The surface moisture was evaporated at room temperature; these leaves were used to study for drying and product development.

Fenugreek leaves were subjected to drying using four different drying methods. *i.e.,* open sun drying (OSD), solar cabinet drying (SCD), mechanical tray drying (MTD) and fluidized bed drying (FBD) at 40, 50, 60 and 70 °C respectively. In case of MTD and FBD the air-flow rate of the drying air was kept at 2 m/s throughout the drying period. After drying the best sample, dried at optimized condition were selected for packaging and storage study and for the product development. These fenugreek leaves were packed in Low Density Polyethylene (LDPE, 300 gauge) and Polypropylene (PP, 300 gauge) materials, normal packaging P_1, active packaging (Moisture absorber sachet is placed in LDPE and PP) P_2 and vacuum packaging P_3. Packed leaves were kept for 3 months storage at ambient conditions, detailed process flow chart is shown in Fig.

3.1. The best dried fenugreek leaves were used for the preparation of fenugreek supplemented biscuits.

Plate 3.1 Sorted and cleaned fenugreek leaves

3.3 Physcio-chemical properties of fenugreek leaves

Physical properties *viz.,* leaf area, leaf thickness, bulk density of fresh fenugreek leaves were determined. Chemical properties *viz.,* proximate composition, rehydration ratio, colour, β-carotene, ascorbic acid and chlorophyll of fresh and dried fenugreek leaves were determined by following the standard procedures as explained below.

3.3.1 Leaf area

By taking maximum leaf length (l) and maximum width (b) and multiplying with constant factor (f) the leaf area was measured using the l x b factor as described by Shoba (2009). Procedure for finding the constant factor. The sample from the plant was taken and spread over a graph sheet, the leaf margin was outlined with the help of a pencil. The constant factor obtained by counting the squares (area of square in a graph sheet is known) in outlines. The area fully covered the square counted and area covered less than half of the square was ignored.

Leaf area = l x b x f … (3.1)

Where,

l = Length, cm

b = Width, cm

f = Constant factor

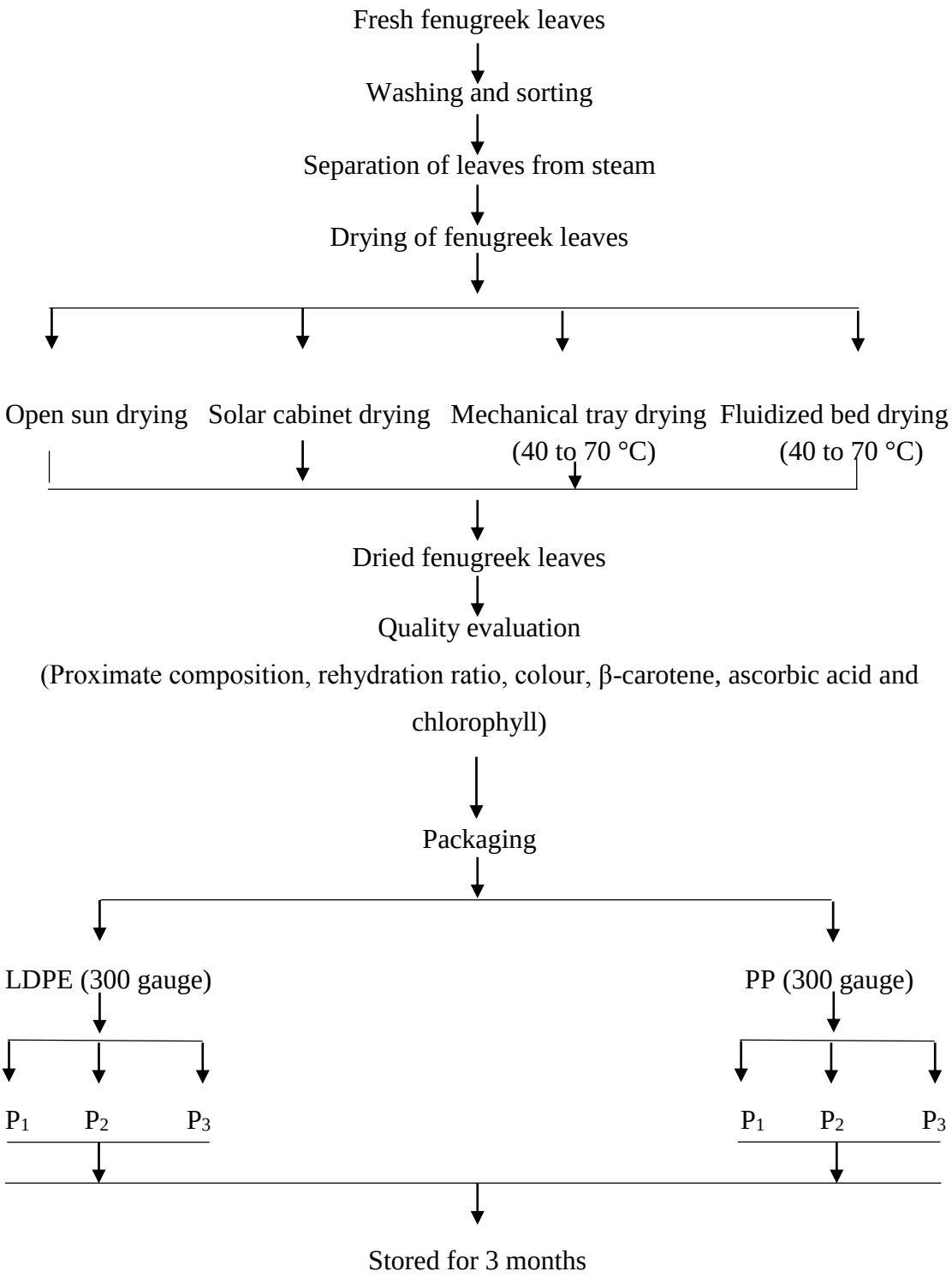

Fig 3.1 Process flow chat for drying and storage of fenugreek leaves

3.3.2 Leaf thickness

A digital venire calipers having a least count of 0.01mm was used to determine the thickness of fenugreek leaves. Ten samples of fenugreek leaves were randomly selected for measurement. The thickness was measured at the centre of the leaf (Plate 3.2.) and readings were tabulated to calculate mean value (Shoba 2009).

Plate 3.2 Thickness measurement of fenugreek leaves

3.3.3 Bulk density

A perfect rectangular wooden box was taken and its volume was determined by formula and then the box was completely filled with fenugreek leaves. The weight of the leaves required to fill the box was recorded and the bulk density was determined using the following relationship:

$$\text{Bulk density (kg/m}^3\text{)} = \frac{\text{Weight of leaves (kg)}}{\text{Volume of wooden box (m}^3\text{)}} \quad \ldots(3.2)$$

3.3.4 Proximate composition

The proximate composition of fresh and dried fenugreek leaves *viz.*, carbohydrates, crude protein, crude fiber, crude fat and total ash content were determined by following the standard procedures as explained below.

3.3.4.1 Carbohydrates

The carbohydrates estimation was carried out as per AOAC (1990). Fresh, dried fenugreek leaves and fenugreek supplemented biscuits were analyzed for carbohydrates. One gram fresh, dried sample and five gram of biscuit was taken in a boiling tube and then hydrolyzed in a water bath at 100 °C for 3 h with 5 ml of HCl

(2.5 N). The tube was cooled to room temperature. The sample was neutralized with sodium carbonate until effervescence ceased and the volume was made up to 100 ml with distilled water. The sample was centrifuged at 9000 rpm for 10 min and the supernatant was collected. The test sample of 0.1 ml was pipetted out into a test tube. One ml of phenol and then 5 ml of sulphuric acid were added to it. The test tube was placed in a water bath at 25-30 ºC for 20 min and then cooled. The cooled solution was transferred into the cuvettes and absorbance was measured at 490 nm in spectrophotometer. To calculate the concentration of carbohydrate present in the sample, a graph of absorbance versus concentration of carbohydrate was plotted along with a standard curve generated from the analysis of D-glucose.

$$\text{Carbohydrates (\%)} = \frac{X}{0.1} \times 100 \quad \ldots (3.3)$$

Where,

X = Concentration of D-glucose from standard graph, ppm

3.3.4.2 Crude protein

The nitrogen content in fresh, dried fenugreek leaves and fenugreek supplemented biscuits was estimated by using Kjeltech instrument as per AOAC (1990). Seven grams of K_2SO_4, 0.8 g of $CuSO_4.5H_2O$ and 0.8 g of fresh and dried fenugreek leaves were added into digestion tube and then 12 ml of H_2SO_4 was added slowly. Methyl red indicator and bromocresol green indicator solutions were prepared. The digestion tubes were placed on fume ejection system until digestion was cleared (clear with light blue-green colour) in flask at the temperature of 410 °C and then cooled to room temperature and 80 ml of distilled water was added. Digested samples were distilled with 40 per cent NaOH. The distillate was collected in 30 ml of 4 per cent boric acid solution and titrated against 0.1N HCl (35.4 per cent) until light pink colour appeared. The per cent protein was computed on total nitrogen basis using the following equation.

$$\text{Nitrogen (\%)} = \frac{\text{Volume of } 0.1\text{N HCL(ml)} \times 0.1 \times 14.007}{\text{Weight of sample (g)} \times 1000} \times 100 \quad \ldots (3.4)$$

$$\text{Per cent of protein on nitrogen basis} = \text{N (\%) x conversion factor} \quad \ldots (3.5)$$

Conversion factor = 6.25

3.3.4.3 Crude fiber

The crude fiber content of fresh, dried fenugreek leaves and fenugreek supplemented biscuits were determined by sequential acid and alkali hydrolysis method using Fibra-Plus apparatus as per AOAC (1990). Accurately, two grams of sample was weighed and transferred to crucible (W). The sample was boiled in 1.25 per cent sulphuric acid and subsequently boiled in 1.25 per cent sodium hydroxide solution. The sample was dried in hot air oven at 100 °C till all the moisture was evaporated. The weight of the crucible before ashing was noted down (W_1). The obtained dried sample was made into ash in a muffle furnace at 550 °C for 4 h. After ashing, the crucibles were cooled in a desiccator and reweighed (W_2). The residue obtained after subtraction of the ash was regarded as fiber. The crude fiber was obtained by using the following equation.

$$\text{Crude fiber } (\%) = \frac{W_1 - W_2}{W} \times 100 \quad \ldots (3.6)$$

Where,

W_1 = Weight of sample before ashing, g

W_2 = Weight of sample after ashing, g

W = Weight of sample,

3.3.4.4 Crude fat

The crude fat content of fresh, dried fenugreek leaves and fenugreek supplemented biscuits were estimated by Soxhlet extraction method as per AOAC (1990), using SOCS-PLUS apparatus. Five gram of sample was weighed accurately and transferred to a thimble (W). The empty beaker weight (W_1) was taken and all the eight beakers were loaded into the system. The petroleum ether was filled into the beaker of 90 ml from the top and boiled for about 80-90 min at 80 ºC. After the completion of process time, the temperature was doubled to 160 ºC for 15-20 min to collect the petroleum ether. All the beakers were removed and placed in a desiccator for about 5 min. The final weight of the beaker (W_2) was noted down and fat content was estimated by using the following equation.

$$\text{Crude fat } (\%) = \frac{W_2 - W_1}{W} \times 100 \quad \ldots (3.7)$$

Where,

W_1 = Initial weight of the beaker, g

W_2 = Final weight of the beaker, g

W = Weight of the sample, g

3.3.4.5 Total ash

The total ash content of fresh, dried fenugreek leaves and fenugreek supplemented biscuits were determined as per AOAC (1990), using muffle furnace. Accurately, 2 g of sample was weighed into a crucible (which was previously heated to about 550 °C and then cooled). The crucible was placed on a clay pipe triangle and heated first over a low flame till all the material was completely charred, followed by heating in a muffle furnace for about 4 h at 550 °C. It was then cooled in a desiccator and weighed. The percentage of ash was calculated by using the following expression.

$$\text{Total ash (\%)} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample (g)}} \times 100 \quad \ldots (3.8)$$

3.3.5 Rehydration ratio

Rehydration quality characteristics of dehydrated fenugreek leaves samples were determined by rehydration test as described by Ranganna (2000). 10 g of dried fenugreek leaves were taken for the experiment. 200 ml of distilled water in glass beakers was taken and the beakers were kept in a water bath, maintained at 80ºC. Dehydrated samples of each were placed in beakers for 10 min. After 10 min the excess water was drained off through filter paper. The drained samples were weighed. Rehydration ratio (RR) were computed using following equations.

$$\text{Rehydration ratio} = \frac{C}{D} \quad \ldots(3.9)$$

Where,

C = Drained weight of rehydrated sample, g

D = Weight of dehydrated samples taken for rehydration test, g

3.3.6 Colour values

Colour is one of the most important qualities for acceptance of products, which reflects sensation to the human eye. Colour is important to consumer as a mean of

identification, as a method of judging quality and for its basic aesthetic value. Dried products are usually darker in colour, but darker colour does not mean better quality. Too dark may imply that the product is over dried. The advantage is that this parameter can be visually determined for assessing dryness quality.

A laboratory colorimeter was used in the present investigation as shown in Plate 3.3. Colour of fenugreek leaves was measured using a Hunter Lab Colorimeter (Model CFLX/DIFF, CFLX-45). A cylindrical glass sample cup (63.5 mm in diameter x 40 mm height) was placed at the light port (31.75 mm diameter). The instrument was initially calibrated with a black as well as with standard white plate supplied with the equipment. The 3- dimensional scale L^*, a^* and b^* is used in a Hunter Lab Colorimeter. The L^* is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The a^* is purplered (positive a^* value) and blue-green (negative a^* value) on a horizontal axis. A second horizontal axis is b^*, that represent yellow (positive b^* value) or blue (negative b^* value) colour. This 3D colour system can be seen in Plate 3.4.

Plate 3.3 Hunter lab colorimeter

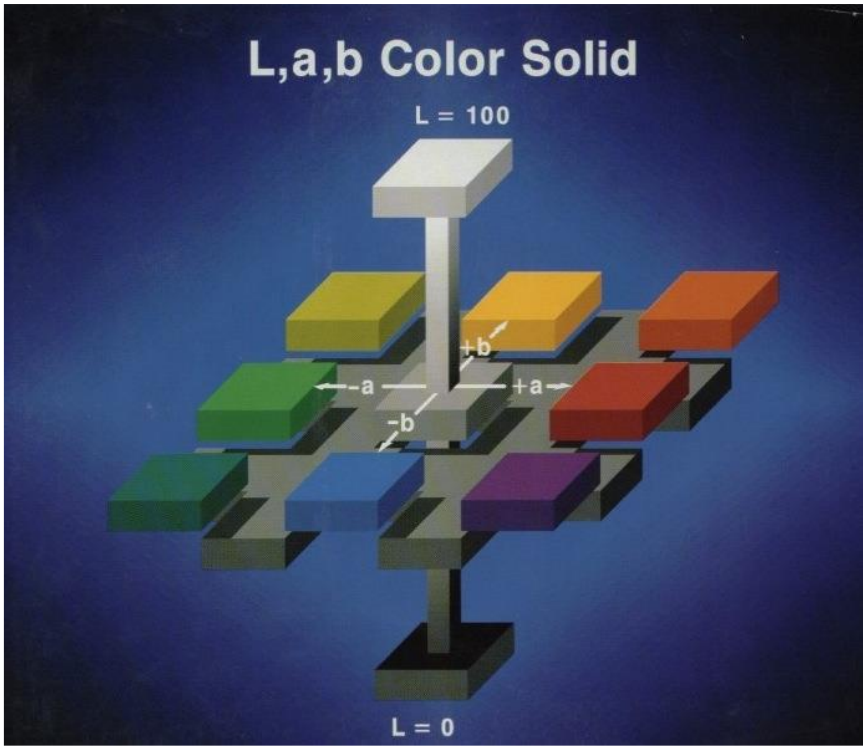

Plate 3.4 Colour scale representing relationship of colour index

3.3.7 β-carotene

β-carotene content fresh and dried fenugreek leaves were determined by following the procedure given by Ranganna (1995). A 10 g of the sample was taken in a pestle mortar made into a fine paste and transferred to a 250 ml beaker. Then 25ml of acetone was added, allowed to stand for 15 min. and filtered using Whatman paper. The procedure was repeated for 3-4 times until the residue was colourless. The filtrate from each extraction was pooled and was transferred to a separating funnel. To this extract, 15ml of petroleum ether and 100 ml of 5 per cent Na_2SO_4 solutions were added and the separating funnel was thoroughly shacked before allowing it to stand. Then the carotenes got transferred to petroleum ether layer. The extraction of carotenes using petroleum ether from acetone solution was repeated until acetone layer became colourless. The Petroleum ether extracts were then pooled, volume was made up to 50 ml and β-carotene was determined by measuring the absorbance at 452 nm. The β-carotene content was calculated by using the following expression:

$$\beta\text{-carotene} = \frac{\text{Concentration of carotene as read from standard curve x Volume made up (50ml)}}{\text{Weight of sample (g)}} \times 100 \qquad \ldots (3.10)$$

3.3.8 Ascorbic acid

Ascorbic acid content of fresh and dried fenugreek leaves were determined by following the procedure given by Ranganna (1995). A 10 g of sample (pulp or powder) was taken in a 100 ml volumetric flask and 50 ml of 4 per cent oxalic acid was added. The sample was thoroughly mixed and the volume was made up to the mark using 4 per cent oxalic acid mixture. The solution was filtered using Whatman No. 4 filter paper and the filtrate was used for the analysis. A 5 ml of filtered sample and 5 ml of 4 per cent oxalic acid mixture were taken in a conical flask and titrated against the standard dye solution. The end point was light pink colour that persisted for 5-10 seconds. The ascorbic acid content was calculated by using the following expression:

$$\text{Ascorbic acid} = \frac{\text{Titro value x Dye factor x Volume made up (50ml)}}{\text{Aliquot taken x Weight of sample (g)}} \times 100 \quad \ldots (3.11)$$

3.3.9 Chlorophyll

The chlorophyll content of fresh and dried fenugreek leaves were determined by following the procedure given by Srivastava *et al.*, (1998). One gram of sample was cut into small pieces and homogenized in a blender. The homogenate was made up to 10 ml with water and centrifuged. To extract the pigment 25 ml, 80 per cent acetone was added to 0.5 ml aliquot and the supernatant recorded for optical density (O.D) at 480, 645 and 663 nm, using acetone as blank. The total chlorophyll mg per 100 g of leaves were calculated using the following equation:

$$\text{Chlorophyll} = \frac{20.2 \text{ x } A645 \text{ x } 8.20 \text{ x } A663}{W \text{ x } 1000} \quad \ldots (3.12)$$

3.4 Drying Methods

Drying, as a preservation method, is a very important aspect of food processing. Drying can be defined as a simultaneous heat and mass transfer operation in which the water activity of the material is lowered by evaporation of water into an unsaturated gas stream. The main function of drying is to lower the water activity of the product and consequently, to inhibit the growth of microorganisms and decrease chemical reactions in order to prolong the shelf-life of the product at room temperature. It also results in

less space needed for storage and lighter weight for transportation (Inchuen *et al.*, 2010). The drying methods employed for the present investigation were;

i. Open sun drying
ii. Solar cabinet drying
iii. Mechanical tray drying (40, 50, 60 and 70 $^{\circ}$C)
iv. Fluidized bed drying (40, 50, 60 and 70 $^{\circ}$C)

3.4.1 Open sun drying

A known weight of fresh fenugreek leaves were kept in aluminum trays. The trays were kept in the open sun for drying (Plate 3.5). The weight loss of the samples was recorded at every one hour interval, upto sunset in a day. After sunset the dried leaves were placed in desiccators to avoid moisture absorption from atmosphere during night time. Sun drying was continued until there were no differences found in weight loss as indicated by the constant consecutive weight readings.

3.4.2 Solar cabinet drying

Fresh fenugreek leaves (200 g) were spread on perforated aluminum trays and kept in direct contact type solar drier (Plate 3.6). The experiments was carried out in Department of Renewable Energy Engineering, CTAE, Udaipur. The weight loss of the sample was recorded at every one hour interval. Drying was continued until there were no differences found in weight loss as indicated by the constant consecutive weight readings.

3.4.3 Mechanical tray drying

A convective tray dryer was used to conduct drying experiments. Plate 3.7 shows the details of tray dryer. The specifications of the dryer are given in Appendix A-1.

a) Planum chamber: It comprised of an insulated box with a single door opening at front. A fan with adjustable speed for regulation of air velocity and heating unit is provided.

Plate 3.5 Drying of fenugreek leaves in open sun drying

Plate 3.6 Drying of fenugreek leaves in solar cabinet drying

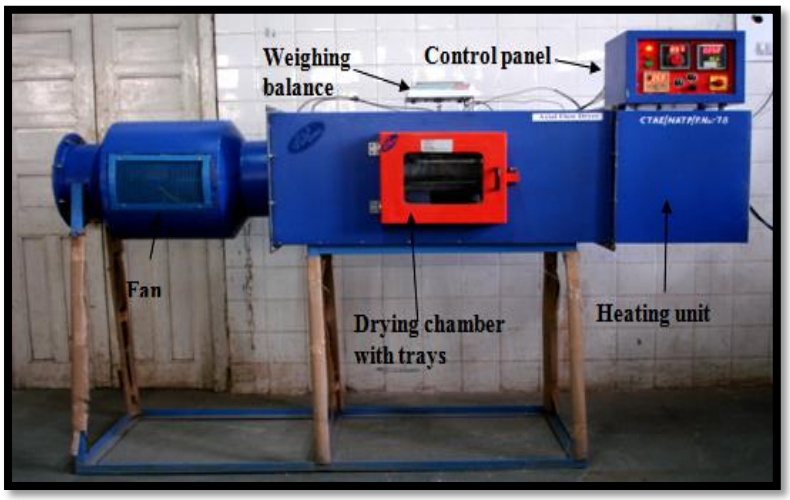

Plate 3.7 Drying of fenugreek in mechanical tray dryer

The air enters the drying chamber due to suction and transfers heat to the sample for drying and simultaneously, absorbs moisture from it. The moisture laden air leaves the dryer by another opening of drying chamber.

b) Heating unit: It consisted of an electric heater of 2.5 kW with thermostatic controller for controlling the temperature of the drying air inside the dryer. Fan: A fan provided at inner left side of drying chamber sucked the filtered atmospheric air inside and then through heating unit; forcing it to pass through the wet product placed in trays. This caused quick and effective drying of product. The fan was operated by a single phase, 50 Hz, 0.375 kW AC motor. The temperature of the drying chamber was pre-set through a temperature indicator cum controller provided on control panel of dryer. A thermostat controlled and maintained the temperature by switching ON/OFF the heating unit. The velocity of drying air, as measured by an anemometer, was kept constant for all the experiments and it was found to be 2 (± 0.1) m/s.

3.4.4 Fluidized bed drying

A fluidized bed dryer was used to conduct drying experiments. The Plate 3.8 shows the details of fluidized bed dryer. The specifications of the dryer are given in Appendix A-2. The details of fluid bed dryer are described as under:

a) Principle of fluidization: When a stream of gas is passed upward through a bed of a material at a certain velocity the bed will first expand, then become suspended and agitated by the gas stream to form a fluidized bed. This has the appearance of the boiling liquid due to the formation of many small bubbles – the so called "bubbling fluidization". At higher velocities, large size bubbles are formed resulting in a more violent type of fluidization called slugging or spouting.

b) Drying process: If a bed of wet material is fluidized by a heated air stream, as in the laboratory batch dryer, the conditions are ideal for drying. Efficient contact between hot air and solid particles can be achieved due to the turbulence of the bed which results in high heat transfer rates causing rapid moisture transfer that is carried away with the exit air. This process has a high thermal efficiency because most of the heat is used in vaporizing the moisture. Because of the very good mixing of particles in the fluidized states, the conditions of temperature and moisture content are uniform throughout the bed; therefore, a uniform product is obtained.

