DEVELOPMENT AND EVALUATION OF PROCESS PROTOCOL FOR VACUUM FRIED BITTER GOURD CHIPS (*Momordica charantia*)

By

POOJA M.R

(2016-18-011)

DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR – 679 573

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THESIS

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2018

DECLARATION

I hereby declare that this thesis entitled **"Development and evaluation of process protocol for vacuum fried bitter gourd chips (*Momordica charantia*)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title, of any other University or Society.

Place: **Tavanur** **POOJA M.R**

Date**:** **(2016-18-011)**

Dr. Sudheer K.P

Professor & Head, Dept. of Agricultural Engineering

ICAR National Fellow & Project Coordinator

Centre of Excellence in Post-Harvest Technology

College of Horticulture

Kerala Agricultural University, Vellanikara

Thrissur, Kerala - 680 656

CERTIFICATE

Certified that this thesis entitled **"Development and evaluation of process protocol for vacuum fried bitter gourd chips (*Momordica charantia*)"** is a bonafide record of research work done independently by Ms. Pooja M.R under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

Tavanur **Dr. Sudheer K.P**

Date: (Major Advisor and Advisory Board)

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Ms. Pooja M.R (2016-18-011)** a candidate for the degree of Master of Technology in Agricultural Engineering with majoring in Agricultural Processing and Food Engineering agree that the thesis entitled **"Development and evaluation of process protocol for vacuum fried bitter gourd chips (*Momordica charantia*)"** may be submitted by **Ms. Pooja M.R (2016-18-011**) in partial fulfilment of the requirement for the degree.

Dr. Sudheer K.P
Professor & Head, Dept. of Agricultural Engineering
Project Coordinator, Centre of Excellence in Post-harvest Technology
College of Horticulture, Kerala Agricultural University,
Vellanikara, KAU (PO), Thrissur, Kerala- 650 656
(Chairman)

Dr. Prince M.V
Professor
Dept. of Processing and Food Engineering
KCAET, Tavanur
(Member)

Dr. P.K Sureshkumar
Professor, Dept. of Agril Engg
College of Horticulture,
Vellanikkara
(Member)

Dr. Rajesh G K
Assistant Professor
Dept. of Processing and Food Engineering
KCAET, Tavanur
(Member)

EXTERNAL EXAMINER
(Dr. Ravindra Naik)

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Tavanur

Date: **Pooja M.R**

Affectionately Dedicated

To

My beloved parents

Sister, friends, researchers

And

My Guide

Dr. Sudheer K.P

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ABBREVIATIONS AND SYMBOLS

%	:	Per cent
&	:	And
/	:	Per
@	:	At the rate of
+	:	Plus
<	:	Less than
±	:	Plus or minus
µg/kg	:	Micro gram per kilo gram
µl	:	Micro litre
a*	:	Greenness or redness
AA	:	Ascorbic acid
AACC	:	American association of cereal chemists
ABTS	:	2, 2’-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid
AC	:	Absorption chromatography
AOAC	:	Association of official analytical chemists
a_w	:	Water activity
b*	:	Blueness or Yellowness
BAF	:	Bitter gourd with atmospheric frying
BBD	:	Bitter gourd pre-treated with blanching cum drying
BFR	:	Bitter gourd pre-treated with freezing
BG	:	Bitter gourd
BGC	:	Bitter gourd pre-treated with edible gum coating
BWP	:	Bitter gourd without pre-treatment (un-treated)
$CaCl_2$	:	Calcium chloride

CAO	:	Canola oil
Cm	:	Centimetre
Cm^{-1}	:	Per centimetre
CMC	:	Carboxy methyl cellulose
CO_2	:	Carbon di oxide
COO	:	Corn oil
cP	:	CentiPoise
CPO	:	Crude palm oil
CRD	:	Completely randomized design
DAD	:	Diode array detector
DPPH	:	Diphely-1-picrylhydrazyl radical
et al.	:	And others
etc	:	Etcetera
EX	:	Excellent
FFA	:	Free fatty acids
Fig	:	Figure
FMF	:	Fuzzy membership function
FR	:	Fair
g/l	:	gram per litre
GD	:	Good
h	:	Hours
HIV	:	Human immunodeficiency virus
HMI	:	Human machine interface
hp	:	Horse power
HPLC	:	High performance liquid chromatography