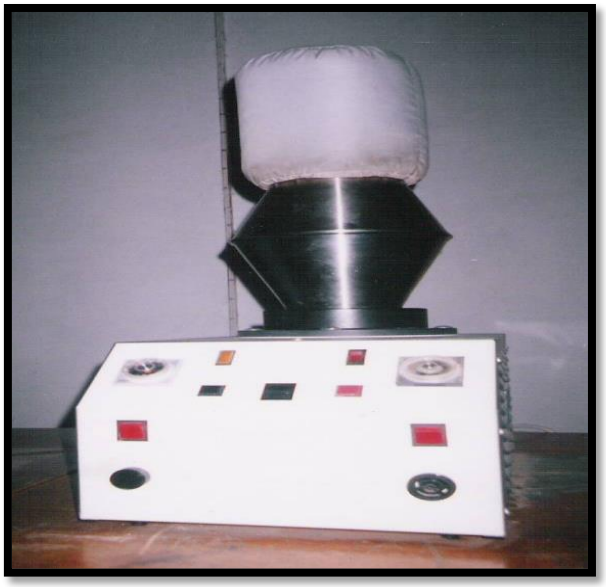

Plate 3.8 Drying of fenugreek in fluidized bed dryer

Fluidization causes very little abrasion to the product and the quality of food is not affected. The temperature of drying air can also be controlled to ensure little or no loss in properties especially for heat-sensitive materials. The similar principles can be applied for industrial fluid bed dryers, therefore, the laboratory fluid bed dryer can be used to assess the feasibility of different materials for large scale fluidized drying.

c) Drying chamber: The lab fluidized bed dryer is simple, compact, portable and easy to operate. The cabinet contains the air distribution system and electrical controls. Air is drawn in through a mesh filter in the base of the cabinet and blown by the centrifugal fan over a 2 kW electrical heater. The tube unit consists of a container with a fine mesh distributor and stainless steel support. A filter bag, which fits over the top of the tub, retains any particles expelled from the fluidized bed.

d) Temperature controller: The temperature controller is located on the right hand side of the control panel. The fluidized dryer has PID controller for the range of 0-200ºC. The temperature controller regulates the heater which raises the temperature of the air fed in to the dryer.

3.5 Drying Characteristics

The drying characteristics *viz.*, moisture content, drying rate and moisture ratio of fenugreek leaves were determined during drying period. The weight of the dried samples was taken at an interval of 60 min in OSD and SCD, whereas in MTD and FBD interval 5 min for first 30 min, of 10 min for next 30 min, 15 min interval for next 1 hour and after that, every 30 min from next hour time till the end of drying process.

3.5.1 Moisture content

The moisture content of fresh, dried fenugreek leaves and fenugreek supplemented biscuits were determined by following AOAC (2000) method. Ten grams of samples were kept in a pre-dried moisture box. The mass of the sample was recorded as W_1. The box was placed in the hot air oven maintained at 70 °C, for 24 h. After drying, the box was kept in the desiccator and then weighed. The mass of the dried sample was recorded as W_2. All measurements were replicated thrice and the average moisture content was calculated. The moisture content of the sample was calculated by using the following equation:

$$\text{Moisture content}\,(\%\,\text{db}) = \frac{W_1 - W_2}{W_2} \times 100 \qquad \ldots (3.13)$$

Where,

W_1 and W_2= Initial and Final weight of the sample, g

3.5.2 Drying rate

The moisture content data recorded during experiments were analyzed to determine the moisture lost from the sample of fenugreek leaves in particular time interval. The drying rates of samples were calculated by following mass balance equation:

$$\text{Drying rate}\ (\text{g water/ g solids /h}) = \frac{dW}{dt \times DM} \times 100 \qquad \ldots (3.14)$$

Where,

dW = Difference in mass (g)

dt = Difference in drying time (h)

DM= Dry matter

3.5.3 Moisture ratio (MR)

The moisture ratio of fenugreek leaves for different drying methods was calculated by using the following equation:

$$\text{Moisture ratio} = \frac{M - M_e}{M_0 - M_e} \quad \ldots (3.15)$$

Where,

M = Moisture content at any specified time t (% db)

M_e = Equilibrium moisture content (% db)

M_0 = Initial moisture content (% db)

3.5.4 Mathematical modelling

The mathematical models *viz.*, Newton, Page, Logarithmic, Diffusion approach and Henderson and Pabis were selected for fitting the experimental data and these selected models were used to describe the drying curve equations during drying.

1.	Newton	$MR = \exp(-k\theta)$	… (3.16)
2.	Logarithmic	$MR = a \exp(-k\theta) + c$	… (3.17)
3.	Page	$MR = \exp(-k\theta)^n$	… (3.18)
4.	Diffusion approach	$MR = a \exp(-k\theta) + (1-a) \exp(-kb\theta)$	… (3.19)
5.	Henderson and Pabis	$MR = a \exp(-k\theta)$	… (3.20)

Where,

MR= Moisture ratio

M_e = Equilibrium moisture content, (per cent db)

M = Moisture content at any time θ, (per cent db)

M_o = Initial moisture content, (per cent db)

k = Drying rate constant

θ = Drying time (min)

n = Dimensionless empirical coefficient

a, b, c = Empirical constants in drying models

The constants of the selected models were estimated by non-linear regression (Fajar *et al.,* 2012). The parameters of all the models were estimated by using MATLAB version 2018b software packages. The proposed models were fitted on the experimental data using linear regression. The statistical parameters – standard square error (SSE) and root mean square error (RMSE) were obtained from the MATLAB version 2018b software package. The best suitable model was selected on the basis of highest R^2 and lowest standard square error (SSE) and root mean square error (RMSE).

3.6 Sensory Evaluation

Consumption of food is directly related to the quality. Small and medium sized processing businesses all over the world increasingly have to consider the production of good quality products. Quality commonly thought of as a degree of excellence, is one of the major positioning tool of the producer for marketability and for consumers satisfaction. It is the combination of characteristics of a product that have significance in determining the degree of acceptability of the product to the user. To retain its quality and nutritive value, it is essential to ensure the integrity and safety of food throughout the food chain. The organoleptic evaluation for assessing the colour, taste and texture was done by a panel of twenty judges using a nine point Hedonic scale (Amerine *et al.,* 1965) as given next. The samples having score 5 and above were considered as acceptable.

Organoleptic score	**Rating**
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

3.7 Optimization of Process Parameters for Drying of Fenugreek Leaves

Optimization of different drying methods was performed using the general factorial design in Design Expert Software 7.7.0. Numerical optimization was performed using statistical models to find the optimal drying method. In the present investigation, the independent variables were kept within the range and dependent variables were chosen as maximum and minimum. Table 3.1 shows the process parameters and responses of fenugreek leaves achieved from General Factorial in Design Expert Software 7.7.0. The maximum desirability function obtained was taken as the optimum method for drying of fenugreek.

Table 3.1 Optimization of process parameters for drying of fenugreek leaves

Parameter	Goal	Lower limit	Upper limit
Drying Methods	is in range	T1	T10
Drying Temperature	is in range	40.00	70.00
Drying time	minimize	150.00	840.00
Final moisture content (% d.b)	minimize	6.24	6.64
Crude protein (%)	maximize	16.62	21.78
Crude fat (%)	minimize	4.41	5.26
Total ash (%)	maximize	2.06	2.19
Crude fiber (%)	maximize	8.01	8.68
Carbohydrates (%)	minimize	55.18	58.53
*L**	minimize	35.34	42.45
*a**	maximize	-7.16	-3.42
*b**	minimize	13.32	16.75
β-carotene, µg/100g	maximize	4824.45	5876.19
Ascorbic acid, mg/100g	maximize	46.25	63.12
Chlorophyll, mg/100g	maximize	46.04	69.34
Rehydration ratio	maximize	1.80	3.39

3.8 Statistical Analysis

The analysis was carried out in three replicates for all experiments. The mean and standard deviation of means were calculated. The data were analyzed by one-way analysis of variance (ANOVA) by using Design Expert Software 7.7.0.

3.9 Storage study of dried fenugreek leaves

Optimized and standardized dried fenugreek leaves were packed in low density polyethylene (LDPE 300 gauge) and Polypropylene (300 gauge) materials, normal packaging, with active packaging (Moisture absorber) and vacuum packaging as

depicted in Plate 3.9 and Plate 3.10. Packed leaves were kept for 3 months storage period at ambient conditions. The quality attributes *viz.*, storage weight loss/gain and gas composition was determined with 15 days of interval during the storage period.

LP_1 LP_2 LP_3

Plate 3.9 Dried fenugreek leaves packed in LDPE with P_1-normal packaging, P_2-with active packaging (moisture absorber) P_3-vacuum packaging

PP_1 PP_2 PP_3

Plate 3.10 Dried fenugreek leaves packed in PP with P_1-normal packaging, P_2-with active packaging (moisture absorber) P_3-vacuum packaging

3.9.1 Storage weight gain

The storage weight loss/gain of packed dried fenugreek leaves were determined (Tejib *et al.*, 2017) and calculated by following formula:

$$\text{Loss or gain in weight (\%)} = \frac{\text{Weight of sample during storage}}{\text{Intial weight of the sample}} \text{x}100 \quad \ldots(3.21)$$

3.9.2 Gas composition

The gas composition of packed dried fenugreek leaves were determined by following procedure (Plate 3.11). The gas concentrations of O_2 was analyzed using a portable headspace gas analyzer. The apparatus uses an electrochemical and an infrared sensor to evaluate the package headspace partial pressures of O_2. The instrument was calibrated with standard gases before actual experimentation. The sampling probe assembly consisted of one piece construction to eliminate the chances of leakage of the gas samples. The end of sampling probe was fitted with a particulate filter and a replaceable needle having tip with dual side-port holes to prevent plugging. A miniature pump with electronically controlled timing was used to draw the package headspace sample for analysis. The drawn sample was fed simultaneously to the O_2 sensors. Sensor signals were converted to concentration values of O_2, which were directly read on the digital display panel.

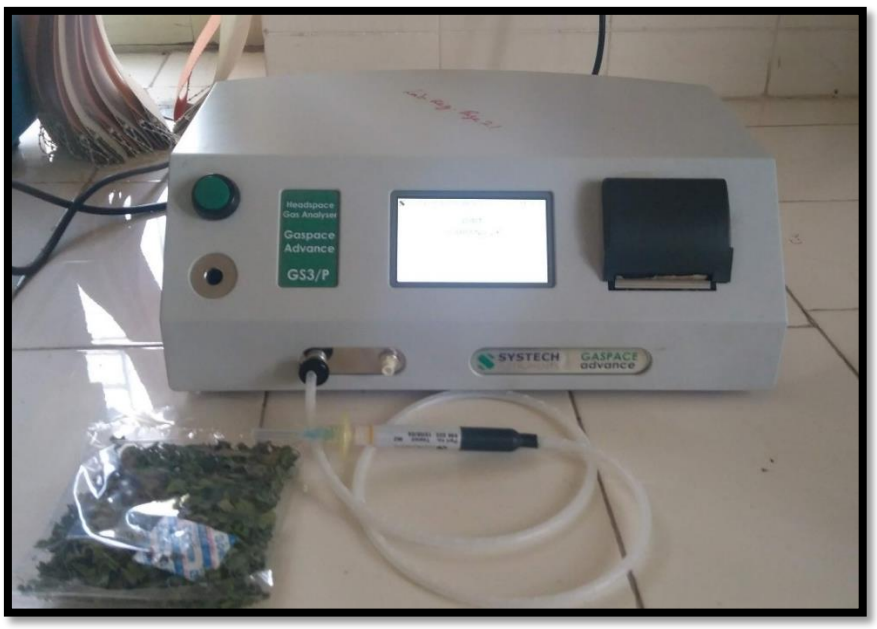

Plate 3.11 Headspace gas analyzer

3.10 Development of Fenugreek Supplemented Biscuits

The optimization of process parameters was carried out for selecting best drying method. After optimization of drying process, fenugreek leaves dried at optimized condition were selected for the biscuit preparation, dried leaves were grounded into powder, Then this fenugreek leaves powder were used in different proportion 5, 10 and 15 per cent, for the development of fenugreek supplemented biscuits. The detailed process flow chart is sown in Fig. 3.2.

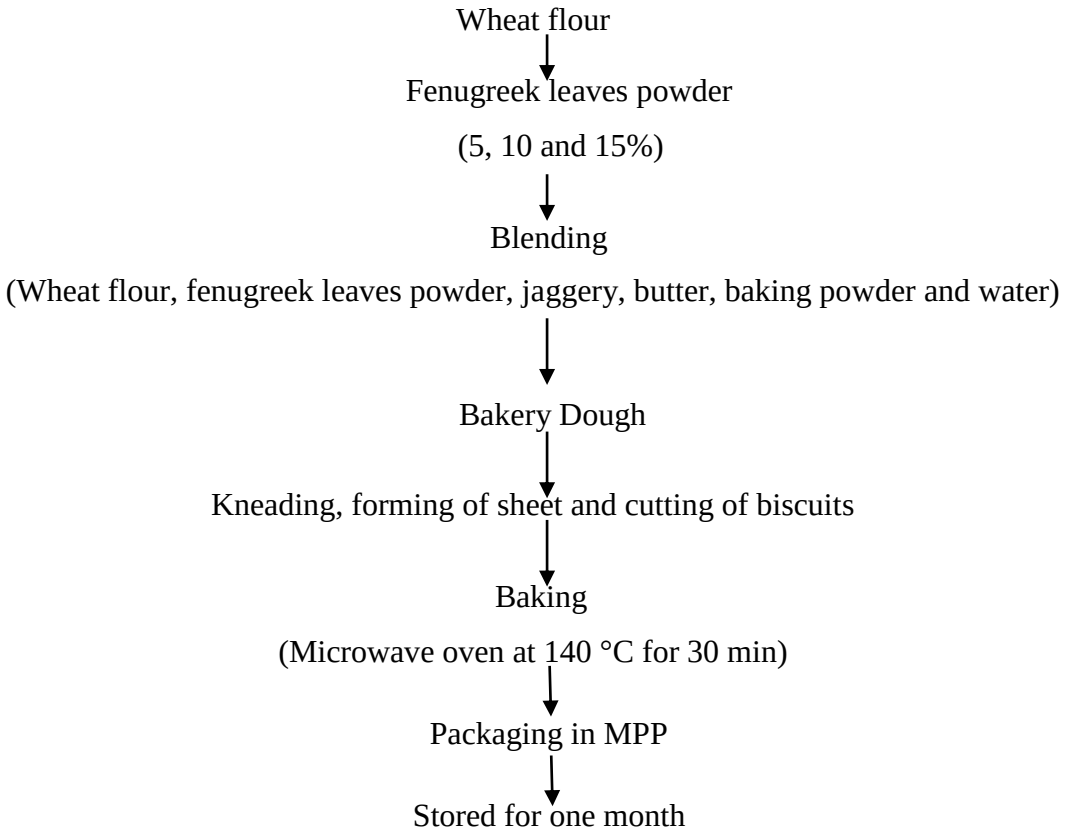

Fig. 3.2 Process flow chat for development of fenugreek supplemented biscuits

Biscuits were prepared by using wheat flour, fenugreek powder, jaggery, butter, baking powder and water. All the ingredients were procured from the local market of Udaipur. The fenugreek supplemented biscuits of various blends were made by using traditional creamy method having different ingredients compositions as given in Table 3.2. Measured quantities of wheat flour and fenugreek powder were mixed together and baking powder were added to the mix. Cream was prepared by adding the ground jaggery to butter and manually whipping it thoroughly for about ten minutes in a pan

with the help of a spoon. The mix of flour was then added to the prepared cream and by adding 4 ml of water, dough was made by hand. The prepared dough was flattened with the help of traditional wooden roller "belan", used in making chapattis, to a thickness of about 7.0 mm. Round shaped were then taken out of the flattened dough with the help of a steel mould. These moulds of biscuits were then kept in a tray and placed in a thermally controlled micro wave oven (Narsing *et al.,* 2017). The baking of biscuits was done at a temperature of 140 ^{o}C for 30 minutes as shown in Plate 3.12. The baked biscuits were packed in metalized polypropylene (MPP) shown in Plate 3.13.

Table 3.2 Composition of the fenugreek supplemented biscuits

Ingredients	C	B_1	B_2	B_3
Wheat flour (g)	100	95	90	85
Fenugreek powder (g)	0	5	10	15
Jaggery (g)	50	50	50	50
Butter (g)	45	45	45	45
Baking powder (g)	1	1	1	1
water (ml)	4	4	4	4
C-Control, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder				

Plate 3.12 Baking of biscuits in microwave oven

Plate 3.13 Biscuits packed in metalized polypropylene

3.10.1 Quality analysis of fenugreek supplemented biscuits

Proximate composition, water activity, colour, textural and sensory characteristics of fenugreek supplemented biscuits were determined by standard procedures are explained below.

3.10.1.1 Proximate composition

Proximate composition *viz.,* moisture content, crude fiber, total ash, crude protein, crude fat and carbohydrates of fenugreek supplemented biscuits were determined using the method AOAC (2000) and the detailed procedure is explained in Section 3.4.1 for moisture content, whereas for remains properties explained in section 3.5.2.1 to 3.5.2.5.

3.10.1.2 Colour

Colour values namely L^*, a^* and b^* of fenugreek supplemented biscuits measured by using Hunters lab colourimeter and the detailed procedure followed is explained in Section 3.5.4.

3.10.1.3 Water activity

The water activity is a key parameter in quality control of any moisture sensitive product or material like biscuit. Water activity is defined as the active part of product's moisture content of free water. It influences the microbial, chemical and enzymatic stability of perishable products such as food, grains and seeds. The water activity of fenugreek biscuits was measured by water activity analyzer. Two grams of sample under test was taken in analyzer sample cup which was provided with water activity

meter. The sensor was placed on the sample cup by firmly closing in such a way that the air should not enter into the sample cup. The reading was directly displayed on the water activity meter and was taken as water activity of the fenugreek biscuits.

3.10.1.4 Textural property

Hardness is textural property that is generally on the same property spectrum. A soft product is one that displays a slight resistance to deformation, a firm product describes one that is moderately resistant to deformation and hardness describes a product which displays substantial resistance to deformation. Hardness of the biscuits were determined by using 6 mm cylindrical probe in textural analyzer (Stable Micro Systems) Depicted in Plate 3.14. During the testing, the samples were held manually against the base plate and the different tests were applied according to TA settings mentioned in Table 3.3.

Plate 3.14 Texture analysis of biscuits

3.10.2 Sensory analysis

The sensory evaluation was carried out for appearance, colour, flavour, texture, taste and overall acceptability of fenugreek biscuits were analyzed and the detailed procedure followed is explained in Section 3.6.3.

Table 3.3 TA settings used in textural analyzer

TA Settings	**Penetration Test**
Modes	Measure Force in Compression
Option	Return To Start
Pre-Test Speed	1.0 mm s^{-1}
Test Speed	0.5 mm s^{-1}
Post-Test Speed	10 mm s^{-1}
Distance	8 mm
Trigger Force	Auto - 5g
Tare Mode	Auto
Data Acquisition Rate	400 pps

3.10.3 Storage study

The packed fenugreek biscuits were kept for one month at ambient conditions. The quality attributes *viz.*, water activity and hardness were determined with seven days of interval during the storage period.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results of experiments carried out on process development for dehydration of fenugreek leaves and value added products. The effect of process variables on the quality of dried fenugreek leaves and fenugreek supplemented biscuits, statistical analysis of experimental data are also presented and discussed in the following sections:

4.1 Physico-Chemical Properties of Fresh Fenugreek Leaves

Physico-chemical properties *viz*., leaf area, leaf thickness, bulk density, proximate composition, β-carotene, chlorophyll, ascorbic acid and colour value of fresh fenugreek leaves were determined. The data are presented in Table 4.1. The results indicated that the average leaf area of fresh fenugreek leaves was found to be 3.81 cm^2, the average leaf thickness was found to be 0.31 mm, and the mean bulk density was found to be 0.0084 kg /m3. Similarly the mean moisture content, carbohydrates, crude protein, crude fiber, crude fat and total ash content of fresh fenugreek leaves were found to be 86.28, 6.01, 4.27, 4.70, 0.90 and 1.49 per cent respectively. The colour values *viz*., L^*, a^* and b^* of the fresh fenugreek leaves were found to be 39.81, -8.71 and 17.50 respectively. Whereas the average β-carotene, ascorbic acid and chlorophyll content were found to be 6529.03 µg/100g, 91.98 mg/100g and 98.41 mg/100g respectively. The results were good agreement with the values of Shoba (2009); Nagi and Roy (2000); Vani and Rajinder (2014) for fresh fenugreek leaves.

4.2 Effect of Different Drying Methods on Drying Characteristics of Fenugreek Leaves

In order to determine the drying characteristics, the fenugreek leaves were dried under open sun, solar cabinet, mechanical tray and fluidized bed. The drying characteristics *viz*., moisture content, drying rate and moisture ratio were determined and results are presented (Appendix B) and discussed hereunder.

Table 4.1 Physico-chemical properties of fresh fenugreek leaves

Parameter	Maximum Value	Minimum Value	Mean Value
Leaf area, cm^2	4.10	3.67	3.81 ± 0.15
Leaf thickness, mm	0.36	0.27	0.31 ± 0.02
Bulk density, kg/m^3	0.0088	0.0079	0.0084 ± 0.002
Moisture content, per cent wb	88.40	84.32	86.28 ± 1.34
Carbohydrates, per cent	7.35	5.33	6.01 ± 1.34
Crude protein, per cent	4.68	4.27	4.27 ± 0.13
Crude fiber, per cent	4.73	4.11	4.70 ± 0.13
Crude fat, per cent	1.10	0.88	0.90 ± 0.06
Total ash, per cent	1.58	1.38	1.49 ± 0.05
Colour			
L^*	41.25	37.32	39.81 ± 1.3
b^*	-9.52	-7.83	-8.71 ± 0.27
a^*	19.48	16.34	17.50 ± 1.32
β-carotene, µg/100g	6532.12	6527.32	6529.03 ± 1.42
Ascorbic acid, mg/100g	93.21	89.32	91.98 ± 1.37
Chlorophyll, mg/100g	99.32	97.12	98.41 ± 0.35

4.2.1 Effect of different drying methods on moisture content of fenugreek leaves

Fresh fenugreek leaves were dried under open sun drying (OSD), solar cabinet drying (SCD), mechanical tray drying (MTD) and fluidized bed drying (FBD) at 40, 50, 60 and 70 °C temperatures respectively. In case of MTD and FBD the air-flow rate of the drying air was kept at 2 m/s throughout the drying period. The results of each drying experiment are presented in the following section.

The variation in the moisture content of fenugreek leaves with elapsed drying time, in OSD, SCD, MTD and FBD are depicted in Fig. 4.1, Fig 4.2, Fig. 4.3 and Fig. 4.4 respectively. From the figures, it can be observed that, the moisture content of fenugreek leaves decreased exponentially with drying time for all drying methods. The drying followed a typical trend of drying behaviour for food materials as reported by

Singh, 2001. The drying rate increased with increase in drying air temperature. This resulted into substantial decrease of drying time. The initial moisture content of fenugreek leaves was ranged from 645.16 to 688.64 per cent (d.b). Similarly the final moisture content of fenugreek leaves was ranged from 6.65 to 7.11 per cent (d.b).

The drying time observed under various drying temperature is presented in Table 4.2. It can be observed that, there was a wide variation in drying time ranged from 150 to 840 min among the different drying methods. Moisture reduction found to be temperature dependent and slow at lower temperature and took more time as compared to drying at higher temperatures. Similar results have be observed by Ankita and Prasad, (2013) for spinach leaves. It can also be observed from these curves that, it is clearly evident that the drying time decreased with increase in drying air temperature. Therefore, experimental results showed that, the drying air temperature has effect on the removal of moisture content. Similar results were described by Doymaz (2006) for mint leaves. While drying the fenugreek leaves, it can also observed that, minimum time for drying of fenugreek leaves was recorded for fluidized bed drying at 70 °C and maximum time was recorded for open sun drying.

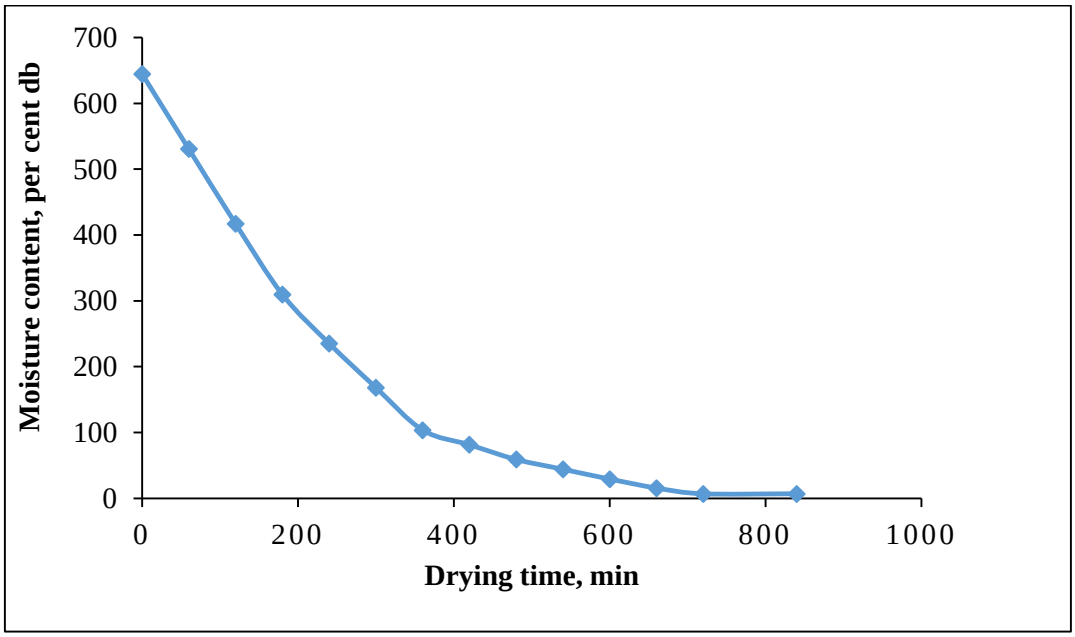

Fig 4.1 Variation in moisture content of fenugreek leaves in open sun drying

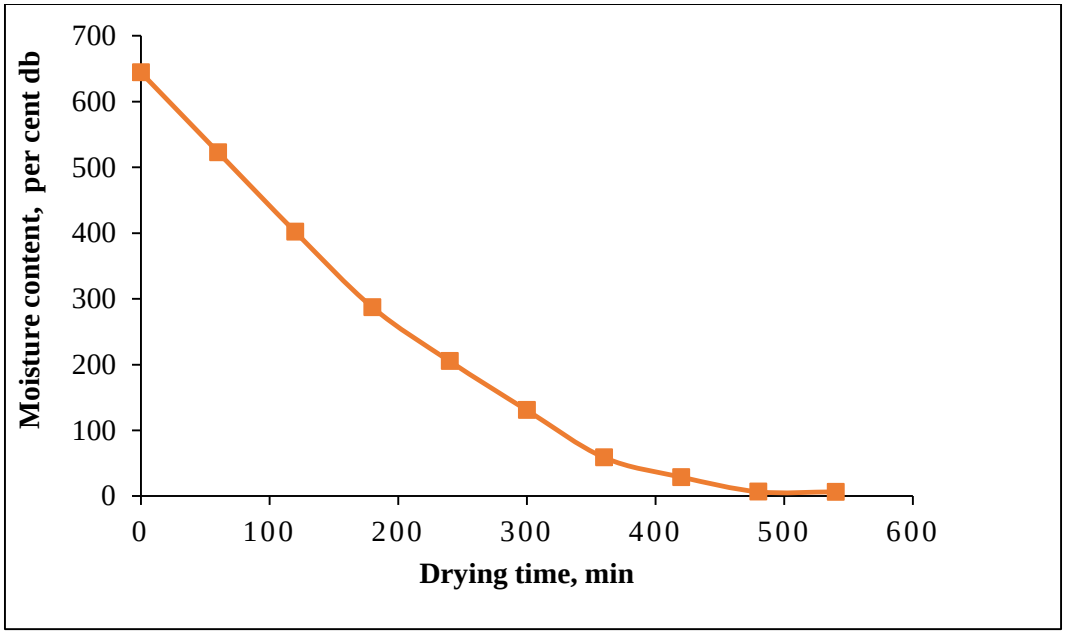

Fig. 4.2 Variation in moisture content of fenugreek leaves in solar cabinet drying

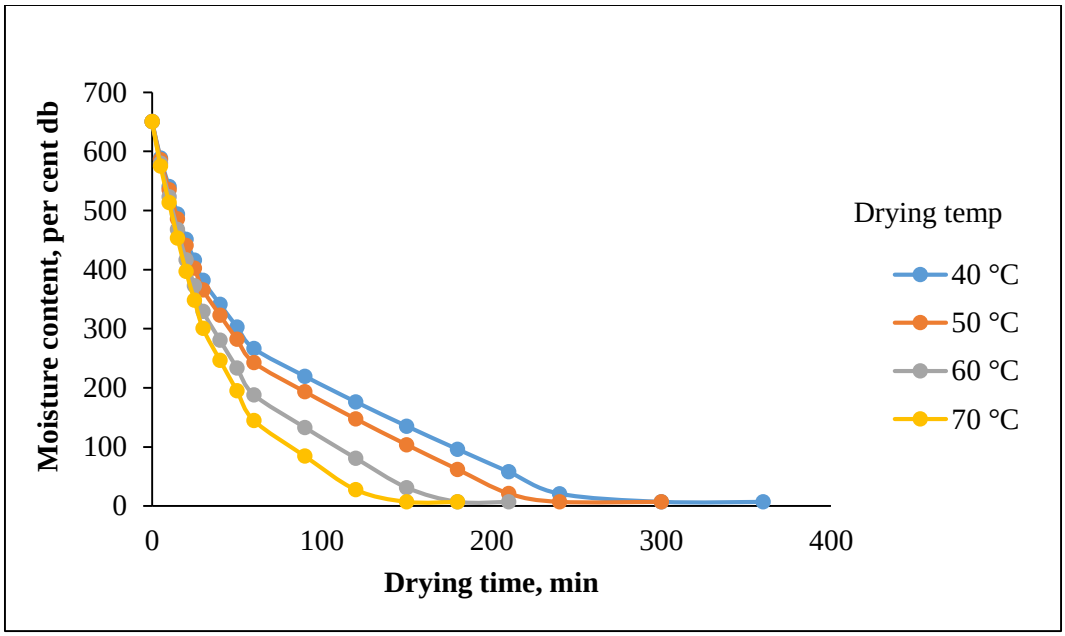

Fig. 4.3 Variation in moisture content of fenugreek leaves in mechanical tray drying

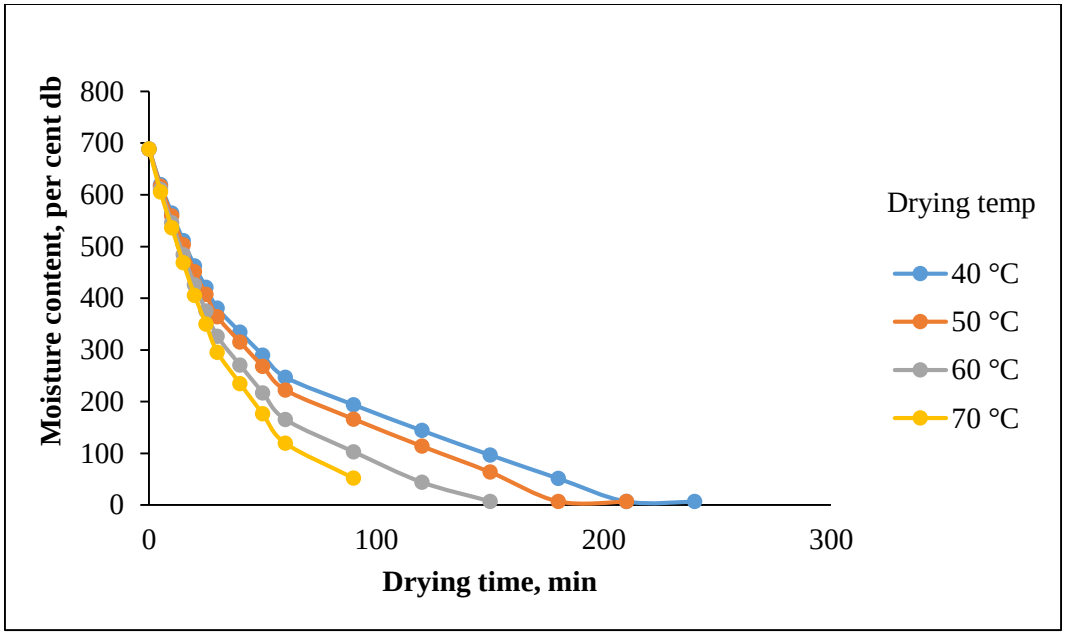

Fig. 4.4 Variation in moisture content of fenugreek leaves in fluidized bed drying

Table 4.2 Drying time required for drying of fenugreek leaves in different drying methods

Treatments	Drying Temperature (°C)	Drying time (min)
Open sun drying		840
Solar drying		540
Tray drying	40 ^{0}C	360
	50 ^{0}C	300
	60 ^{0}C	210
	70 ^{0}C	180
Fluidized bed drying	40 ^{0}C	240
	50 ^{0}C	210
	60 ^{0}C	180
	70 ^{0}C	150

4.2.2 Effect of different drying methods on drying rate of fenugreek leaves

The drying rate for the fenugreek leaves was estimated from the difference in its moisture loss in a known time interval and expressed as g of moisture evaporated per g of dry matter per min. The drying rate of fenugreek leaves under different drying

methods, OSD, SCD, MTD and FBD were calculated and plotted with moisture content presented in Fig. 4.5, Fig 4.6, Fig. 4.7 and Fig. 4.8 respectively.

From the figures, it can be seen that, the drying rate subsequently reduced with drying time. It can also be seen that, drying rate follow typical drying rate curves. The initial stage of drying rate for fenugreek leaves was ranged from 0.019 to 0.166 g-water/ g-DM-min among the drying methods. These drying rates continuously decreased with respect to time.

From the observation it can be seen that, a constant rate-drying period was not found in drying curves. The entire drying process took place in the falling rate period; the curves typically demonstrated smooth diffusion controlled drying behaviour for all drying methods. Moreover, an important influence of air drying temperature on drying rate could be observed in these curves. It is obvious from these curves that the higher the drying temperature, the greater the drying rate, so the highest values of drying rate were obtained during the experiment in fluidized bed drying at 70 ºC. These results are similar to the earlier studies outcomes of different vegetables (Akpinar, 2006; Doymaz, 2006; Doymaz *et al.*, 2006; Kadam *et al.*, 2011).

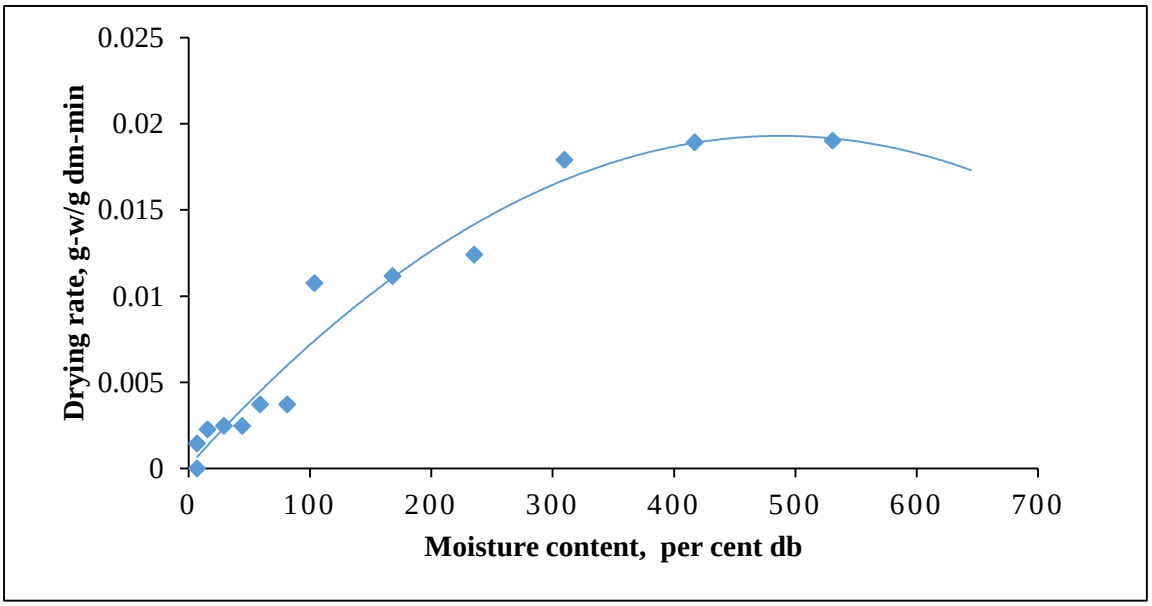

Fig 4.5 Variation in drying rate of fenugreek leaves in open sun drying

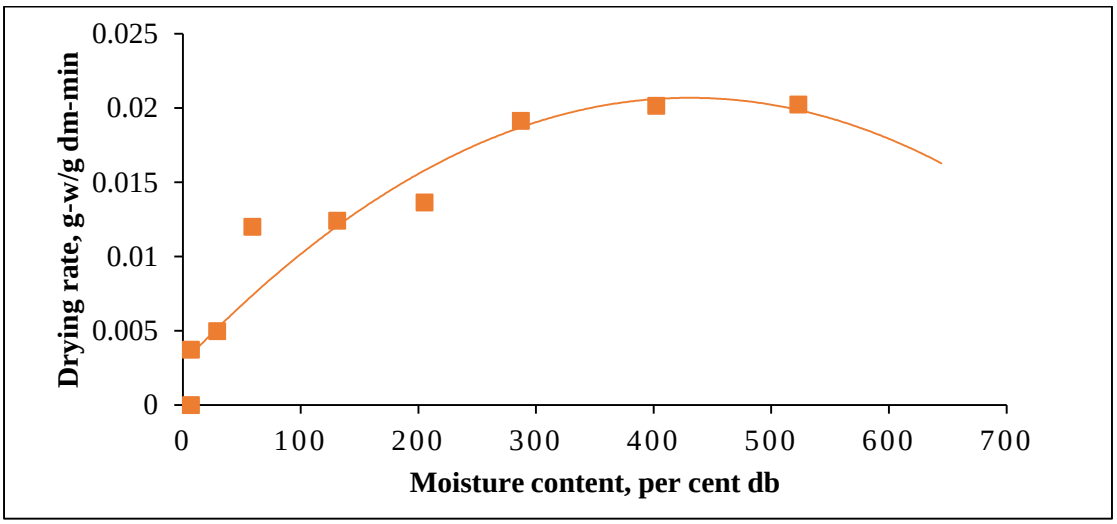

Fig 4.6 Variation in drying rate of fenugreek leaves in solar cabinet drying

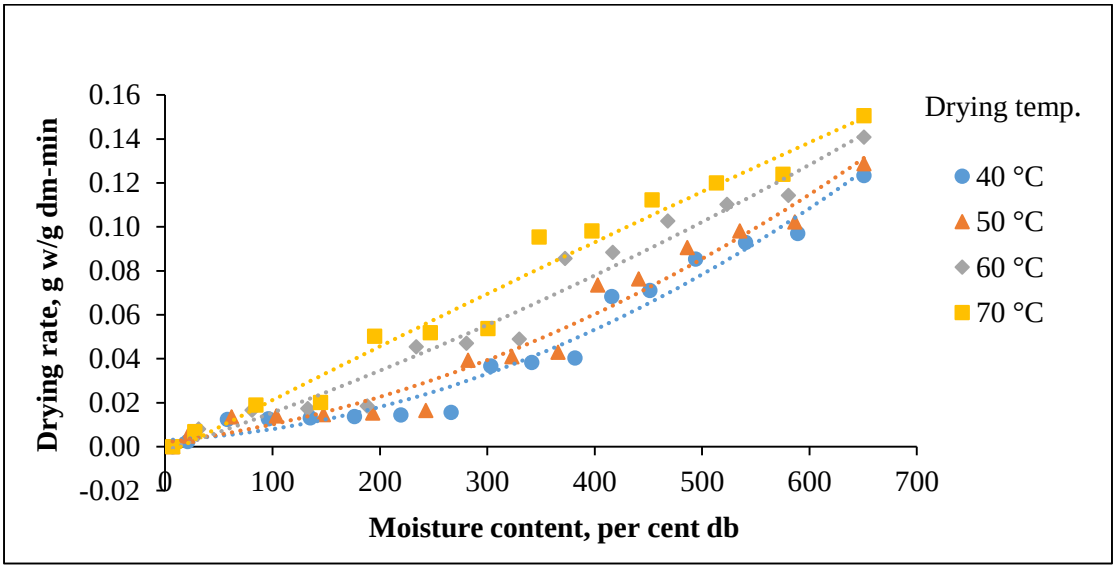

Fig 4.7 Variation in drying rate of fenugreek leaves in mechanical tray drying

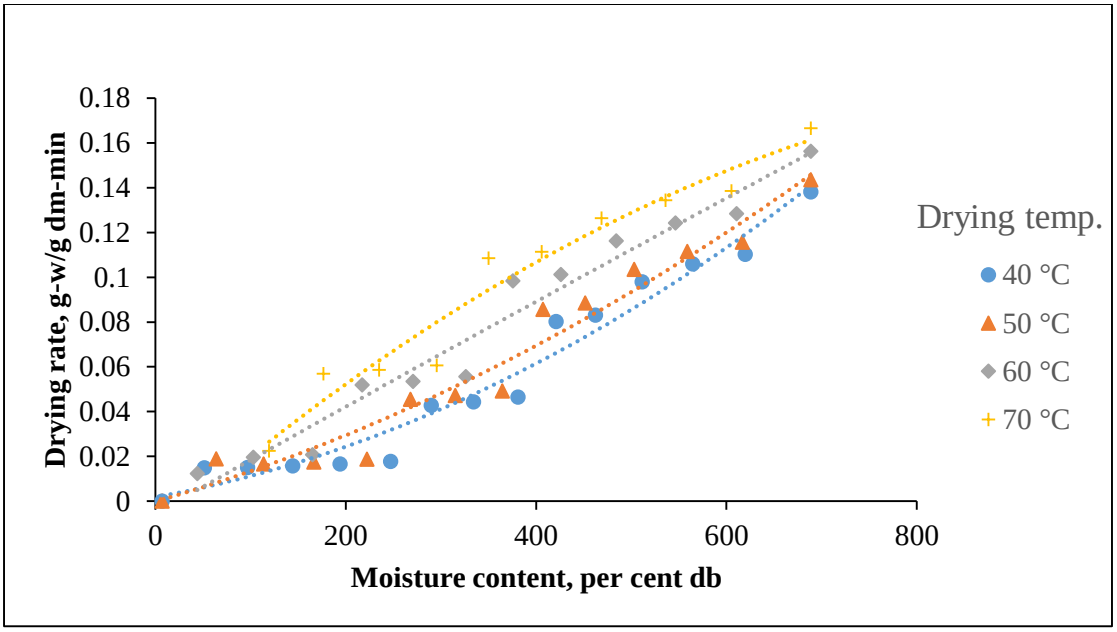

Fig 4.8 Variation in drying rate of fenugreek leaves in fluidized bed drying

A second order polynomial relationship was found to have fitted adequately to desirable variations in the drying rates with moisture content at all three experimental temperatures and is represented by Eqn. (4.1):

$$Y = ax^2 + bx + c \quad \text{... (4.1)}$$

Where, Y is the rate of drying in g water evaporated per g dry matter per min. a, b and c are constants and x is the moisture content in g water per g of dry matter. The predicted equations with their coefficient of determination values are presented in the Table 4.3. From the table, it can be seen that, values of regression coefficients (a, b and c) of the Eqn. (4.1) varies with variation in drying air temperature. It can also be seen from Table 4.3 that, the values of coefficient of determinations were more than 0.90 for all the experiments conducted which shows the data follows polynomial relation (II degree). Similar trend was also reported by various research workers for different food products such as for mushroom by Murumkar *et al*., (2007); for papaya by Jain *et al*., (2011) and for onion by Revaskar *et al.*, (2014).

Table 4.3 Drying rate equation with respect to moisture content (g-w/g dm-min)

Treatments		Equation	R^2
Tray drying	40 ^{0}C	$y = 2E\text{-}07x^2 + 4E\text{-}05x + 0.0005$	0.9854
	50 ^{0}C	$y = 4E\text{-}07x^2 - 4E\text{-}05x + 0.0053$	0.9854
	60 ^{0}C	$y = 3E\text{-}07x^2 + 3E\text{-}05x + 0.0034$	0.99
	70 ^{0}C	$y = 3E\text{-}07x^2 + 6E\text{-}05x + 0.0048$	0.969
Fluidized bed drying	40 ^{0}C	$y = 2E\text{-}07x^2 + 8E\text{-}05x + 0.0018$	0.966
	50 ^{0}C	$y = 1E\text{-}07x^2 + 0.0001x - 1E\text{-}04$	0.9635
	60 ^{0}C	$y = -9E\text{-}09x^2 + 0.0002x - 0.0055$	0.9631
	70 ^{0}C	$y = -2E\text{-}07x^2 + 0.0004x – 0.0156$	0.9524

4.2.3 Effect of different drying methods on moisture ratio of fenugreek leaves

The moisture ratio of fenugreek leaves under different drying methods, MTD and FBD were calculated and plotted in Fig 4.9 and Fig. 4.10 respectively. From the figure, it can be seen that, in mechanical tray drying the moisture ratio was varied from 1.00 to 0.023 in 240 min, 1.00 to 0.023 in 210 min, 1.00 to 0.039 in 150 min and 1.00 to 0.33 in 120 min at 40, 50, 60 and 70 °C respectively. Whereas in fluidized bed drying the moisture ratio was varied from 1.00 to 0.066 in 180 min, 1.00 to 0.084 in 150 min, 1.00 to 0.055 in 120 min and 1.00 to 0.067 in 90 min at 40, 50, 60 and 70 °C respectively.

The variation might be due to different drying air temperature. From the figure. It can be seen that, the moisture ratio reduced exponentially with the drying time. Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in heat supply rate to the leaves and the acceleration of moisture migration (Demir *et al.,* 2004). Experimental results showed that drying air temperature is effective parameter for the drying of fenugreek leaves. These results were in agreement with earlier research by Silva *et al.,* (2008) for coriander leaves and stems;

Aghbashlo *et al.*, (2009) for carrots; Premi *et al.*, (2010) for drum stick leaves and Porntewabancha and Siriwongwilaichat (2010) for lettuce leaves.

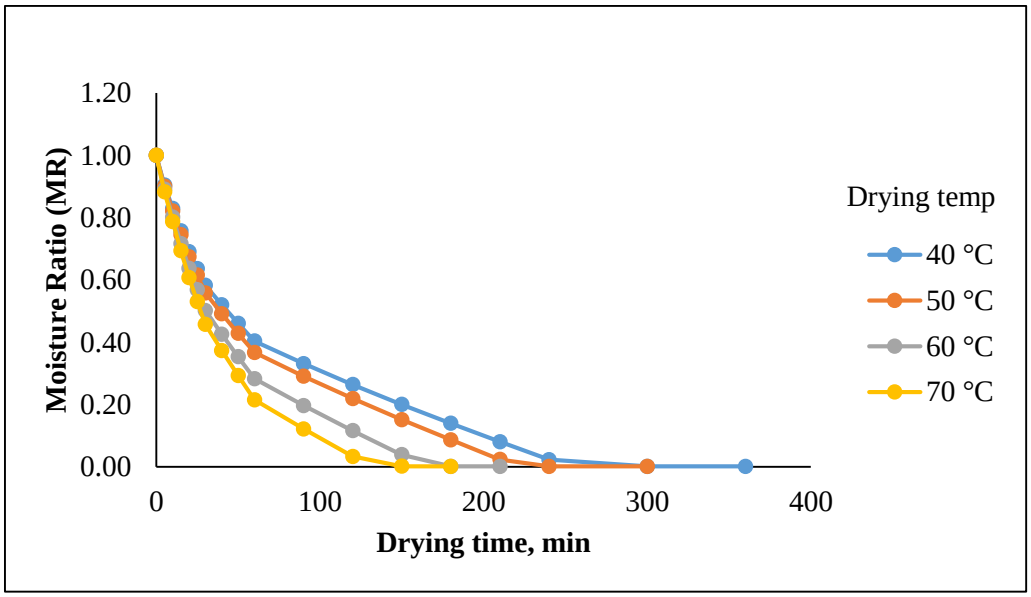

Fig. 4.9 Variation in moisture ratio of fenugreek leaves in mechanical tray drying

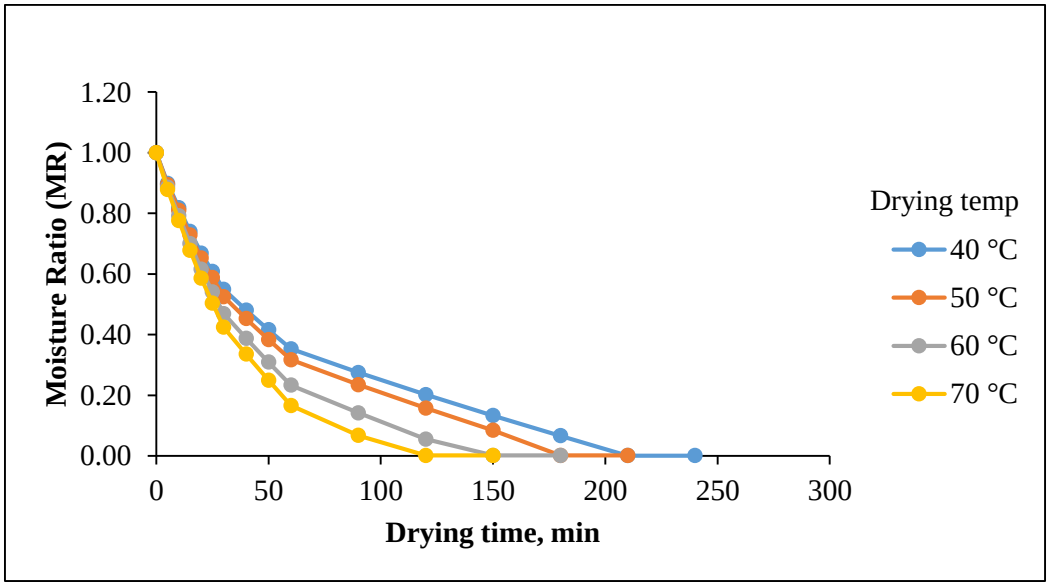

Fig. 4.10 Variation in moisture ratio of fenugreek leaves in fluidized bed drying

4.2.4 Mathematical modelling of drying of fenugreek leaves in different drying methods

Five different drying models namely, Newton, Logarithmic, Page, Diffusion approach and Henderson and Pabis models were selected and fitted to the drying data

based on their ability to model the drying phenomenon of fenugreek leaves. The drying constants and the statistical validity of models was evaluated in MATLAB 2018b Software package. The estimated values of statistical parameters *viz.*, standard square error (SSE), coefficient of determination (R^2) and root mean square error (RMSE) constant is shown in Table 4.4. Among these models, the best model suitable to fit the data was selected on basis of highest values of coefficient of determination (R^2) and the lowest value of standard square error (SSE) and root mean square error (RMSE), which were estimated by MATLAB 2018b Software package.

The statistical parameters for different models used for drying of fenugreek leaves have been presented in Table 4.4. From the table, it was observed that in all models the values of R^2 were greater than 0.99 indicating a good fit. The values of coefficient of determination (R^2) for diffusion approach model at all levels of temperatures were greater than 0.99 and the values of standard square error (SSE) and root mean square error (RMSE) were in range 0.001 to 0.008 and 0.011 to 0.024 respectively, which were lower than the rest of other. Hence, diffusion approach model was found to be the best suited model than the other models to represent the drying of fenugreek leaves. The selected diffusion approach model for fluidized bed drying studies was validated by comparing the predicted and observed values of moisture ratio in all drying experiments. The predicted and observed values of moisture ratio were plotted as shown in Fig 4.11. Similar result found by researches for earlier studies (Zakirpour *et al.*, 2011).

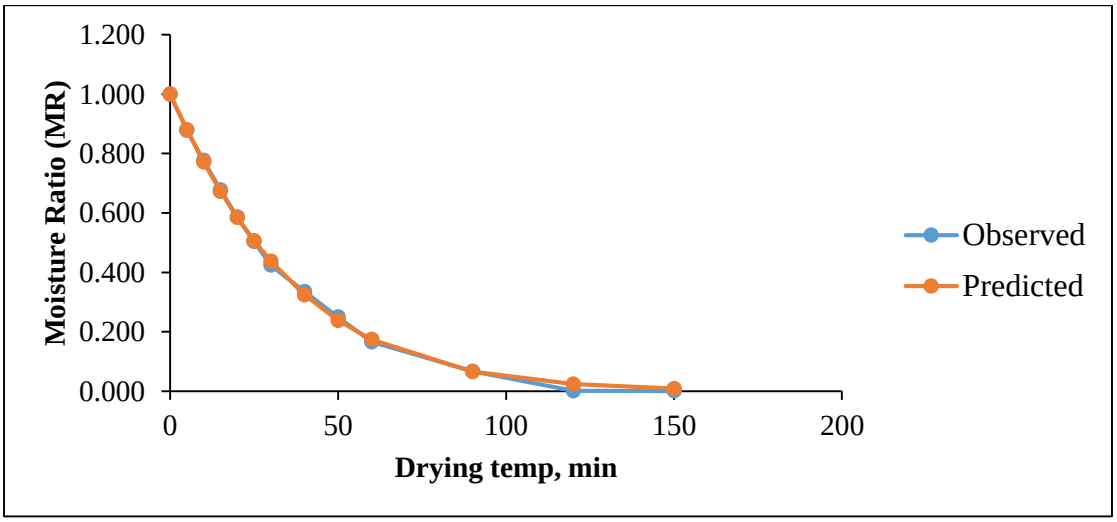

Fig. 4.11 Experimental and predicted values of moisture ratio by diffusion approach model for fluidized bed drying at 70 °C of fenugreek leaves

Table 4.4 Effect of different drying methods on drying constants and estimated values of statistical parameters of different drying models of fenugreek leaves

Name of the model	Drying method	Air temp (° C)	Drying constant					Statistical parameters		
			k	n	a	b	c	SSE	R^2	RMSE
Newton	MTD	40	0.015					0.042	0.976	0.050
		50	0.017					0.027	0.984	0.041
		60	0.021					0.006	0.996	0.021
		70	0.025					0.002	0.999	0.011
	FBD	40	0.017					0.022	0.986	0.039
		50	0.019					0.013	0.991	0.030
		60	0.024					0.002	0.999	0.012
		70	0.028					0.003	0.998	0.016
Logarithmic	MTD	40	0.014		0.913		0.027	0.025	0.986	0.041
		50	0.016		0.934		0.022	0.018	0.990	0.036
		60	0.021		0.979		0.004	0.005	0.997	0.021
		70	0.024		1.014		0.014	0.001	0.999	0.010
	FBD	40	0.017		0.939		0.024	0.016	0.990	0.035
		50	0.019		0.961		0.014	0.010	0.993	0.029
		60	0.023		1.006		0.010	0.002	0.999	0.013
		70	0.027		1.040		0.031	0.001	0.999	0.010
Page	MTD	40	0.033	0.799				0.011	0.994	0.027
		50	0.032	0.837				0.009	0.995	0.025
		60	0.028	0.930				0.004	0.998	0.017
		70	0.024	1.016				0.002	0.999	0.011
	FBD	40	0.031	0.852				0.009	0.994	0.025
		50	0.029	0.893				0.007	0.995	0.023
		60	0.025	0.993				0.002	0.999	0.013
		70	0.021	1.079				0.001	0.999	0.011

Name of the model	Drying method	Air temp (° C)	Drying constant					Statistical parameters		
			k	n	a	b	c	SSE	R^2	RMSE
Diffusion approach model	MTD	40	0.061		0.248	0.161		0.008	0.996	0.023
		50	0.062		0.229	0.194		0.007	0.996	0.023
		60	0.022		0.545	0.941		0.006	0.996	0.022
		70	0.239		0.011	0.107		0.002	0.999	0.012
	FBD	40	0.062		0.218	0.208		0.007	0.995	0.024
		50	0.062		0.183	0.251		0.006	0.996	0.022
		60	0.066		0.023	0.355		0.002	0.999	0.013
		70	0.044		1.357	0.817		0.001	0.999	0.011
Henderson and Pabis	MTD	40	0.013		0.929			0.027	0.985	0.041
		50	0.015		0.947			0.019	0.989	0.036
		60	0.021		0.982			0.005	0.997	0.020
		70	0.025		1.004			0.002	0.999	0.011
	FBD	40	0.954		0.016			0.017	0.989	0.034
		50	0.018		0.970			0.010	0.993	0.028
		60	0.024		0.999			0.002	0.999	0.013
		70	0.028		1.017			0.003	0.998	0.015

4.3 Effect of Different Drying Methods on Quality Characteristics of Dried Fenugreek Leaves

Quality characteristics *viz.,* proximate composition, rehydration ratio, colour and chemical properties of fenugreek leaves were determined and presented hereunder. The optimization of process methods were carried out in Design Expert software by general factorial method based on goal of response. The detailed results are presented hereunder.

4.3.1 Effect of different drying methods on proximate composition of dried fenugreek leaves

The proximate composition of dried fenugreek leaves *viz*., carbohydrates, crude protein, crude fiber, crude fat and total ash content of dried fenugreek leaves in different drying methods were analyzed. Open sun drying (OSD), solar cabinet drying (SCD), mechanical tray drying (MTD) and fluidized bed drying (FBD) were taken as different drying methods. The data obtained are presented in Table 4.5. The detailed results are presented hereunder.

Table 4.5 Effect of different drying methods on proximate composition of dried fenugreek leaves

Treatments	Proximate composition, per cent				
	Carbohydrates	Crude protein	Crude fiber	Crude fat	Total ash
T_1	58.53	16.64	8.01	5.25	2.06
T_2	57.32	18.33	8.15	5.13	2.11
T_3	57.67	17.03	8.08	5.16	2.09
T_4	57.32	18.32	8.22	5.10	2.13
T_5	57.28	19.73	8.41	4.83	2.16
T_6	57.15	20.63	8.53	4.63	2.18
T_7	55.81	18.03	8.32	4.94	2.11
T_8	55.43	20.04	8.46	4.75	2.15
T_9	55.32	20.84	8.55	4.53	2.17
T_{10}	55.18	21.76	8.67	4.43	2.19
T_1- OSD, T_2- SCD, T_3- MTD 40 °C, T_4- MTD 50 °C, T_5- MTD 60 °C, T_6- MTD 70 °C, T_7- FBD 40 °C, T_8- FBD 50 °C, T_9- FBD 60 °C and T_{10}- FBD 70 °C					

4.3.1.1 Effect of different drying methods on carbohydrates of dried fenugreek leaves

The effect of different drying methods on carbohydrate content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.5. From the data, it was observed that in open sun drying and solar cabinet drying, the carbohydrate content of dried fenugreek leaves was 58.53 and 57.32 per cent, respectively. Similarly in mechanical tray drying the carbohydrate content of dried fenugreek leaves was ranged from 57.15 to 57.67 per cent and in fluidized bed drying the carbohydrate content of dried fenugreek leaves was ranged from 55.18 to 55.81 per cent among the different drying methods.

Table 4.6 shows the analysis of variance (ANOVA) for carbohydrate content of dried fenugreek leaves. The model F-value of 64826.40 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.999 is in reasonable agreement with the "Adj R-Squared" value of 1.00. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 731.75 indicates an adequate signal. Hence, this model could be used to navigate the design space.

Table 4.6 Analysis of variance (ANOVA) for effect of different drying methods on carbohydrates of dried fenugreek leaves

Source	Sum of Squares	df	Mean Sum of Squares	F-Value	p-value Prob > F	Factor	Coeff. Est.	SE	95% CI Low	95% CI High
Model (Factorial)	36.52	9	4.058	64826.40	< 0.0001(S)	Intercept	56.70	0.001	56.70	56.71
A-Treatments	36.52	9	4.058	64826.40	< 0.0001	A[1]	1.82	0.004	1.81	1.83
Pure Error	0.001	20	0.0001			A[2]	0.61	0.004	0.60	0.62
Cor Total	36.52	29				A[3]	0.97	0.004	0.96	0.98
Std. Dev.	0.008					A[4]	0.62	0.004	0.61	0.63
Mean	56.703					A[5]	0.58	0.004	0.57	0.59
C.V. %	0.014					A[6]	0.45	0.004	0.44	0.46
PRESS	0.003					A[7]	-0.89	0.004	-0.90	-0.88
R-Squared	0.999					A[8]	-1.27	0.004	-1.28	-1.26
Adj R-Squared	0.999					A[9]	-1.38	0.004	-1.39	-1.37
Pred R-Squared	1.00									
Adeq Precision	731.76									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

The variation in carbohydrate content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.12. From the figure, it can be observed that, the highest carbohydrate content of 58.53 per cent was observed in open sun drying (T_1), whereas lowest carbohydrate content of 55.18 per cent was found in fluidized bed drying at 70 °C (T_{10}) among the treatments. The carbohydrate content decreased with the increase in drying air temperature. The variation in carbohydrate content might be due to the considerable loss in moisture content with increase in drying time and drying air temperature. Similar results have been reported by Alakali *et al.* (2015), Gernah and Sengev (2011) and Mensah *et al.* (2012) for moringa leaves.

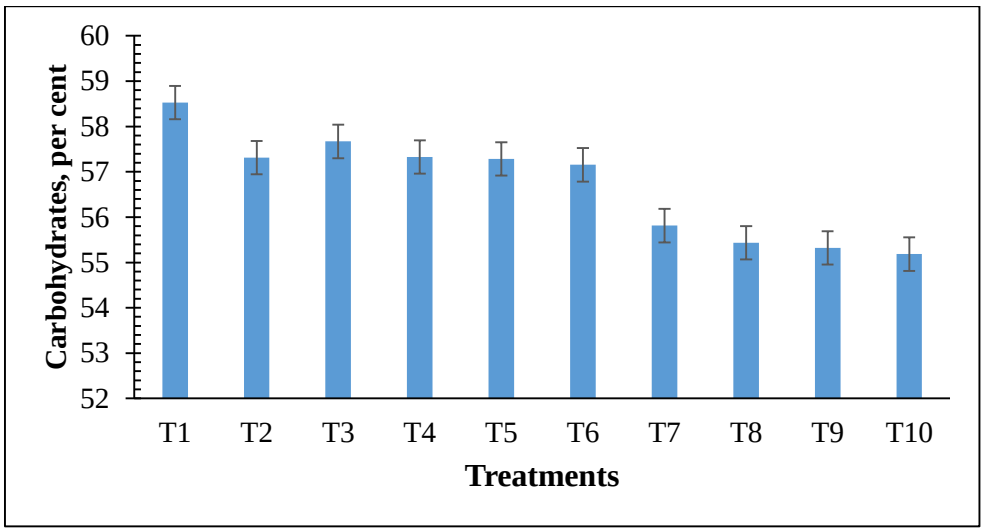

Fig. 4.12 Effect of different drying methods on carbohydrates of dried fenugreek leaves

4.3.1.2 Effect of different drying methods on crude protein content of dried fenugreek leaves

The effect of different drying methods on crude protein content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.5. From the data, it was observed that in open sun drying and solar cabinet drying, the crude protein content of dried fenugreek leaves was 16.64 and 18.33 per cent, respectively. Similarly in mechanical tray drying the crude protein content of dried fenugreek leaves was ranged from 17.3 to 20.63 per cent and in fluidized bed drying the crude protein content of dried fenugreek leaves was ranged from 18.03 to 21.76 per cent among the different drying methods.

Table 4.7 shows the analysis of variance (ANOVA) for crude protein content of dried fenugreek leaves. The model F-value of 12390.32 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 332.81 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in crude protein content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.13 From the figure, it can be observed that, the highest crude protein content of 21.76 per cent was observed in fluidized bed drying at 70 °C (T_{10}), whereas lowest crude protein content of 16.64 per cent was found in open sun drying (T_1) among the treatments. The crude protein content increased with the increase in drying air temperature. The increase in crude protein content might be due to the considerable loss in moisture content and increase in dry matter contents and also due to the denaturation of protein with increase in drying time and drying air temperature. Similar results have been reported by Alakali *et al.* (2015), Gernah and Sengev (2011) and Mensah *et al.* (2012) for moringa leaves.

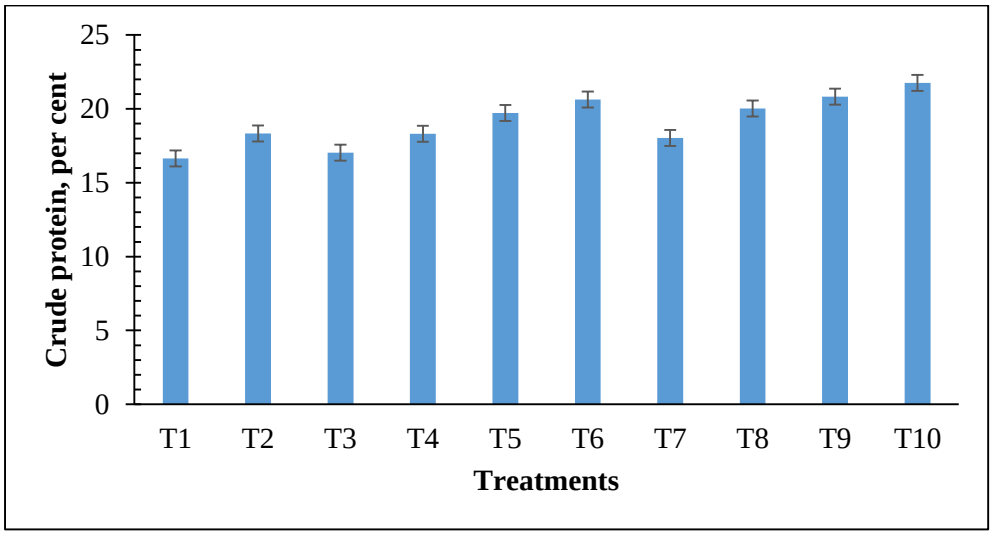

Fig. 4.13 Effect of different drying methods on crude protein content of dried fenugreek leaves

Table 4.7 Analysis of variance (ANOVA) for effect of different drying methods on crude protein content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	79.17	9	8.797	12390.32	< 0.0001(S)	Intercept	19.13	0.0049	19.12	19.14
A-Treatments	79.17	9	8.797	12390.32	< 0.0001	A[1]	-2.49	0.0146	-2.52	-2.46
Pure Error	0.01	20	0.001			A[2]	-0.80	0.0146	-0.83	-0.77
Cor Total	79.19					A[3]	-2.10	0.0146	-2.13	-2.07
Std. Dev.	0.03					A[4]	-0.82	0.0146	-0.85	-0.79
Mean	19.13					A[5]	0.60	0.0146	0.57	0.63
C.V. %	0.14					A[6]	1.50	0.0146	1.47	1.53
PRESS	0.03					A[7]	-1.11	0.0146	-1.14	-1.08
R-Squared	0.99					A[8]	0.90	0.0146	0.87	0.93
Adj R-Squared	0.99					A[9]	1.70	0.0146	1.67	1.73
Pred R-Squared	0.99									
Adeq Precision	332.81									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

4.3.1.3 Effect of different drying methods on crude fiber content of dried fenugreek leaves

The effect of different drying methods on crude fiber content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.5. From the data, it was observed that in open sun drying and solar cabinet drying, the crude fiber content of dried fenugreek leaves was 8.01 and 8.15 per cent, respectively. Similarly in mechanical tray drying the crude fiber content of dried fenugreek leaves was ranged from 8.08 to 8.53 per cent and in fluidized bed drying the crude fiber content of dried fenugreek leaves was ranged from 8.32 to 8.67 per cent among the different drying methods.

Table 4.8 shows the analysis of variance (ANOVA) for crude fiber content of dried fenugreek leaves. The model F-value of 1658.26 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 121.99 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in crude fiber content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.14. From the figure, it can be observed that, the highest crude fiber content of 8.67 per cent was observed in fluidized bed drying at 70 °C (T_{10}) whereas lowest crude fiber content of 8.01 per cent was found in open sun drying (T_1) among the treatments. The crude fiber content increased with the increase in drying air temperature. An increased temperature leads to breakage of weak bonds between polysaccharide chains. Also glycosidic linkages in the dietary fiber polysaccharides may be broken, lead to the loss in fiber content. The apparent increase in fiber content observed in this study could be due to removal of moisture which tends to increase the concentration of nutrients. Similar results have been reported by Alakali *et al.* (2015), Gernah and Sengev (2011) and Mensah *et al.* (2012) for moringa leaves.

Table 4.8 Analysis of variance (ANOVA) for effect of different drying methods on crude fiber content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	1.29	9	0.14	1658.26	< 0.0001(S)	Intercept	8.34	0.0017	8.34	8.34
A-Treatments	1.29	9	0.14	1658.26	< 0.0001	A[1]	-0.33	0.0051	-0.34	-0.32
Pure Error	0.002	20	0.0001	1658.26		A[2]	-0.19	0.0051	-0.20	-0.18
Cor Total	1.29	29				A[3]	-0.26	0.0051	-0.27	-0.25
Std. Dev.	0.009					A[4]	-0.12	0.0051	-0.13	-0.11
Mean	8.34					A[5]	0.07	0.0051	0.06	0.08
C.V. %	0.11					A[6]	0.18	0.0051	0.17	0.19
PRESS	0.004					A[7]	-0.02	0.0051	-0.03	-0.01
R-Squared	0.9987					A[8]	0.12	0.0051	0.11	0.13
Adj R-Squared	0.9981					A[9]	0.21	0.0051	0.20	0.22
Pred R-Squared	0.9970									
Adeq Precision	122.00									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

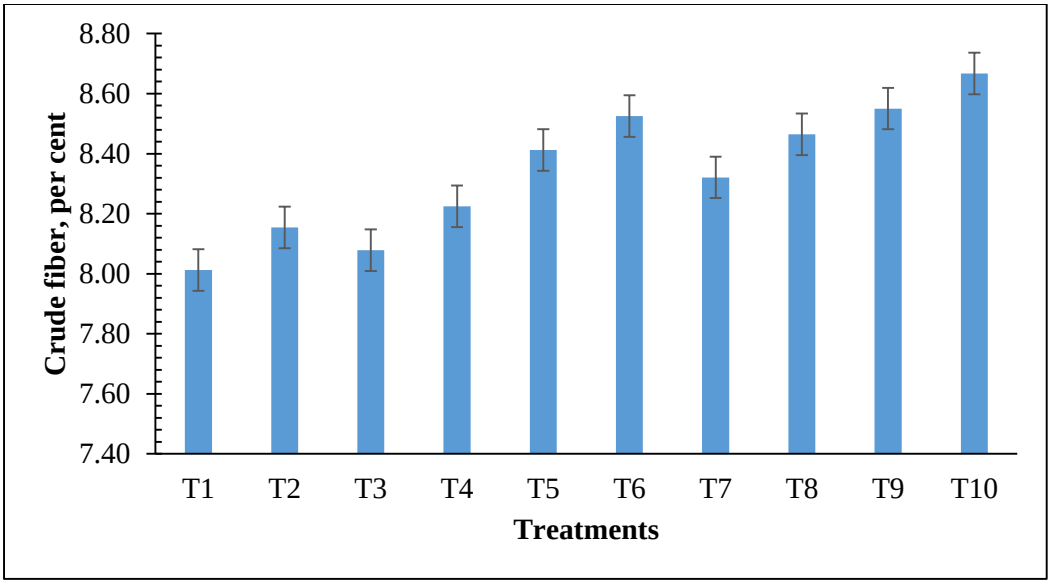

Fig. 4.14 Effect of different drying methods on crude fiber content of dried fenugreek leaves

4.3.1.4 Effect of different drying methods on crude fat content of dried fenugreek leaves

The effect of different drying methods on crude fat content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.5. From the data, it was observed that in open sun drying and solar cabinet drying, the crude fat content of dried fenugreek leaves was 5.25 and 5.13 per cent, respectively. Similarly in mechanical tray drying the crude fat content of dried fenugreek leaves was ranged from 4.63 to 5.16 per cent and in fluidized bed drying the crude fat content of dried fenugreek leaves was ranged from 4.43 to 4.95 per cent among the different drying methods.

Table 4.9 shows the analysis of variance (ANOVA) for crude fat content of dried fenugreek leaves. The model F-value of 1243.48 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 101.26 indicates an adequate signal. Hence, this model could be used to navigate the design space.

Table 4.9 Analysis of variance (ANOVA) for effect of different drying methods on crude fat content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	2.22	9	0.25	1243.48	< 0.0001(S)	Intercept	4.88	0.0026	4.87	4.88
A-Treatments	2.22	9	0.25	1243.48	< 0.0001	A[1]	0.37	0.0077	0.36	0.39
Pure Error	0.004	20	0.0002			A[2]	0.25	0.0077	0.24	0.27
Cor Total	2.22	29				A[3]	0.29	0.0077	0.27	0.30
Std. Dev.	0.01					A[4]	0.23	0.0077	0.21	0.24
Mean	4.88					A[5]	-0.04	0.0077	-0.06	-0.03
C.V. %	0.29					A[6]	-0.24	0.0077	-0.26	-0.23
PRESS	0.01					A[7]	0.06	0.0077	0.05	0.08
R-Squared	0.9982					A[8]	-0.13	0.0077	-0.14	-0.11
Adj R-Squared	0.9974					A[9]	-0.35	0.0077	-0.36	-0.33
Pred R-Squared	0.9960									
Adeq Precision	101.27									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

The variation in crude fat content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.15. From the figure, it can be observed that, the highest crude fat content of 5.25 per cent was observed in open sun drying (T_1), whereas lowest crude fat content of 4.43 per cent was found in fluidized bed drying at 70 °C (T_{10}) among the treatments. The crude fat content decreased with the increase in drying air temperature. The reduction in crude fat content might be due to the reduction in moisture content during drying resulted in increased nutrient content of the dried samples. Similar results have been reported by Alakali *et al.* (2015), Gernah and Sengev (2011) and Mensah *et al.* (2012) for moringa leaves.

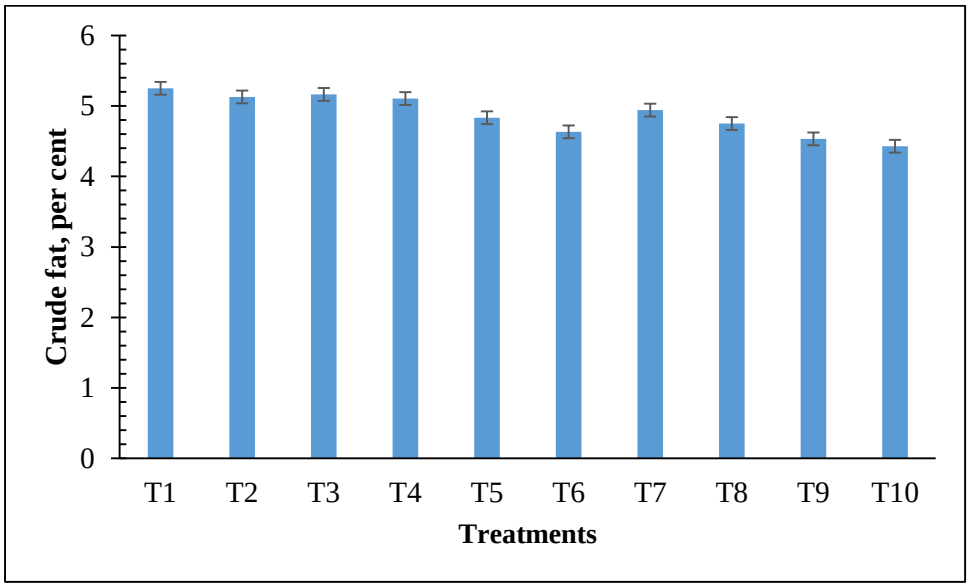

Fig. 4.15 Effect of different drying methods on crude fat content of dried fenugreek leaves

4.3.1.5 Effect of different drying methods on total ash content of dried fenugreek leaves

The effect of different drying methods on total ash content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.5. From the data, it was observed that in open sun drying and solar cabinet drying, the total ash content of dried fenugreek leaves was 2.06 and 2.11 per cent, respectively. Similarly in mechanical tray drying the total ash content of dried fenugreek leaves was ranged from 2.09 to 2.18 per cent and in fluidized bed drying the total ash content of dried fenugreek leaves was ranged from 2.11 to 2.19 per cent among the different drying methods.

Table 4.10 shows the analysis of variance (ANOVA) for total ash content of dried fenugreek leaves. The model F-value of 227.95 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.97 is in reasonable agreement with the "Adj R-Squared" value of 0.98. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 45.33 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in total ash content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.16. From the figure, it can be observed that, the highest total ash content of 2.19 per cent was observed in fluidized bed drying at 70 °C (T_{10}), whereas lowest total ash content of 2.06 per cent was found in open sun drying (T_1) among the treatments. The total ash content increased with the increase in drying air temperature. The increase in total ash content might be due to the considerable loss in moisture content with increase in drying time and drying air temperature. Similar results have been reported by Alakali *et al.* (2015), Gernah and Sengev (2011) and Mensah *et al.* (2012) for moringa leaves.

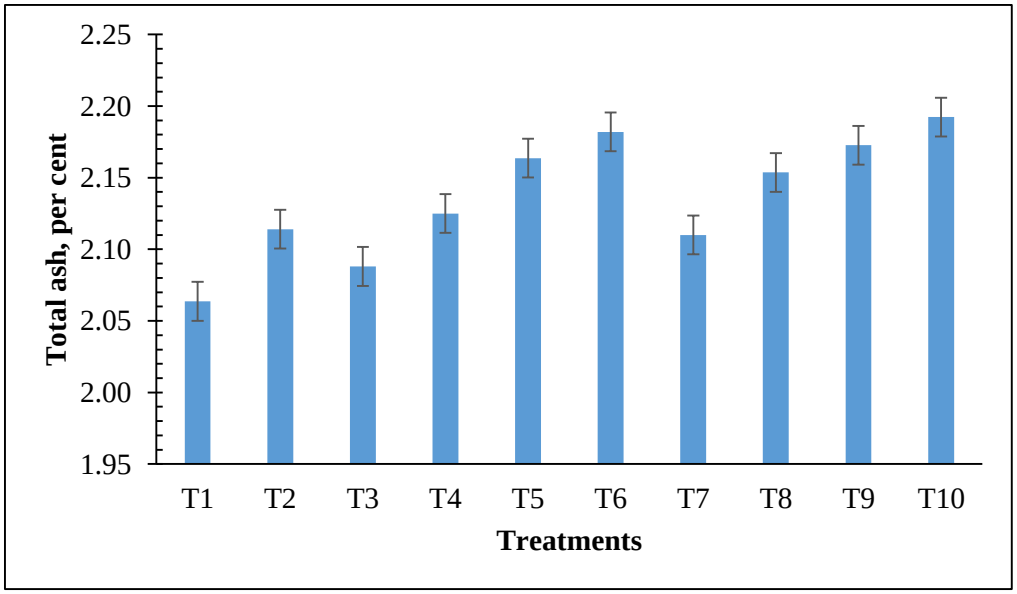

Fig. 4.16 Effect of different drying methods on total ash content of dried fenugreek leaves

Table 4.10 Analysis of variance (ANOVA) for effect of different drying methods on total ash content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	0.05	9	0.0055	227.95	< 0.0001(S)	Intercept	2.14	0.0009	2.13	2.14
A-Treatments	0.05	9	0.0055	227.95	< 0.0001	A[1]	-0.07	0.0027	-0.08	-0.07
Pure Error	0.0005	20	0.00002			A[2]	-0.02	0.0027	-0.03	-0.02
Cor Total	0.05	29				A[3]	-0.05	0.0027	-0.05	-0.04
Std. Dev.	0.005					A[4]	-0.01	0.0027	-0.02	-0.01
Mean	2.14					A[5]	0.03	0.0027	0.02	0.03
C.V. %	0.23					A[6]	0.05	0.0027	0.04	0.05
PRESS	0.001					A[7]	-0.03	0.0027	-0.03	-0.02
R-Squared	0.990					A[8]	0.02	0.0027	0.01	0.02
Adj R-Squared	0.986					A[9]	0.04	0.0027	0.03	0.04
Pred R-Squared	0.978									
Adeq Precision	45.33									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

4.3.2 Effect of different drying methods on rehydration ratio of dried fenugreek leaves

The effect of different drying methods on rehydration ratio of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.11. From the data, it was observed that in open sun drying and solar cabinet drying, the rehydration ratio of dried fenugreek leaves was 1.81 and 2.02 respectively. Similarly in mechanical tray drying the rehydration ratio of dried fenugreek leaves was ranged from 2.14 to 3.24 and in fluidized bed drying the rehydration ratio of dried fenugreek leaves was ranged from 2.85 to 3.36 among the different drying methods.

Table. 4.11 Effect of different drying methods on rehydration ratio of dried fenugreek leaves

Treatments		**Rehydration ratio**
Sun drying		1.81
Solar drying		2.02
Tray drying	40 ^{0}C	2.14
	50 ^{0}C	2.86
	60 ^{0}C	3.06
	70 ^{0}C	3.24
Fluidized bed drying	40 ^{0}C	2.85
	50 ^{0}C	3.06
	60 ^{0}C	3.22
	70 ^{0}C	3.36

Table 4.12 shows the analysis of variance (ANOVA) for rehydration ratio of dried fenugreek leaves. The model F-value of 1912.91 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 120.23 indicates an adequate signal. Hence, this model could be used to navigate the design space.

Table 4.12 Analysis of variance (ANOVA) for effect of different drying methods on rehydration ratio of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	8.44	9	0.94	1912.91	< 0.0001(S)	Intercept	2.76	0.004	2.75	2.77
A-Treatments	8.44	9	0.94	1912.91	< 0.0001	A[1]	-0.94	0.012	-0.96	-0.91
Pure Error	0.01	20	0.0005			A[2]	-0.74	0.012	-0.77	-0.72
Cor Total	8.45	29				A[3]	-0.63	0.012	-0.65	-0.60
Std. Dev.	0.022					A[4]	0.09	0.012	0.07	0.12
Mean	2.762					A[5]	0.29	0.012	0.27	0.32
C.V. %	0.801					A[6]	0.48	0.012	0.45	0.50
PRESS	0.022					A[7]	0.09	0.012	0.06	0.11
R-Squared	0.999					A[8]	0.29	0.012	0.27	0.32
Adj R-Squared	0.998					A[9]	0.46	0.012	0.44	0.49
Pred R-Squared	0.997									
Adeq Precision	120.24									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

The variation in rehydration ratio of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.17. From the figure, it can be observed that, the highest rehydration ratio of 3.36 was observed in fluidized bed drying at 70 °C (T_{10}), whereas lowest total rehydration ratio of 1.81 was found in open sun drying (T_1) among the treatments. The rehydration ratio increased with the increase in drying air temperature. The increase in rehydration ratio content might be due to change in texture or structure of sample by the treatment and temperature of drying. Similar results have been reported by Ahmed *et al.*, (2001) for coriander leaves and Porntewabancha and Siriwongwilaichat (2010) for lattice leaves.

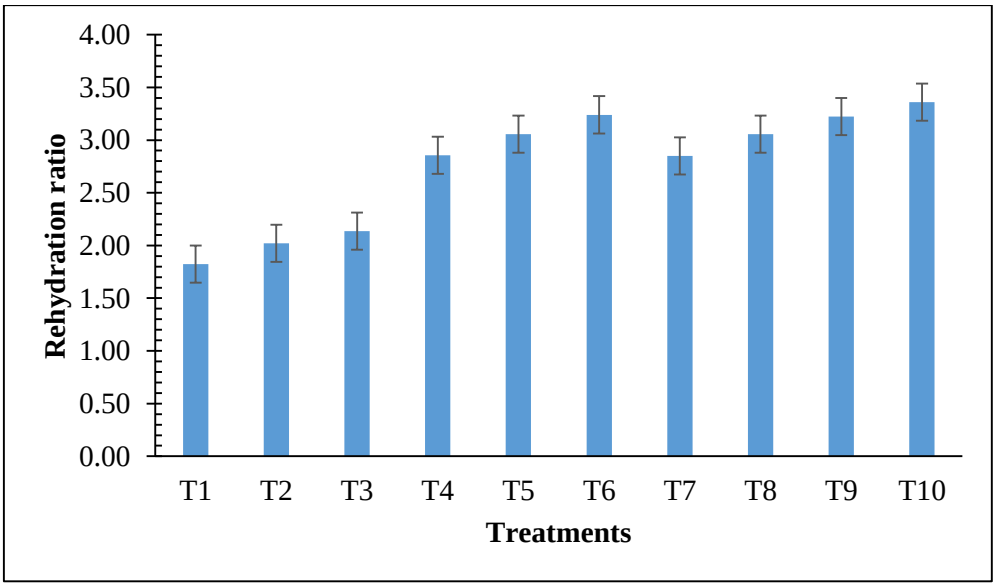

Fig. 4.17 Effect of different drying methods on rehydration ratio of dried fenugreek leaves

4.3.3 Effect of different drying methods on colour values of dried fenugreek leaves

Colour is often used as an indication of quality and freshness for food products. Hence it has become important for food processors to be able to evaluate and grade their products based on colour. Colour values were measured using a Hunter lab colorimeter. The colour values of dried fenugreek leaves *viz.*, *L** (Lightness), *a**(Greenness) and *b** (yellowness) were analyzed and presented in Table 4.13.

Table 4.13 Effect of different drying methods on colour values of dried fenugreek leaves

Treatments	Colour values		
	L*	***a****	***b****
T_1	38.73	-6.92	16.23
T_2	38.71	-6.96	16.42
T_3	38.69	-7.01	16.62
T_4	38.13	-6.83	15.65
T_5	35.45	-3.53	14.31
T_6	35.73	-4.01	14.47
T_7	35.67	-7.06	14.37
T_8	38.25	-6.05	14.26
T_9	37.73	-6.39	13.44
T_{10}	42.35	-6.97	15.48
T_1- OSD, T_2- SCD, T_3- MTD 40 °C, T_4- MTD 50 °C, T_5- MTD 60 °C, T_6- MTD 70 °C, T_7- FBD 40 °C, T_8- FBD 50 °C, T_9- FBD 60 °C and T_{10}- FBD 70 °C			

4.3.3.1 Effect of different drying methods on colour *L** value of dried fenugreek leaves

The effect of different drying methods on colour *L** value of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.13. From the data, it was observed that in open sun drying and solar cabinet drying, the colour *L** value of dried fenugreek leaves was 38.73 and 38.71 respectively. Similarly in mechanical tray drying the colour *L** value of dried fenugreek leaves was ranged from 35.73 to 38.69 and in fluidized bed drying the colour *L** value of dried fenugreek leaves was ranged from 35.67 to 42.35, among the different drying methods.

Table 4.14 shows the analysis of variance (ANOVA) for colour *L** value of dried fenugreek leaves. The model F-value of 1130.36 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 113.43 indicates an adequate signal. Hence, this model could be used to navigate the design space.

Table 4.14 Analysis of variance (ANOVA) for effect of different drying methods on colour *L values of dried fenugreek leaves**

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	112.92	9	12.55	1130.36	< 0.0001(S)	Intercept	37.94	0.019	37.90	37.98
A-Treatments	112.92	9	12.55	1130.36	< 0.0001	A[1]	0.79	0.058	0.67	0.91
Pure Error	0.22	20	0.01			A[2]	0.77	0.058	0.65	0.89
Cor Total	113.14	29				A[3]	0.75	0.058	0.63	0.87
Std. Dev.	0.11					A[4]	0.19	0.058	0.07	0.31
Mean	37.94					A[5]	-2.49	0.058	-2.61	-2.37
C.V. %	0.28					A[6]	-2.21	0.058	-2.33	-2.09
PRESS	0.50					A[7]	-2.27	0.058	-2.39	-2.15
R-Squared	0.998					A[8]	0.31	0.058	0.19	0.43
Adj R-Squared	0.997					A[9]	-0.21	0.058	-0.33	-0.09
Pred R-Squared	0.996									
Adeq Precision	113.44									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

The variation in colour *L** value of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.18. From the figure, it can be observed that, , the highest colour *L** value of 42.35 was observed in fluidized bed drying at 70 °C (T_{10}), whereas lowest colour *L** value of 35.73 was found in mechanical tray drying at 40 °C (T_5) among the treatments. The variation in colour *L** value might be due to chlorophyll degradation, the degree of color change was dependent on drying temperature and drying time. Similar results have been reported by Rudra *et al.,* (2008) for mint and coriander puree.

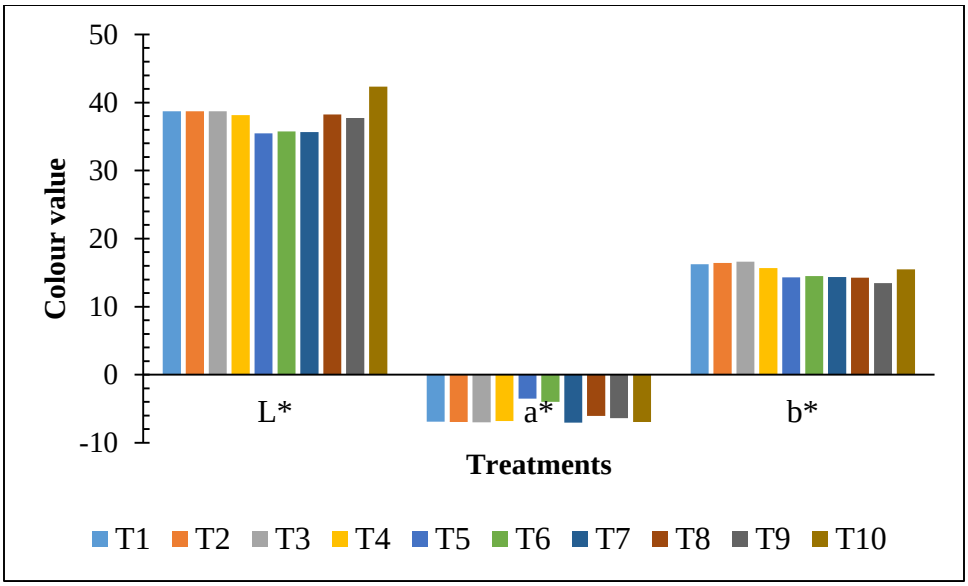

Fig 4.18 Effect of different drying methods on colour *L value of dried fenugreek leaves**

4.3.3.2 Effect of different drying methods on colour *a** value of dried fenugreek leaves

The effect of different drying methods on colour *a** value of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.13. From the data, it was observed that in open sun drying and solar cabinet drying, the colour *a** value of dried fenugreek leaves was -6.92 and -6.96 respectively. Similarly in mechanical tray drying the colour *a** value of dried fenugreek leaves was ranged from -3.53 to -7.01 and in fluidized bed drying the colour *a** value of dried fenugreek leaves was ranged from -6.05 to -7.06, among the different drying methods.

Table 4.15 shows the analysis of variance (ANOVA) for colour *a** value of dried fenugreek leaves. The model F-value of 464.20 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.98 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 58.03 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in colour *a** value of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.18. From the figure, it can be observed that, the highest colour *a** value of -7.06 was observed in fluidized bed drying at 40 °C (T_7), whereas lowest colour *a** value of -3.53 was found in mechanical tray drying at 60 °C (T_5) among the treatments. The variation in colour *a** value might be due to the chlorophyll degradation, the degree of color change was dependent on drying temperature and drying time. Similar results have been reported by Rudra *et al.,* (2008) for mint and coriander puree.

4.3.3.3 Effect of different drying methods on colour *b** value of dried fenugreek leaves

The effect of different drying methods on colour *b** value of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.13. From the data, it was observed that in open sun drying and solar cabinet drying, the colour *b** value of dried fenugreek leaves was 16.23 and 16.42 respectively. Similarly in mechanical tray drying the colour *b** value of dried fenugreek leaves was ranged from 14.31 to 16.62 and in fluidized bed drying the colour *b** value of dried fenugreek leaves was ranged from 13.44 to 15.48, among the different drying methods.

Table 4.16 shows the analysis of variance (ANOVA) for colour *b** value of dried fenugreek leaves. The model F-value of 229.97 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.97 is in reasonable agreement with the "Adj R-Squared" value of 0.98. "Adeq Precision" value measures the signal to noise ratio.

Table 4.15 Analysis of variance (ANOVA) for effect of different drying methods on colour *a values of dried fenugreek leaves**

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	46.37	9	5.15	464.20	< 0.0001(S)	Intercept	-6.17	0.019	-6.213	-6.133
A-Treatments	46.37	9	5.15	464.20	< 0.0001	A[1]	-0.75	0.058	-0.867	-0.627
Pure Error	0.22	20	0.01			A[2]	-0.79	0.058	-0.907	-0.667
Cor Total	46.60	29				A[3]	-0.84	0.058	-0.957	-0.717
Std. Dev.	0.11					A[4]	-0.66	0.058	-0.777	-0.537
Mean	-6.17					A[5]	2.64	0.058	2.523	2.763
C.V. %	1.71					A[6]	2.16	0.058	2.043	2.283
PRESS	0.50					A[7]	-0.89	0.058	-1.007	-0.767
R-Squared	0.995					A[8]	0.12	0.058	0.003	0.243
Adj R-Squared	0.993					A[9]	-0.22	0.058	-0.337	-0.097
Pred R-Squared	0.989									
Adeq Precision	58.03									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

Table 4.16 Analysis of variance (ANOVA) for effect of different drying methods on colour *b values of dried fenugreek leaves**

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	32.36	9	3.60	229.97	< 0.0001(S)	Intercept	15.13	0.023	15.08	15.18
A-Treatments	32.36	9	3.60	229.97	< 0.0001	A[1]	1.11	0.068	0.96	1.25
Pure Error	0.31	20	0.016			A[2]	1.30	0.068	1.15	1.44
Cor Total	32.67	29				A[3]	1.50	0.068	1.35	1.64
Std. Dev.	0.13					A[4]	0.53	0.068	0.38	0.67
Mean	15.13					A[5]	-0.82	0.068	-0.96	-0.67
C.V. %	0.83					A[6]	-0.66	0.068	-0.80	-0.51
PRESS	0.70					A[7]	-0.76	0.068	-0.90	-0.61
R-Squared	0.990					A[8]	-0.87	0.068	-1.01	-0.72
Adj R-Squared	0.986					A[9]	-1.69	0.068	-1.83	-1.54
Pred R-Squared	0.978									
Adeq Precision	44.05									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

A ratio greater than 4 is desirable. A ratio of 44.05 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in colour *b** value of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.13. From the figure, it can be observed that, the highest colour *b** value of 16.62 was observed in mechanical tray drying at 40 °C (T_3), whereas lowest colour *b** value of 13.44 was found in fluidized bed drying at 60 °C (T_9) among the treatments. The variation in colour *b** value might be due to the chlorophyll degradation, the degree of color change was dependent on drying temperature and drying time. Similar results have been reported by Rudra *et al.,* (2008) for mint and coriander puree.

4.3.4 Effect of different drying methods on chemical properties of dried fenugreek leaves

The chemical properties of dried fenugreek leaves *viz.*, β-carotene, ascorbic acid and chlorophyll content were analyzed and presented in Table 4.17.

Table 4.17 Effect of different drying methods on chemical properties of dried fenugreek leaves

Treatments	Chemical properties		
	β-carotene (µg/100g)	Ascorbic acid (mg/100g)	Chlorophyll (mg/100g)
T_1	5876.15	60.60	63.24
T_2	5618.49	61.60	65.74
T_3	5360.83	62.61	68.27
T_4	5024.81	55.44	55.28
T_5	4824.53	50.93	49.23
T_6	4911.31	48.50	53.58
T_7	4930.30	60.50	47.17
T_8	4876.27	53.62	48.99
T_9	5012.22	48.66	53.26
T_{10}	4901.42	46.63	56.78
T_1- OSD, T_2- SCD, T_3- MTD 40 °C, T_4- MTD 50 °C, T_5- MTD 60 °C, T_6- MTD 70 °C, T_7- FBD 40 °C, T_8- FBD 50 °C, T_9- FBD 60 °C and T_{10}- FBD 70 °C			

4.3.4.1 Effect of different drying methods on β-carotene content of dried fenugreek leaves

The effect of different drying methods on β-carotene content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.17. From the data, it was observed that in open sun drying and solar cabinet drying, the β-carotene content of dried fenugreek leaves was 5876.15 and 5618.49 µg/100g respectively. Similarly in mechanical tray drying the β-carotene content of dried fenugreek leaves was ranged from 4911.31 to 5360.83 µg/100g and in fluidized bed drying the β-carotene content of dried fenugreek leaves was ranged from 4901.42 to 5012.22 µg/100g, among the different drying methods.

Table 4.18 shows the analysis of variance (ANOVA) for β-carotene content of dried fenugreek leaves. The model F-value of 8805225.03 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 27356.10 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in β-carotene content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.19. From the figure, it can be observed that, the highest β-carotene content of 5876.15 µg/100g was observed in open sun drying (T_1), whereas lowest β-carotene content of 4824.53 µg/100g was found in mechanical tray drying at 50 °C (T_5) among the treatments. The variation in β-carotene content might be due to the increase in drying air temperatures. Similar results have been reported by Singh *et al.* (2006) for green leafy vegetables; and Olushola (2006) for moringa leaves.

4.3.4.2 Effect of different drying methods on ascorbic acid content of dried fenugreek leaves

The effect of different drying methods on ascorbic acid content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.17.

Table 4.18 Analysis of variance (ANOVA) for effect of different drying methods on β-carotene of dried fenugreek leaves

Source	Sum of Squares	df	Mean Sum of Squares	F-Value	p-value Prob > F	Factor	Coeff. Est.	SE	95% CI Low	95% CI High
Model (Factorial)	3513284.78	9	390364.98	88052250.03	< 0.0001(S)	Intercept	5133.63	0.012	5133.60	5133.66
A-Treatments	3513284.78	9	390364.98	88052250.03	< 0.0001	A[1]	742.52	0.036	742.44	742.59
Pure Error	0.089	20	0.004			A[2]	484.86	0.036	484.78	484.93
Cor Total	3513284.86	29				A[3]	227.20	0.036	227.12	227.27
Std. Dev.	0.067					A[4]	-108.82	0.036	-108.90	-108.75
Mean	5133.63					A[5]	-309.10	0.036	-309.18	-309.03
C.V. %	0.001					A[6]	-222.32	0.036	-222.40	-222.25
PRESS	0.200					A[7]	-203.33	0.036	-203.41	-203.26
R-Squared	0.99					A[8]	-257.36	0.036	-257.44	-257.29
Adj R-Squared	0.99					A[9]	-121.41	0.036	-121.49	-121.34
Pred R-Squared	0.99									
Adeq Precision	27356.11									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

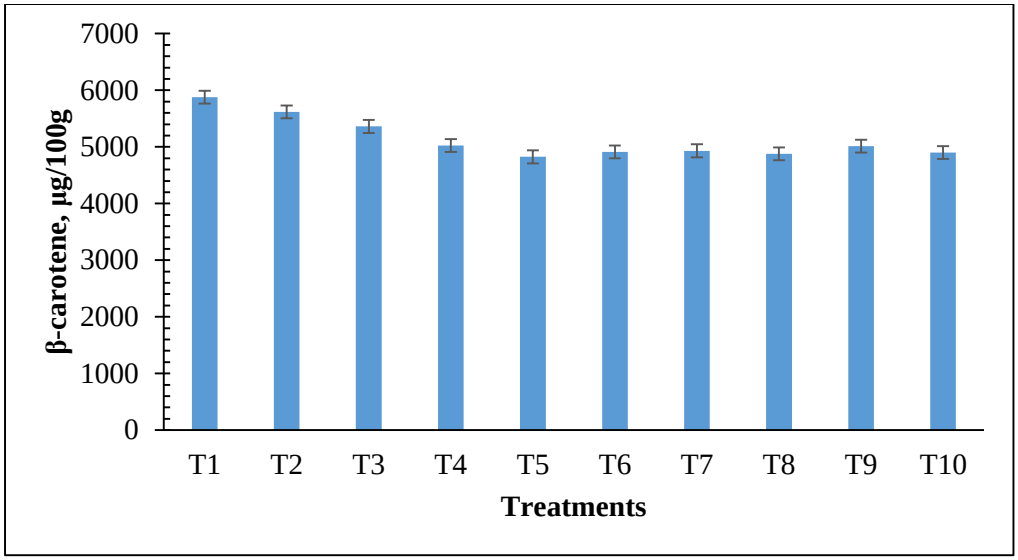

Fig.4.19 Effect of different drying methods on β-carotene of dried fenugreek leaves

From the data, it was observed that in open sun drying and solar cabinet drying, the ascorbic acid content of dried fenugreek leaves was 60.61 and 61.60 mg/100g respectively. Similarly in mechanical tray drying the ascorbic acid content of dried fenugreek leaves was ranged from 48.40 to 62.61 mg/100g and in fluidized bed drying the ascorbic acid content of dried fenugreek leaves was ranged from 46.63 to 60.50 mg/100g, among the different drying methods.

Table 4.19 shows the analysis of variance (ANOVA) for ascorbic acid content of dried fenugreek leaves. The model F-value of 528.57 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant. The "Pred R-Squared" value of 0.99 is in reasonable agreement with the "Adj R-Squared" value of 0.99. "Adeq Precision" value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 60.29 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in ascorbic acid content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.20. From the figure, it can be observed that, the highest ascorbic acid content of 62.61 mg/100g was observed in mechanical tray drying at 40 °C (T_3), whereas lowest ascorbic acid content of 46.63 mg/100g was found in fluidized bed drying at 70 °C (T_{10}) among the treatments.

Table 4.19 Analysis of variance (ANOVA) for effect of different drying methods on ascorbic acid content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	1002.32	9	111.37	528.57	< 0.0001(S)	Intercept	54.91	0.08	54.73	55.08
A-Treatments	1002.32	9	111.37	528.57	< 0.0001	A[1]	5.69	0.25	5.16	6.21
Pure Error	4.21	20	0.21			A[2]	6.69	0.25	6.17	7.22
Cor Total	1006.54	29				A[3]	7.70	0.25	7.18	8.23
Std. Dev.	0.46					A[4]	0.53	0.25	0.01	1.06
Mean	54.91					A[5]	-3.98	0.25	-4.50	-3.45
C.V. %	0.84					A[6]	-6.41	0.25	-6.93	-5.88
PRESS	9.48					A[7]	5.59	0.25	5.07	6.12
R-Squared	0.996					A[8]	-1.29	0.25	-1.81	-0.76
Adj R-Squared	0.994					A[9]	-6.25	0.25	-6.77	-5.72
Pred R-Squared	0.991									
Adeq Precision	60.30									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

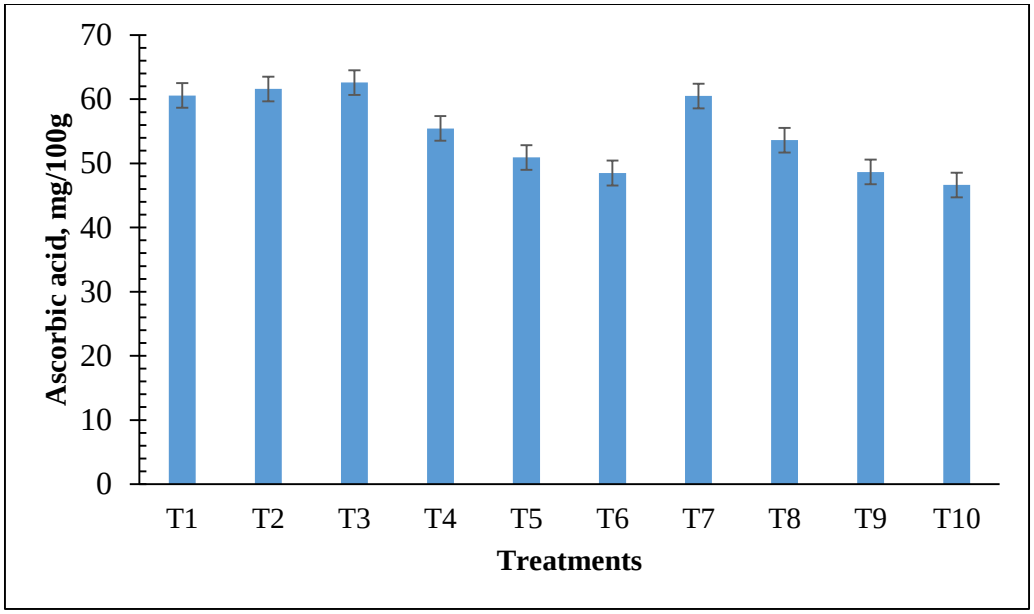

Fig. 4.20 Effect of different drying methods on ascorbic acid content of dried fenugreek leaves

The ascorbic acid content decreased with the increase in drying air temperature. The reduction in ascorbic acid content might be due to the increase in drying air temperatures. Similar results have been reported by Singh *et al.* (2006) for green leafy vegetables; and Olushola (2006) for moringa leaves.

4.3.4.3 Effect of different drying methods on chlorophyll content of dried fenugreek leaves

The effect of different drying methods on chlorophyll content of dried fenugreek leaves were determined and analyzed statistically and presented in Table 4.17. From the data, it was observed that in open sun drying and solar cabinet drying, the chlorophyll content of dried fenugreek leaves was 63.24 and 65.75 mg/100g, respectively. Similarly in mechanical tray drying the chlorophyll content of dried fenugreek leaves was ranged from 49.23 to 68.27 mg/100g and in fluidized bed drying the chlorophyll content of dried fenugreek leaves was ranged from 47.17 to 56.78 mg/100g among the different drying methods.

Table 4.20 shows the analysis of variance (ANOVA) for chlorophyll content of dried fenugreek leaves. The model F-value of 133.22 implies the model is significant. The values of "Prob > F" are less than 0.05 indicateing the model term A (Treatments) are significant. The values greater than 0.1 indicate the model terms are not significant.

Table 4.20 Analysis of variance (ANOVA) for effect of different drying methods on chlorophyll content of dried fenugreek leaves

Source	**Sum of Squares**	**df**	**Mean Sum of Squares**	**F-Value**	**p-value Prob > F**	**Factor**	**Coeff. Est.**	**SE**	**95% CI Low**	**95% CI High**
Model (Factorial)	1454.71	9	161.63	133.22	< 0.0001(S)	Intercept	56.16	0.201	55.74	56.57
A-Treatments	1454.71	9	161.63	133.22	< 0.0001	A[1]	7.08	0.603	5.82	8.34
Pure Error	24.27	20	1.21			A[2]	9.59	0.603	8.33	10.85
Cor Total	1478.98	29				A[3]	12.11	0.603	10.85	13.37
Std. Dev.	1.10					A[4]	-0.88	0.603	-2.13	0.38
Mean	56.16					A[5]	-6.93	0.603	-8.19	-5.67
C.V. %	1.96					A[6]	-2.57	0.603	-3.83	-1.31
PRESS	54.60					A[7]	-8.98	0.603	-10.24	-7.72
R-Squared	0.984					A[8]	-7.16	0.603	-8.42	-5.90
Adj R-Squared	0.976					A[9]	-2.89	0.603	-4.15	-1.63
Pred R-Squared	0.963									
Adeq Precision	33.17									
df- Degrees of freedom, SE- Standard error, Coeff. Est- Coefficient of estimate, CI- Confidence of interval, S- Significant										

The “Pred R-Squared” value of 0.96 is in reasonable agreement with the "Adj R-Squared" value of 0.97. “Adeq Precision” value measures the signal to noise ratio. A ratio greater than 4 is desirable. A ratio of 33.17 indicates an adequate signal. Hence, this model could be used to navigate the design space.

The variation in chlorophyll content of dried fenugreek leaves obtained by different drying methods are depicted in Fig. 4.21. From the figure, it can be observed that, the highest chlorophyll content of 68.27 mg/100g was observed in mechanical tray drying at 40 °C (T_3), whereas lowest chlorophyll content of 47.17 mg/100g was found in fluidized bed drying at 40 °C (T_7) among the treatments. The variation in chlorophyll content might be due to the temperature sensitivity of the pigment. Similar results have been reported by Ahmed *et al.* (2001) for coriander leaves.

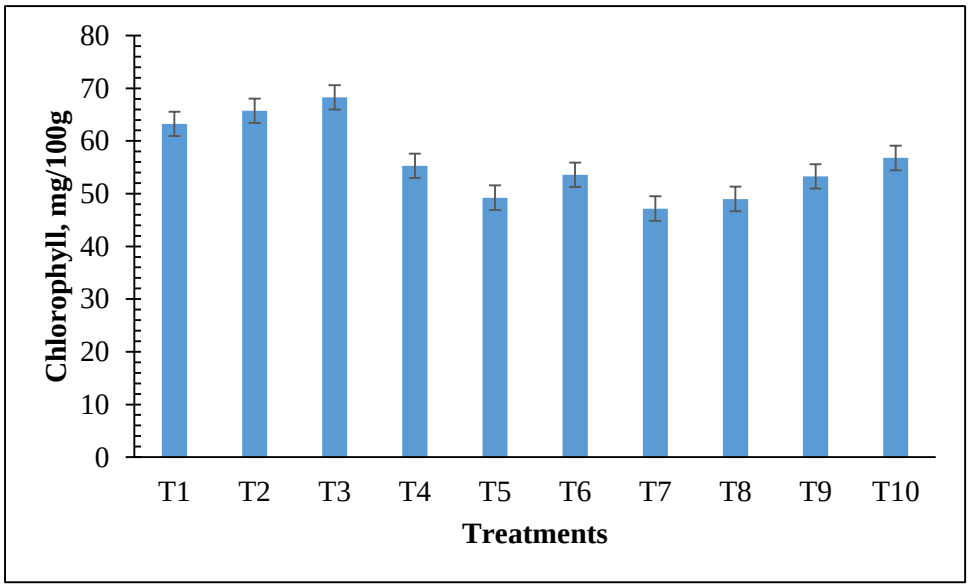

Fig. 4.21 Effect of different drying methods on chlorophyll content of dried fenugreek leaves

4.3.5 Effect of different drying methods on sensory characteristics of dried fenugreek leaves

Fenugreek leaves dried in different drying methods were served for the evaluation to twenty panelists at a time. The score sheet (Appendix C) was provided with product and panelists were requested to mark the product according to their liking. The sensory evaluation was carried out for colour, flavour, appearance and over all acceptability. The mean sensory score of dried fenugreek leaves sample are shown in Table 4.21. The detailed results are presented hereunder.

From the table, it can be observed that, the colour, flavor, appearance and over all acceptability scores were ranged from 5.5 to 8.5, 6.5 to 9, 5.5 to 7.5 and 6 to 8.3 respectively. Among the treatment, the highest over all acceptability score of 8.3 was observed for fluidized bed drying at 40 °C (T_7), whereas, lowest over all acceptability score of 6.0 was observed for mechanical tray drying at 60 °C (T_5) and 70 °C (T_6).

Table 4.21 Effect of different drying methods on sensory characteristics of dried fenugreek leaves

Treatments	Colour	Flavour	Appearance	Overall acceptability
T_1	7.5	7.0	6.5	7.0
T_2	7.0	7.3	7.0	7.1
T_3	7.5	7.5	6.5	7.2
T_4	6.5	7.5	6.5	6.8
T_5	5.5	6.5	6.0	6.0
T_6	5.5	7.0	5.5	6.0
T_7	8.5	9.0	7.5	8.3
T_8	7.5	8.5	7.5	7.8
T_9	7.0	8.0	6.5	7.2
T_{10}	6.5	7.5	6.5	6.8
T1- OSD, T2- SCD, T3- MTD 40 °C, T4- MTD 50 °C, T5- MTD 60 °C, T6- MTD 70 °C, T7- FBD 40 °C, T8- FBD 50 °C, T9- FBD 60 °C and T10- FBD 70 °C				

4.3.6 Optimization of process parameters for drying of fenugreek leaves

4.3.6 Optimization of process parameters for drying of fenugreek leaves

Optimization of different drying methods was performed using the general factorial design in Design Expert Software 7.7.0. Numerical optimization was performed using statistical models to find the optimal drying method. In the present investigation, the independent variables were kept within the range and dependent variables were chosen as maximum and minimum. Table 4.22 shows the process parameters and responses of fenugreek leaves achieved from General Factorial in Design Expert Software 7.7.0. The maximum desirability function obtained was taken as the optimum method for drying of fenugreek. The experimental sample had the optimum conditions of fluidized bed drying at 60 °C (T_9), with a desirability of 0.534 was found to be best drying method among the drying methods. Based on the data,

fluidized bed drying at 60 °C (T_9) was selected for the storage studies and development of fenugreek supplemented biscuits.

Table 4.22 Effect of different drying methods on optimization of fenugreek leaves

Parameter	Goal	Lower limit	Upper limit	Predicted value
Drying Methods	is in range	T1	T10	T9
Drying Temperature	is in range	40.00	70.00	60.00
Drying time	minimize	150.00	840.00	180.00
Final moisture content (% d.b)	minimize	6.24	6.64	6.49
Crude protein (%)	maximize	16.62	21.78	20.84
Crude fat (%)	minimize	4.41	5.26	4.53
Total ash (%)	maximize	2.06	2.19	2.17
Crude fiber (%)	maximize	8.01	8.68	8.55
Carbohydrates (%)	minimize	55.18	58.53	55.32
*L**	minimize	35.34	42.45	37.73
*a**	maximize	-7.16	-3.42	-6.39
*b**	minimize	13.32	16.75	13.44
β-carotene, µg/100g	maximize	4824.45	5876.19	5012.22
Ascorbic acid, mg/100g	maximize	46.25	63.12	48.66
Chlorophyll, mg/100g	maximize	46.04	69.34	53.26
Rehydration ratio	maximize	1.80	3.39	3.22

4.4 Effect of packaging materials and packaging methods on quality characteristics of selected dried fenugreek leaves during storage

Fenugreek leaves dried in fluidized bed drying at 60 °C were packed in low density polyethylene (LDPE 300 gauge) and polypropylene (PP 300 gauge) materials, normal packaging P_1, active packaging (Moisture absorber) P_2 and vacuum packaging P_3. Packed leaves was kept for 3 months storage at ambient conditions. The quality attributes *viz.*, storage weight gain and gas composition was determined with 15 days of interval. The results are presented hereunder.

4.4.1 Weight gain in storage

The variation in the storage weight of fenugreek leaves was presented in Table 4.23. From the table, it can be observed that, the storage weight gain of fenugreek leaves packed in LDPE was ranged from 0 to 1.53 per cent, whereas the storage weight gain of fenugreek leaves packed in PP was ranged from 0 to 1.41 per cent, among the

packaging methods during storage. The highest weight gain of 1.53 per cent was observed in LDPE (LP_1) at 90^{th} day of storage. Similarly the lowest weight gain of 1.37 per cent was observed in PP (PP_2) at 90^{th} day of storage. The weight gain of fenugreek leaves increased during the storage period, this might be due to absorption of moisture content from the atmosphere. Similar results have been reported by Tejib *et al.*, (2017) for dehydrated sapota packaged in MAP.

Table 4.23 Weight gain of dried fenugreek leaves during storage period

Packaging materials	Packaging method	Storage Period (days)						
		1^{th}	**15^{th}**	**30^{th}**	**45^{th}**	**60^{th}**	**75^{th}**	**90^{th}**
LDPE	**LP_1**	0	1.163	1.251	1.353	1.388	1.471	1.538
	LP_2	0	1.088	1.190	1.234	1.299	1.368	1.458
	LP_3	0	1.088	1.190	1.234	1.299	1.368	1.458
PP	**PP_1**	0	1.091	1.145	1.230	1.267	1.353	1.419
	PP_2	0	0.992	1.080	1.148	1.230	1.297	1.376
	PP_3	0	1.096	1.106	1.177	1.271	1.354	1.402
P_1- normal packaging, P_2- active packaging and P_3- Vacuum packaging								

The interaction between packaging materials (A), packaging methods (B) and storage period (C) on storage weight gain of fenugreek leaves were analysed statistically. The analysis of variance of storage weight gain in selected dried fenugreek leaves packed in different packaging materials during storage period is presented in Table 4.24. From the table, it is observed that, the increase in storage weight gain of dried fenugreek leaves during storage period differed significantly at 1 per cent level. The model F-value of 39976.35 implies the model is significant. The values of "Prob > F" less than 0.05 indicate model terms are significant. In this case A, B, C, AB, AC, BC, ABC are significant model terms.The "Pred R-Squared" of 0.99 is in reasonable agreement with the "Adj R-Squared" of 0.99. "Adeq Precision" measures the signal to noise ratio. A ratio of 665.70 indicates an adequate signal. Hence, as the ratio is greater than 4.0, this model can be used to navigate the design space.

Table 4.24 Analysis of variance (ANOVA) for weight gain of fenugreek leaves during storage period

Source	Sum of Squares	df	Mean Sum of Squares	F-value	p-value Prob > F
Model (Factorial)	26.24	41	0.640	39976.35	< 0.0001(S)
A-Packaging material	0.09	1	0.092	5767.68	< 0.0001
B-Packaging Method	0.12	2	0.058	3621.86	< 0.0001
C-Storage	25.89	6	4.315	269583.1	< 0.0001
AB	0.06	2	0.029	1810.07	< 0.0001
AC	0.02	6	0.003	171.02	< 0.0001
BC	0.05	12	0.004	239.94	< 0.0001
ABC	0.02	12	0.001	82.87	< 0.0001
Pure Error	0.001	84	0.00002		
Cor Total	26.24	125			
Std. Dev.	0.004		R-Squared		0.9999
Mean	1.08		Adj R-Squared		0.9999
C.V. %	0.37		Pred R-Squared		0.9999
PRESS	0.003		Adeq Precision		665.70

4.4.2 Gas composition (O_2)

The variation in gas composition the of fenugreek leaves was presented in Table 4.25. From the table, it can be observed that, the gas composition of fenugreek leaves packed in LDPE was ranged from 13.24 to 18.76 per cent, whereas the gas composition of fenugreek leaves packed in PP was ranged from 13.11 to 16.38 per cent, among the packaging methods during storage. The highest gas composition of 18.76 per cent was observed in LDPE (LP_1) at 90^{th} day of storage. Similarly the lowest gas composition of 15.52 per cent was observed in PP (PP_2) at 90^{th} day of storage. The gas composition of fenugreek leaves increased during the storage period, this might be due to absorption of moisture content and oxygen from the atmosphere. Similar results have been reported by Tejib *et al.,* (2017) for dehydrated sapota packaged in MAP.

The interaction between packaging materials (A), packaging methods (B) and storage period (C) on gas composition of fenugreek leaves were analysed statistically. The analysis of variance of gas composition in selected dried fenugreek leaves packed in different packaging materials during storage period is presented in Table 4.26.

Table 4.25 Gas composition (O_2) of dried fenugreek leaves during storage period

Packaging materials	Packaging method	Storage Period (days)						
		1th	15th	30th	45th	60th	75th	90th
LDPE	LP_1	15.38	16.27	17.02	18.06	17.77	18.43	18.76
	LP_2	15.52	14.76	15.79	15.68	15.98	16.37	17.15
	LP_3	13.21	14.82	13.91	13.87	15.92	15.84	16.04
PP	PP_1	15.22	14.82	14.90	15.59	15.33	16.09	16.38
	PP_2	15.43	12.85	13.60	13.96	14.59	14.95	15.52
	PP_3	13.11	14.91	14.13	14.54	15.42	16.09	16.04
P_1- normal packaging, P_2- active packaging and P_3- Vacuum packaging								

Table 4.26 Analysis of variance (ANOVA) for gas composition of fenugreek leaves during storage period

Source	Sum of Squares	df	Mean Sum of Squares	F-value	p-value Prob > F
Model (Factorial)	228.66	41	5.58	23.16	< 0.0001(S)
A-Packaging material	41.01	1	41.01	170.28	< 0.0001
B-Packaging Method	57.53	2	28.77	119.44	< 0.0001
C-Storage	64.07	6	10.68	44.34	< 0.0001
AB	24.39	2	12.20	50.64	< 0.0001
AC	3.18	6	0.53	2.20	< 0.0001
BC	32.67	12	2.72	11.30	< 0.0001
ABC	5.80	12	0.48	2.01	< 0.0001
Pure Error	20.23	84	0.24		
Cor Total	248.89	125			
Std. Dev.	0.491		R-Squared		0.9187
Mean	15.50		Adj R-Squared		0.8790
C.V. %	3.17		Pred R-Squared		0.8171
PRESS	45.520		Adeq Precision		20.86

From the table, it is observed that, the increase gas composition of dried fenugreek leaves during storage period differed significantly at 1 per cent level. The model F-value of 23.16 implies the model is significant. The values of "Prob > F" less than 0.05 indicate model terms are significant. In this case A, B, C, AB, AC, BC, ABC are significant model terms.The "Pred R-Squared" of 0.81 is in reasonable agreement

with the "Adj R-Squared" of 0.87. "Adeq Precision" measures the signal to noise ratio. A ratio of 20.85 indicates an adequate signal. Hence, as the ratio is greater than 4.0, this model can be used to navigate the design space.

4.5 Development of Fenugreek Supplemented Biscuits

The optimized (Fluidized bed drying at 60 °C) dried fenugreek leaves was used for the preparation of fenugreek supplemented biscuits, dried leaves were grounded into powder, the fenugreek leaves powder were used in different proportion 5, 10 and 15 per cent, for the development of fenugreek supplemented biscuits. The effect of different proportion of fenugreek leaves powder on, proximate composition, water activity, colour, textural and sensory characteristics of fenugreek supplemented biscuits were determined, data are also presented and discussed in the following sections:

4.5.1 Effect of different proportion of fenugreek leaves powder on proximate composition of fenugreek supplemented biscuits

Proximate composition *viz*., moisture content, crude fiber, total ash, crude protein, crude fat and carbohydrates of fenugreek supplemented biscuits were determined. The detailed results are presented hereunder.

The effect of different proportion of fenugreek leaves powder on proximate composition of fenugreek supplemented biscuits were determined and analyzed statistically and presented in Table 4.27. From the table, it was observed that, the moisture content of FSB was ranged from 1.58 to 1.88 per cent, whereas crude fiber content ranged from 0.86 to 2.86 per cent. Similarly total ash content was ranged from 2.05 to 5.97 per cent, whereas crude protein content was ranged from 5.87 to 10.77 per cent, the crude fat content was ranged from 24.76 to 28.08 per cent. Similarly the carbohydrate content was ranged from 54.35 to 62.15 per cent among the treatments.

The variation in the proximate composition of FSB were depicted in Fig. 4.22. From the figure, it can be seen that, the highest moisture content, fiber, ash and protein content of 1.88, 2.86, 5.97 and 10.77 per cent respectively, was found in $B_{3,}$ similarly the highest fat and carbohydrate content of 28.08 and 62.15 per cent respectively, was found in control sample, among the treatments. The moisture content, crude fiber content, total ash content crude protein content were increased with increase in FLP proportion as compare to control sample, whereas the crude fat content and

carbohydrate content were decreased with increase in FLP proportion among the treatments. Similar results were found in close agreement of Narsing *et al.,* (2017) for spinach supplemented biscuits.

Table 4.27 Effect of different proportion of fenugreek leaves powder on proximate composition of fenugreek supplemented biscuits

Formulation	Proximate composition, per cent					
	Moisture content	Crude fiber	Total ash	Crude protein	Crude fat	Carbohydrates
C	1.58	0.86	2.05	5.87	28.08	62.15
B_1	1.72	1.25	3.44	7.54	26.40	60.27
B_2	1.82	2.33	4.87	8.85	25.13	57.63
B_3	1.88	2.86	5.97	10.77	24.76	54.35
Std. Dev.	0.03	0.02	0.02	0.04	0.02	0.02
Mean	1.75	1.83	4.08	8.26	26.09	58.60
C.V. %	1.71	1.22	0.45	0.47	0.09	0.03
C-Control, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder						

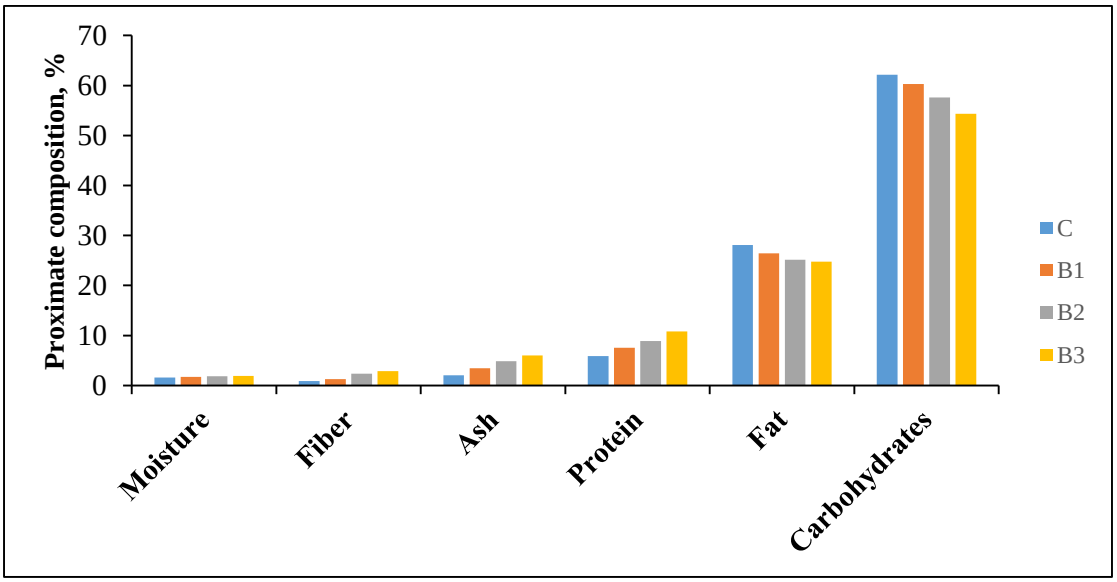

Fig. 4.22 Effect of different proportion of fenugreek leaves powder on proximate composition of fenugreek supplemented biscuits

4.5.2 Effect of different proportion of fenugreek leaves powder (FLP) on water activity of fenugreek supplemented biscuits (FSB)

The effect of different proportion of fenugreek leaves powder on water activity of fenugreek supplemented biscuits were determined and analyzed statistically and

presented in Table 4.28. From the table, it was observed that, the water activity of FSB was ranged from 0.35 to 0.39 among the treatments. The heights water activity of 0.39 was found in $B_{3,}$ whereas the lowest water activity of 0.35 was found in control sample, and also observed that, the water activity increased with increase in FLP levels. Similar results have been reported by Messay and Shimelis (2012) for mango seed kernels and wheat flour biscuits.

4.5.3 Effect of different proportion of fenugreek leaves powder (FLP) on colour values of fenugreek supplemented biscuits (FSB)

The effect of different proportion of fenugreek leaves powder (FLP) on colour values *L**, *a** and *b** of fenugreek supplemented biscuits (FSB) were presented in Table 4.28. From the table, it was observed that, the colour *L** value was ranged from 40.75 to 66.18, similarly colour *a** value was ranged from -0.62 to -11.86, whereas the colour *b** values was ranged from 4.45 to 33.93 among the treatments.

The variation in the colour values were depicted in Fig. 4.23. From the figure, it can be seen that, the highest colour *L**, *a** and *b** values of 66.18, 11.86 and 33.93 respectively, in control sample among the treatments, whereas the lowest colour *L**, *a** and *b** values of 40.75, 0.62 and 4.45 respectively, was found in $B_{3,}$ among the treatments. The colour values decreased with increase in the FLP levels. Similar results have been reported by Narsing *et al.,* (2017) for spinach supplemented biscuits.

4.5.4 Effect of different proportion of fenugreek leaves powder (FLP) on textural properties of fenugreek supplemented biscuits (FSB)

The effect of different proportion of fenugreek leaves powder (FLP) on hardness of fenugreek supplemented biscuits (FSB) was presented in Table 4.28. From the table, it was observed that, the hardness of FSB was ranged from 2137.00 g to 3433.33 g, and also observed that, the highest hardness of FSB was found to be 3433.33 g for B_3, whereas lowest hardness of FSB was found to be 2137.00 g for control sample among the treatments. The hardness increased with increase in the FLP levels. Similar results have been reported by Narsing *et al.,* (2017) for spinach supplemented biscuits.

Table 4.28 Effect of different proportion of fenugreek leaves powder on water activity, colour values and textural properties of fenugreek supplemented biscuits

Formulation	Water activity	Colour Values			Hardness, g
		L*	a*	b*	
C	0.35	66.18	11.86	33.93	2137.00
B_1	0.36	47.84	1.54	14.26	2394.67
B_2	0.37	42.07	0.43	5.57	2494.33
B_3	0.39	40.75	0.62	4.45	3433.33
Std. Dev.	0.015	0.09	0.02	0.03	3.20
Mean	0.37	49.21	3.61	14.55	2614.83
C.V. %	4.08	0.18	0.60	0.21	0.12
C- control, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder					

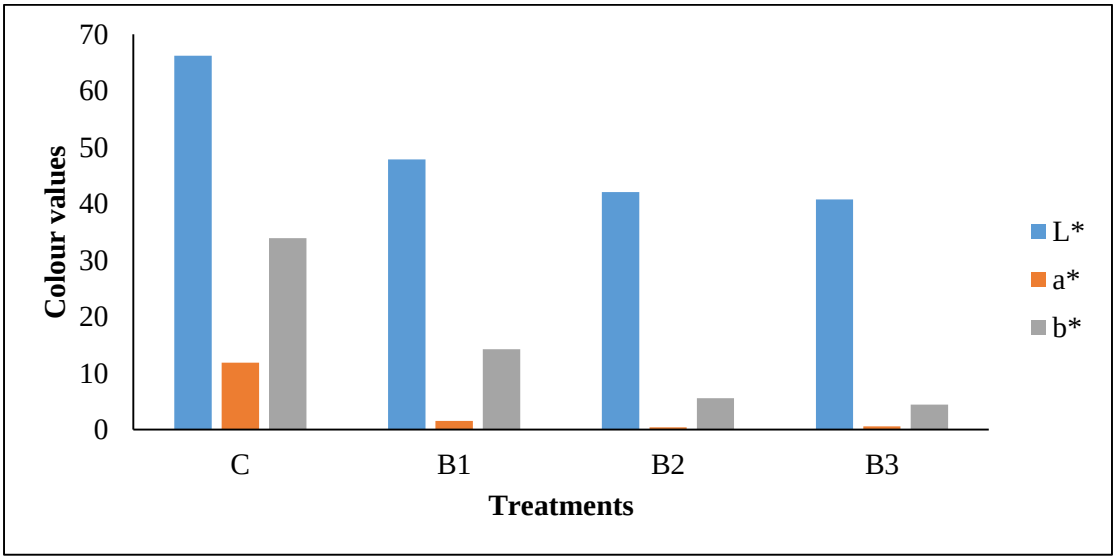

Fig 4.23 Effect of different proportion of fenugreek leaves powder on colour values of fenugreek supplemented biscuits

4.5.5 Effect of different proportion of fenugreek leaves powder (FLP) on sensory characteristics of fenugreek supplemented biscuits (FSB)

Fenugreek supplemented biscuits were served for the evaluation to twenty panelists at a time. The score sheet (Appendix D) was provided with product and panelists were requested to mark the product according to their liking. The sensory evaluation was carried out for appearance, colour, flavour, texture, taste and overall acceptability. The mean sensory score of dried fenugreek leaves sample are shown in Table 4.29. The detailed results are presented hereunder.

Table 4.29 Effect of different proportion of fenugreek leaves powder (FLP) on sensory characteristics of fenugreek supplemented biscuits (FSB)

Formulation	Sensory score					
	Appearance	Colour	Flavour	Texture	Taste	Overall acceptability
C	8.72	8.33	8.14	8.14	8.24	8.34
B_1	7.62	7.44	7.95	7.94	7.54	7.64
B_2	7.12	7.25	6.53	7.13	7.45	7.05
B_3	6.84	7.13	6.33	6.84	6.52	6.72
C- control, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder						

From the table, it can be observed that, appearance, colour, flavour, texture, taste and overall acceptability was ranged from 6.84 to 8.72, 7.13 to 8.33, 6.33 to 8.14, 6.84 to 8.14 and 6.52 to 8.24 respectively. Among the treatment, the highest overall acceptability score of 8.34 was observed for control sample, whereas, the lowest over all acceptability score of 6.52 for B_3. On the basis of sensory score, overall acceptability of 7.64 for 5 per cent fenugreek leaves powder (B_1) was best fenugreek supplemented biscuits among the different treatments.

4.5.6 Storage study

Fenugreek supplemented biscuits was kept for 30 days of storage at ambient conditions. The quality attributes *viz.,* water activity and hardness was determined with 15 days of interval. The results are presented hereunder.

4.5.6.1 Water activity

The variation in the water activity of fenugreek supplemented biscuit during storage was presented in Table 4.30. From the table, it can be seen that, the water activity of fenugreek supplemented biscuit was ranged from 0.35 to 0.432 among the treatments during storage period. The maximum water activity of 0.432 was observed in B_3 (%fenugreek powder) at 28^{th} day, among the samples during the storage period. Similarly the minimum water activity of 0.35 was observed in C (without fenugreek leaf powder). The water activity of fenugreek supplemented biscuit was increased during storage period. Similar results of increase in water activity have been reported by Mohammad *et al.* (2003) and Hathorn *et al*. (2008) for bread.

Table 4.30 Water activity of fenugreek supplemented biscuit during storage period

Formulation	Storage period, days				
	1st	7th	14th	21st	28th
C	0.350	0.359	0.372	0.384	0.392
B_1	0.360	0.369	0.382	0.390	0.398
B_2	0.370	0.379	0.392	0.400	0.412
B_3	0.390	0.399	0.412	0.420	0.432
C-without fenugreek powder, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder					

4.5.6.2 Hardness

The variation in the hardness of fenugreek supplemented biscuit during storage was presented in Table 4.31. From the table, it can be seen that, the hardness of fenugreek supplemented biscuit was ranged from 2137.00 to 3454.93 g among the treatments during storage period. The maximum hardness of 3454.93 g was observed in B_3 (%fenugreek powder) at 28th day, among the samples during the storage period. Similarly the minimum hardness of 2137.00 g was observed in C (without fenugreek leaf powder). The hardness of fenugreek supplemented biscuit was increased during storage period. Similar results of increase in hardness have been reported by Kadan *et al.* (2001) for bread during storage.

Table 4.31 Hardness (g) of fenugreek supplemented biscuit during storage period

Formulation	Storage period, days				
	1st	7th	14th	21st	28th
C	2137.00	2140.49	2143.60	2150.18	2158.60
B_1	2394.67	2398.16	2401.27	2407.85	2416.27
B_2	2494.33	2497.82	2500.93	2507.51	2515.93
B_3	3433.33	3436.82	3439.93	3446.51	3454.93
C- control, B_1- 5 % fenugreek powder, B_2- 10 % fenugreek powder and B_3- 15 % fenugreek powder					

CHAPTER V

SUMMARY AND CONCLUSION

Fenugreek (*Trigonella foenum-graecum*) constitutes a self-pollinated annual herbaceous legume, belongs to Fabaceae family and popularly known as Greek hay, bird's foot (Petropoulos, 2002) and methi. Fenugreek is supposed to be originated from southeastern Europe and western Asia. Presently, it is extensively cultivated in many parts of the world, including India, northern Africa and United States. Fresh or dried forms of fenugreek leaves are very popular kitchen herb due to its associated properties of pleasant flavor, powerful antioxidant properties, health promoting effects and antimicrobial activities.

Drying has the advantage of facilitating the conservation of foods, prolonging shelf-life and reducing the volume of the product, which facilitates and reduces costs of transportation, promoting physical-chemical stability and adding economic value to the final product (Akpinar 2006). Dehydrated leafy vegetables have the potential to become an important product because of relatively inexpensive, quickly cookable and rich in several nutrients which are essential for human health. Besides, dehydrated leafy vegetables have the great potential to use throughout the year.

Foods rich in protein and fiber are now preferred primarily by consumers to maintain their health and keep them away from many types of diseases such as cardiovascular disease, diabetes, weight gain, etc. Therefore, there is a new trend in the market to develop a product that combines health benefits with good sensory properties. Many health benefits, such as lowering cholesterol, reducing the level of the glycemic index, colon cancer, intestinal disorders and improving metabolism through the use of foods rich in dietary fiber. Hence, a research studies is taking up to study the drying, storage and packaging of fenugreek leafy vegetable. The present research work was carried out with following specific objectives.

1. To study the physico-chemical properties of fenugreek leaves
2. To study the drying characteristics of fenugreek leaves
3. To develop fenugreek supplemented biscuits
4. To study the quality of dried fenugreek leaves and fenugreek supplemented biscuits
5. To study the storage life of dried fenugreek leaves

The fresh fenugreek leaves were procured from local market of Naguar, Rajasthan. The fresh fenugreek leaves were sorted and separated from main branches. These leaves were used for study of drying and product development.

The mean values of physico-chemical properties of fresh fenugreek leaves *viz.*, leaf area, leaf thickness, and bulk density were found to be 3.81 cm^2, 0.31 mm and 0.0084 kg/m^3 respectively. Moisture content, carbohydrates, crude protein, crude fiber, crude fat and total ash content were found to be 86.28 per cent (w.b), 6.01 per cent, 4.27 per cent, 4.70 per cent, 0.90 per cent and 1.49 per cent respectively. The average β-carotene, chlorophyll and ascorbic acid content were found to be 6529.03 µg/100g, 98.41 mg/100g and 91.98 mg/100g respectively. The L^*, a^* and b^* were found to be 39.81, -8.71 and 17.50 respectively.

Fresh fenugreek leaves were dried under open sun drying (OSD), solar cabinet drying (SCD), mechanical tray drying (MTD) and fluidized bed drying (FBD) at 40, 50, 60 and 70 °C temperatures respectively. In case of MTD and FBD the air-flow rate of the drying air was kept at 2 m/s throughout the drying period.

There was a wide variation in drying time from 540 to 840, 180 to 360 and 150 to 240 min for sun, solar, tray and fluidized bed dryer respectively. Minimum drying time was observed for higher air temperature of 70 °C for mechanical tray and fluidized bed dryer.

The entire drying process took place in the falling rate period. Higher the drying temperature, greater the drying rate, hence the highest values of drying rate were obtained during experiments at 70 °C for mechanical tray and fluidized bed dryer. The moisture ratio decreased as the drying time increased.

For best drying model selection, drying curves were fitted to five selected and well known drying models *viz.,* Newton model, Page model, Logarithmic model, Diffusion approach model and Henderson and Pabis models were selected. The goodness of fit was determined using 3 parameters: highest value of coefficient of determination (R^2) and the lowest values of standard square mean (SSE) and root mean square error (RMSE) were obtained from the MATLAB version 2018b software package. Among the models diffusion approach model for fluidized bed drying was found the most satisfactory than any other models to represent the drying of fenugreek leaves.

Optimization of different drying methods was performed using the general factorial design in Design Expert Software 7.7.0. Numerical optimization was performed using statistical models to find the optimal drying method.

Fenugreek leaves dried in fluidized bed drying at 60 °C were packed in low density polyethylene (LDPE 300 gauge) and polypropylene (PP 300 gauge) materials, normal packaging P_1, active packaging (Moisture absorber) P_2 and vacuum packaging P_3. Packed leaves was kept for 3 months storage at ambient conditions.

The highest moisture content, fiber, ash and protein content of 1.88, 2.86, 5.97 and 10.77 per cent respectively, were found in B_3 and the highest fat and carbohydrate content of 28.08 and 62.15 per cent respectively, were found in control sample (C). The highest colour L^*, a^* and b^* values of 66.18, 11.86 and 33.93 respectively were found in control sample (C). The highest water activity of 0.39 and hardness of 3433.33 g were found in B_3.The highest overall acceptability score of 8.34 was found for control sample (C).

The optimized (Fluidized bed drying at 60 °C) dried fenugreek leaves was used for the preparation of fenugreek supplemented biscuits, dried leaves were grounded into powder, the fenugreek leaves powder were used in different proportion 5, 10 and 15 per cent, for the development of fenugreek supplemented biscuits.

These biscuits were packed in MPP and kept for 1 month of storage. The maximum water activity of 0.432 and hardness of 3454.93 g were found in B_3 during storage period.

Important conclusions drawn from the present investigation are given below:

1. The quality characteristics of dried fenugreek leaves *viz.,* carbohydrates (58.53 per cent) and crude fat (5.25 per cent) were found to be high in open sun drying (T_1). The maximum of crude protein (21.76 per cent), crude fiber (8.67 per cent) and total ash (2.19 per cent) were found in fluidized bed drying at 70 °C (T_{10}).
2. The rehydration ratio of 3.36 were found to be highest in fluidized bed drying at 70 °C (T_{10}).
3. In case of colour values *viz.,* colour L^* value of 42.35 were found to be highest in fluidized bed drying at 70 °C (T_{10}). Colour a^* value of -7.06 were found to

be highest in fluidized bed drying at 40 °C (T_7) and colour b^* value of 16.62 were found to be maximum in mechanical tray drying 40 °C (T_3).

4. The maximum of β-carotene (5876.15 µg/100 g) were found in open sun drying (T_1). Ascorbic acid (62.61 mg/100g) and chlorophyll (68.27 mg/100g) were found to be high in mechanical tray drying 40 °C (T_3).
5. The sensory evaluation was carried out for colour, flavour, appearance and over all acceptability. The highest over all acceptability score of 8.3 were found in fluidized bed drying at 40 °C (T_7).
6. Among the rang of variables taken for sun, solar, tray and fluidized bed drying of fenugreek leaves, the sample dried at 60 °C in fluidized bed dryer was found optimum in terms of response *viz.*, drying time (180 min), final moisture content (6.49 % w.b), L* (37.73), a* (-6.39), b* (13.44), β-carotene (5012.21µg/100g), Ascorbic acid (48.66 mg/100g) and chlorophyll (53.26 mg/100g).
7. Among the packaging condition, fenugreek leaves packed in PP (300 gauge) with active packaging was found best during three months of storage period with lowest gain of storage weight (1.37 per cent) and less respiration rate (15.52 per cent).
8. Among the fenugreek supplemented biscuits with 5 per cent fenugreek powder found best *viz.*, moisture content (1.75 per cent), carbohydrates (60.27 per cent), L* (47.96), a*(1.52), b*(14.26), hardness (2395 g), overall acceptability (7.66) as compared with control sample.

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ABSTRACT

Fenugreek (*Trigonella foenum-graecum*) constitutes a self-pollinated annual herbaceous legume, belongs to Fabaceae family. Fresh or dried forms of fenugreek leaves are very popular kitchen herb due to its associated properties of pleasant flavor, powerful antioxidant properties, health promoting effects and antimicrobial activities. It is a rich source of β-carotene, a precursor of vitamin A. It is also a good source of vitamin C. Beside its medicinal value, it is also used as a part of various food product developments as food stabilizer, adhesive, and emulsifying agent. More importantly it is used for the development of healthy and nutritious extruded and bakery product.

Drying of foods is aimed at producing high density product, which when adequately packaged has longer shelf life after which the food can be rapidly and simply reconstituted without substantial loss of flavour, taste, colour and aroma. Hence, a research studies is taking up to study the drying, storage, packaging and product development of fenugreek leaves.

The fresh fenugreek leaves (local variety) were procured from local market of Naguar, Rajasthan, The fresh leaves were dried in open sun, solar cabinet, mechanical tray and fluidized bed dryer. In case of mechanical tray drying and fluidized bed drying fenugreek leaves were dried at temperature of 40, 50, 60 and 70 °C at 2 m/s air velocity. All the data were statistically analyzed. Drying curves were fitted to five well known thin layer drying models viz, Newton, Logarithmic, Page, Diffusion approach and Henderson and Pabis. Among the models diffusion approach model for fluidized bed drying was found the most satisfactory than any other models to represent the drying of fenugreek leaves.

The optimization of process parameters was carried out using the general factorial method in Design Expert 7.7.0 software on the basis of goal of response. The sample dried at 60 °C in fluidized bed dryer was found optimum in terms of response *viz.*, drying time (180 min), final moisture content (6.49 % w.b), L^* (37.73), a^* (-6.39), b^* (13.44), β-carotene (5012.21µg/100g), Ascorbic acid (48.66 mg/100g) and chlorophyll (53.26 mg/100g).

Fenugreek leaves dried in fluidized bed drying at 60 °C were packed in LDPE (300 gauge) and PP (300 gauge) materials, normal packaging P_1, active packaging (Moisture absorber) P_2 and vacuum packaging P_3. Packed leaves was kept for 3 months

storage at ambient conditions. fenugreek leaves packed in PP (300 gauge) with active packaging was found best during three months of storage period with lowest gain of storage weight (1.37 per cent) and less respiration rate (15.52 per cent).

Fenugreek leaves dried in fluidized bed drying at 60 °C were used for preparation of fenugreek supplemented biscuits with different proportion 5, 10 and 15 per cent of fenugreek leaves powder. the fenugreek supplemented biscuits with 5 per cent fenugreek powder found best *viz.,* moisture content (1.75 per cent), carbohydrates (60.27 per cent), L^* (47.96), a^*(1.52), b^*(14.26), hardness (2395 g), overall acceptability (7.66) as compared with control sample.

सार

मेथी (Trigonella foenum-graecum) एक स्व-प्रदूषित वार्षिक जड़ी बूटी वाले फल का निर्माण करती है, जो फेबासी परिवार से संबंधित है। मेथी के पत्तों के ताजे या सूखे रूप सुखद स्वाद, शक्तिशाली एंटीऑक्सीडेंट गुण, स्वास्थ्य को बढ़ावा देने वाले प्रभाव और रोगाणुरोधी गतिविधियों के अपने संबंधित गुणों के कारण बहुत लोकप्रिय रसोई जड़ी बूटी है। यह विटामिन prec ए t-कैरोटीन का एक समृद्ध स्रोत है। यह विटामिन सी का भी एक अच्छा स्रोत है। इसके औषधीय महत्व के अलावा, इसका उपयोग विभिन्न खाद्य उत्पाद विकासों के एक भाग के रूप में भी किया जाता है जैसे कि खाद्य स्टेबलाइज़र, चिपकने वाला, और पायसीकारी एजेंट। अधिक महत्वपूर्ण बात यह स्वस्थ और पौष्टिक extruded और बेकरी उत्पाद के विकास के लिए प्रयोग किया जाता है।

खाद्य पदार्थों को सुखाने का उद्देश्य उच्च घनत्व वाले उत्पाद का उत्पादन करना है, जो कि जब पर्याप्त रूप से पैक किया जाता है, तो लंबे समय तक शैल्फ जीवन होता है, जिसके बाद स्वाद, स्वाद, रंग और सुगंध के पर्याप्त नुकसान के बिना भोजन को तेजी से और बस पुनर्गठित किया जा सकता है। इसलिए, मेथी के पत्तों के सुखाने, भंडारण, पैकेजिंग और उत्पाद विकास का अध्ययन करने के लिए एक शोध अध्ययन किया जा रहा है।

ताजा मेथी के पत्ते (स्थानीय किस्म) राजस्थान के नागुअर के स्थानीय बाजार से खरीदे गए थे। ताजी पत्तियों को खुली धूप, सौर कैबिनेट, यांत्रिक ट्रे और द्रवित बेड ड्रायर में सुखाया जाता था। यांत्रिक ट्रे सूखने और द्रवित बिस्तर के मामले में, मेथी के पत्तों को 40 मीटर, 50, 60 और 70 डिग्री सेल्सियस के तापमान पर 2 मीटर / सेकंड के वायु वेग से सुखाया जाता था। सभी आंकड़ों का सांख्यिकीय विश्लेषण किया गया था। सूखने वाले घटता को पांच प्रसिद्ध पतली परत सुखाने वाले मॉडल अर्थात न्यूटन, लॉगरिदमिक, पेज, डिफ्यूजन के दृष्टिकोण और हेंडरसन और पाबिस में लगाया गया था। द्रवित बिस्तर सुखाने के लिए मॉडल प्रसार दृष्टिकोण मॉडल में मेथी की पत्तियों के सुखाने का प्रतिनिधित्व करने के लिए किसी भी अन्य मॉडल की तुलना में सबसे संतोषजनक पाया गया था।

प्रतिक्रिया के लक्ष्य के आधार पर डिजाइन एक्सपर्ट 7.7.0 सॉफ्टवेयर में सामान्य तथ्यात्मक विधि का उपयोग करके प्रक्रिया मापदंडों का अनुकूलन किया गया था। द्रवित बेड ड्रायर में 60 ° C पर सुखाया जाने वाला नमूना प्रतिक्रिया अर्थात के मामले में इष्टतम पाया गया। सुखाने का समय (180 मिनट), अंतिम नमी की मात्रा (6.49% wb), L * (37.73), एक * -6.39)।

बी * (13.44), β-कैरोटीन (5012.21 /g / 100 ग्राम), एस्कॉर्बिक एसिड (48.66 मिलीग्राम / 100 ग्राम) और क्लोरोफिल (53.26 मिलीग्राम / 100 ग्राम)।

60 डिग्री सेल्सियस पर सूखने वाले तरल पदार्थ बिस्तर में मेथी के पत्तों को LDPE (300 गेज) और पीपी (300 गेज) सामग्री, सामान्य पैकेजिंग पी 1, सक्रिय पैकेजिंग (नमी अवशोषक) पी 2 और वैक्यूम पैकेजिंग पी 3 में पैक किया गया था। परिवेशी परिस्थितियों में पैक किए गए पत्तों को 3 महीने के भंडारण के लिए रखा गया था। सक्रिय पैकेजिंग के साथ पीपी (300 गेज) में पैक किए गए मेथी के पत्तों को भंडारण अवधि के तीन महीनों के दौरान भंडारण वजन (1.37 प्रतिशत) के सबसे कम लाभ और कम श्वसन दर (15.52 प्रतिशत) के साथ सबसे अच्छा पाया गया।

मेथी के पत्तों को 60 ° C पर द्रवित बिस्तर में सुखाया जाता है, मेथी के पूरक बिस्कुट को 5, 10 और 15 प्रतिशत मेथी के पत्तों के पाउडर के साथ तैयार किया जाता है। 5 प्रतिशत मेथी पाउडर के साथ मेथी के पूरक बिस्कुट सबसे अच्छे पाए गए। नमी, (1.75 प्रतिशत), कार्बोहाइड्रेट (60.27 प्रतिशत), एल * (47.96), एक * (1.52), बी * (14.26), कठोरता (। 2395 जी), नियंत्रण नमूने की तुलना में समग्र स्वीकार्यता (7.66)।

APPENDIX – A

A-1 Specifications of tray dryer

Sl. No.	Particulars	Details
1	Model	12 TD
2	Make	Labline, Gujrat
3	Outer dimensions (mm)	1450 x 650 x 950
4	Drying chamber (mm)	1320 x 500 x 860
5	No. of trays (metal)	2 (Aluminium)
6	Tray size (mm)	340 x 270 x 38
7	Floor area (cm^2)	75.5 x 35.0
8	Loading density (kg / m^2)	1.089
9	No. of heaters i. Energy ii. Temperature range iii. Control	4 2.5 kWh Upto 92 °C Thermostatic
10	No. of fans	One
11	Motor	One, 1- phase, 230V, 50Hz, 0.375 kW (0.5HP)
12	Rating controls	on – of (thermostatic)

A-2 Specifications of fluidized bed dryer

Sl. No.	Particulars	Details
1	Model	HE-75/2001-2002
2	Make	Sherwood Scientific Ltd. Cambridge,England
3	Serial No	14475
4	Weight	18.5 kg
5	Bag	Nylon
6	Drying tube size (materials)	2 and 5 litres (stainless steel and glass)
7	Heater	1 (2 kW)
8	Fan	1 (Centrifugal)
9	Air velocity range	1.80-3.65 (m/s)
10	Blower setting	½ -10

APPENDIX – B

B-1 Open sun drying data for drying of fenugreek leaves

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.57	644.60		1.000	0
60	169.37	84.14	530.55	0.0190	0.821	-0.1968
120	138.88	80.66	417.04	0.0189	0.644	-0.4408
180	110.03	75.59	309.63	0.0179	0.475	-0.7438
240	90.03	70.16	235.17	0.0124	0.359	-1.0254
300	72.03	62.71	168.16	0.0112	0.254	-1.3717
360	54.69	50.88	103.60	0.0108	0.153	-1.8803
420	48.69	44.83	81.26	0.0037	0.118	-2.1409
480	42.69	37.08	58.92	0.0037	0.083	-2.4943
540	38.69	30.57	44.03	0.0025	0.059	-2.8263
600	34.69	22.56	29.14	0.0025	0.036	-3.327
660	31.03	13.43	15.51	0.0023	0.015	-4.2297
720	28.68	6.33	6.76	0.0015	0.001	-7.0687
840	28.69	6.37	6.80	0.0000	0.001	-7.0025

B-2 Solar cabinet drying data for drying of fenugreek leaves

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.57	644.60		1.000	0
60	167.37	83.95	523.11	0.0202	0.810	-0.2111
120	134.88	80.09	402.15	0.0202	0.620	-0.4777
180	104.03	74.18	287.29	0.0191	0.440	-0.8203
240	82.03	67.25	205.39	0.0137	0.312	-1.1648
300	62.03	56.70	130.93	0.0124	0.195	-1.633
360	42.69	37.08	58.92	0.0120	0.083	-2.4943
420	34.69	22.56	29.14	0.0050	0.036	-3.327
480	28.68	6.33	6.76	0.0037	0.001	-7.0687
540	28.65	6.24	6.65	0.0000	0.001	-7.2988

B-3 Mechanical tray drying data for drying of fenugreek leaves at 40 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.68	650.75		1.000	0
5	183.56	85.49	589.05	0.1234	0.904	-0.1006
10	170.65	84.39	540.58	0.0969	0.829	-0.1874
15	158.27	83.17	494.10	0.0930	0.757	-0.2784
20	146.91	81.87	451.45	0.0853	0.691	-0.3699
25	137.44	80.62	415.91	0.0711	0.636	-0.453
30	128.33	79.24	381.74	0.0684	0.583	-0.5401
40	117.60	77.35	341.45	0.0403	0.520	-0.6536
50	107.40	75.20	303.16	0.0383	0.461	-0.7749
60	97.61	72.71	266.41	0.0367	0.404	-0.9069
90	85.15	68.71	219.64	0.0156	0.331	-1.105
120	73.60	63.80	176.26	0.0145	0.264	-1.3322
150	62.66	57.49	135.22	0.0137	0.200	-1.6083
180	52.24	49.00	96.08	0.0130	0.140	-1.9695
210	42.09	36.70	57.98	0.0127	0.080	-2.5206
240	32.22	17.32	20.95	0.0123	0.023	-3.7742
300	28.53	6.64	7.11	0.0023	0.001	-6.5125
360	28.53	6.64	7.11	0.0000	0.001	-6.5125

B-4 Mechanical tray drying data for drying of fenugreek leaves at 50 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.68	650.75		1.000	0
5	182.85	85.43	586.37	0.1288	0.900	-0.1052
10	169.24	84.26	535.28	0.1022	0.821	-0.1974
15	156.16	82.94	486.17	0.0982	0.745	-0.2948
20	144.09	81.51	440.89	0.0906	0.674	-0.3939
25	133.93	80.11	402.73	0.0763	0.615	-0.4857
30	124.12	78.54	365.92	0.0736	0.558	-0.5831
40	112.69	76.36	323.01	0.0429	0.492	-0.7101
50	101.79	73.83	282.09	0.0409	0.428	-0.8484
60	91.30	70.82	242.71	0.0394	0.367	-1.0023
90	78.14	65.91	193.31	0.0165	0.290	-1.2365
120	65.88	59.56	147.31	0.0153	0.219	-1.5186
150	54.25	50.89	103.64	0.0146	0.151	-1.8886
180	43.12	38.22	61.88	0.0139	0.086	-2.4477
210	32.27	17.45	21.15	0.0136	0.023	-3.7589
240	28.49	6.49	6.94	0.0047	0.001	-6.6617
300	28.49	6.49	6.94	0.0000	0.001	-6.6617

B-5 Mechanical tray drying data for drying of fenugreek leaves at 60 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.68	650.75		1.000	0
5	181.24	85.30	580.33	0.1408	0.891	-0.1157
10	166.02	83.95	523.19	0.1143	0.802	-0.2205
15	151.33	82.40	468.04	0.1103	0.717	-0.3333
20	137.65	80.65	416.71	0.1027	0.637	-0.451
25	125.88	78.84	372.51	0.0884	0.568	-0.5649
30	114.46	76.73	329.66	0.0857	0.502	-0.6893
40	101.42	73.73	280.71	0.0490	0.426	-0.8533
50	88.91	70.04	233.74	0.0470	0.353	-1.0409
60	76.81	65.32	188.32	0.0454	0.283	-1.2634
90	62.04	57.06	132.88	0.0185	0.197	-1.6261
120	48.17	44.70	80.83	0.0174	0.116	-2.1546
150	34.93	23.73	31.12	0.0166	0.039	-3.2483
180	28.52	6.59	7.06	0.0080	0.002	-6.4919
210	28.51	6.56	7.02	0.0000	0.001	-6.5311

B-6 Mechanical tray drying data for drying of fenugreek leaves at 70 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	86.68	650.75		1.000	0
5	179.95	85.20	575.49	0.1505	0.883	-0.1241
10	163.44	83.70	513.51	0.1240	0.787	-0.2394
15	147.46	81.93	453.51	0.1200	0.694	-0.3652
20	132.49	79.89	397.34	0.1123	0.607	-0.4994
25	119.43	77.69	348.30	0.0981	0.531	-0.6333
30	106.72	75.04	300.60	0.0954	0.457	-0.7834
40	92.39	71.17	246.81	0.0538	0.373	-0.9851
50	78.59	66.10	195.00	0.0518	0.293	-1.2275
60	65.20	59.14	144.74	0.0503	0.215	-1.5368
90	49.14	45.79	84.46	0.0201	0.122	-2.1074
120	33.98	21.61	27.56	0.0190	0.033	-3.4025
150	28.53	6.62	7.09	0.0068	0.002	-6.4741
180	28.52	6.59	7.06	0.0000	0.001	-6.5126

B-7 Fluidized bed drying data for drying of fenugreek leaves at 40 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	87.32	688.64		1.000	0
5	182.49	86.10	619.60	0.1381	0.899	-0.1067
10	168.52	84.95	564.50	0.1102	0.818	-0.2008
15	155.08	83.65	511.50	0.1060	0.740	-0.3005
20	142.65	82.22	462.51	0.0980	0.669	-0.4025
25	132.13	80.81	421.00	0.0830	0.608	-0.4979
30	121.96	79.21	380.92	0.0802	0.549	-0.5995
40	110.17	76.98	334.42	0.0465	0.481	-0.732
50	98.91	74.36	290.02	0.0444	0.416	-0.8774
60	88.06	71.20	247.24	0.0428	0.353	-1.0408
90	74.54	65.98	193.92	0.0178	0.275	-1.2907
120	61.92	59.05	144.17	0.0166	0.202	-1.5987
150	49.93	49.21	96.88	0.0158	0.133	-2.0184
180	38.44	34.03	51.59	0.0151	0.066	-2.7106
210	27.13	6.52	6.98	0.0149	0.001	-6.7877
240	27.13	6.52	6.98	0.0000	0.001	-6.7877

B-8 Fluidized bed drying data for drying of fenugreek leaves at 50 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	87.32	688.64		1.000	0
5	181.79	86.05	616.84	0.1436	0.895	-0.1112
10	167.12	84.83	558.98	0.1157	0.810	-0.2107
15	152.98	83.42	503.22	0.1115	0.728	-0.317
20	139.85	81.87	451.47	0.1035	0.653	-0.4269
25	128.63	80.28	407.20	0.0885	0.588	-0.5316
30	117.76	78.46	364.36	0.0857	0.525	-0.6446
40	105.27	75.91	315.10	0.0493	0.453	-0.7925
50	93.31	72.82	267.93	0.0472	0.384	-0.9582
60	81.76	68.98	222.39	0.0455	0.317	-1.1492
90	67.54	62.45	166.32	0.0187	0.235	-1.4494
120	54.22	53.23	113.81	0.0175	0.158	-1.8465
150	41.53	38.94	63.76	0.0167	0.084	-2.4715
180	27.14	6.56	7.02	0.0189	0.001	-6.6323
210	27.13	6.52	6.98	0.0000	0.001	-6.6772

B-9 Fluidized bed drying data for drying of fenugreek leaves at 60 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	87.32	688.64		1.000	0
5	180.18	85.93	610.49	0.1563	0.885	-0.1216
10	163.90	84.53	546.29	0.1284	0.791	-0.2339
15	148.15	82.88	484.17	0.1242	0.700	-0.3561
20	133.41	80.99	426.07	0.1162	0.615	-0.4856
25	120.58	78.97	375.46	0.1012	0.541	-0.6141
30	108.10	76.54	326.27	0.0984	0.469	-0.757
40	94.00	73.02	270.66	0.0556	0.388	-0.9477
50	80.43	68.47	217.15	0.0535	0.309	-1.1737
60	67.27	62.30	165.26	0.0519	0.233	-1.4559
90	51.44	50.70	102.84	0.0208	0.142	-1.9538
120	36.51	30.54	43.98	0.0196	0.055	-2.8915
150	27.15	6.59	7.06	0.0123	0.001	-6.5684
180	27.12	6.49	6.94	0.0000	0.001	-6.7001

B-10 Fluidized bed drying data for drying of fenugreek leaves at 70 °C

Time (min)	Weight (g)	MC, % (wb)	MC, % (db)	DR (g of water/g of dry matter-min)	MR	LN(MR)
0	200.00	87.32	688.64		1.000	0
5	178.89	85.82	605.40	0.1665	0.878	-0.1301
10	161.32	84.28	536.11	0.1386	0.777	-0.2529
15	144.28	82.42	468.91	0.1344	0.678	-0.3885
20	128.25	80.23	405.73	0.1264	0.586	-0.5353
25	114.13	77.78	350.02	0.1114	0.504	-0.6854
30	100.36	74.73	295.75	0.1086	0.424	-0.8571
40	84.97	70.15	235.06	0.0607	0.335	-1.0922
50	70.11	63.83	176.45	0.0586	0.250	-1.3879
60	55.66	54.44	119.48	0.0570	0.166	-1.795
90	38.54	34.20	51.97	0.0225	0.067	-2.6997
120	27.13	6.52	6.98	0.0150	0.001	-6.6318
150	27.11	6.46	6.90	0.0000	0.001	-6.7235

APPENDIX – C

C-1 Sensory evaluation of fenugreek leaves (score card)

Evaluation Card for Numerical Scoring Test (IS:6273 (part II)-1971)

Name: Date:

Product: Time:

Please rate these samples for overall quality according to the following grade description and scoring:

9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Sample No	Colour	Flavour	Appearance	Overall acceptability
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Signature of evaluator

APPENDIX – D

D-1 Sensory evaluation of fenugreek supplemented biscuits (score card)

Evaluation Card for Numerical Scoring Test (IS:6273 (part II)-1971)

Name: Date:

Product: Time:

Please rate these samples for overall quality according to the following grade description and scoring:

9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slightly
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

Sample	Sensory score					
	Appearance	**Colour**	**Flavour**	**Texture**	**Taste**	**Overall acceptability**
1						
2						
3						
4						

Signature of evaluator