HPMC	:	Hydroxyl propyl methyl cellulose
i.e.,	:	That is
JMFM	:	Judgement membership function
JS	:	Judgement subset
KAU	:	Kerala agricultural university
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg/cm	:	Kilogram per centimetre
kg/cm^2	:	Kilo gram per centimetre squares
kg/kg db	:	Kilogram per kilogram in dry basis
kg/m^3	:	Kilogram per cubic meter
kg/h	:	Kilo gram per hour
KOH	:	Potassium Hydroxide
kPa	:	Kilo Pascal
kW	:	Kilo watt
l	:	Litre
L*	:	Lightness or Darkness
l/min	:	Litre per minute
LDPE	:	Low density poly ethylene
m Pa s	:	Milli Pascal second
m^3/h	:	Metre cube per hour
MAP	:	Modified atmospheric packaging
MC	:	Moisture content
MC	:	Methyl cellulose
MD	:	Maltodextrin

meq O_2/kg	:	Milli equivalent oxygen per kilo gram
mg KOH/g	:	Potassium hydroxide in milligrams per gram
min	:	Minute
ml	:	Milli litre
mm	:	Milli metre
mm/s	:	Milli metre per second
MT	:	Metric Tons
N	:	Newton
N_2	:	Nitrogen
NFME	:	Normalized fuzzy membership function
NIIST	:	National Institute for Interdisciplinary Science and Technology
NS	:	Not satisfactory
Ns/m^2	:	Newton second per square metre
ºC	:	Degree Celsius
OLO	:	Olive oil
OPSTAT	:	Operational Status
Pa.s	:	Pascal second
PET	:	Polyethylene terephthalate
PID	:	Proportional Integral Derivative
PO	:	Palm oil
POD	:	Peroxidise
POO	:	Palm olein oil
ppb	:	Parts per billion
PPO	:	Polyphenol oxidase

pps	:	Parts per second
PV	:	Peroxide value
RBO	:	Rice bran oil
rpm	:	Revaluation per minutes
RSM	:	Response surface methodology
s	:	Seconds
SEM	:	Scanning electron microscopy
SPI	:	Soy protein isolate
SPSS	:	Stastical package for social science
SS	:	Stainless steel
TA	:	Texture analyser
TPC	:	Total polar compounds
VF	:	Vacuum frying
w.b	:	Wet basis
W/V	:	Weight per volume
WASP	:	Web Agri Stat Package
WPI	:	Whey protein isolate
X1	:	Frying temperature
X2	:	Frying pressure
X3	:	Frying pressure
α	:	Alpha
β	:	Beta
ΔE	:	Colour difference

CHAPTER-I

INTRODUCTION

India is the world's second largest producer of fruits and vegetables, with a production of 2.53 million tons/annum. India contributes 12% in vegetable production, but per capita vegetable consumption is only 135 g/day as against the recommended dietary allowances of 250 g/day. To improve the consumption and nutritive value, development of ready-to-eat products from locally available fruits and vegetables is inevitable (Ravindranath, 2005).

Bitter gourd (*Momordica charantia*) commonly known as bitter melon or Karela in India, belongs to Cucurbitaceae family. Bitter gourd resembles a cucumber but with gourd like bumps on skin and is varying in colour, size, shape and bitter in taste. Bitter gourd is one of nature's most bountiful gifts and it is considered as most bitter among all fruits and vegetables. The plant grows well in tropical regions such as India, tropical Africa, America, Thailand, Middle East, China and Malaysia. In India, the area and production of bitter gourd is 95 ha and 1030 MT respectively, during 2016-17. The highest bitter gourd production was recorded in Chhattisgarh followed by Orissa and Madhya Pradesh. Moreover, it also grown in other states likes Andhra Pradesh, Bihar, Assam, Kerala, Uttar Pradesh and Karnataka (NHB, 2017).

Bitter gourd is rich in β-carotene, vitamin C, b-complex vitamin, potassium, phosphorus, essential dietary fibre, some carbohydrates, minerals and protein (Behera *et al.,* 2010). In addition, it enhances the resistance against infection, is good for decontaminating the blood and also found to be good for diabetes (Joseph and Jini, 2013).

Bitter gourd is difficult to be stored at room temperature because of its delicate and perishable nature. The optimum storage condition of bitter gourd is a temperature of 12-13ºC and a relative humidity of 85-90% (Mohammed and Wickham 1993). The shelf life of bitter gourd is about three to four weeks when it is under refrigerated condition (0-7ºC).

The estimated post harvest loss of the bitter gourd was 25% (Thakur and Sharma, 2016). A realistic solution for reducing the post harvest loss in bitter gourd is the adoption of the appropriate processing technologies. Numerous value added products like chips, pickles, curries, powder and medicinal products, are made from bitter gourd. Nowadays with growing demand of snacks around the world, products like chips, French fries and other fried food products are becoming more marketable. Bitter gourd chips, with its unique sensory attributes are a popular variety of snacks served in various occasions, along with salt, spices and flavour.

Deep fat frying is one of the oldest and most common technologies in food sector in where the food is immersed in hot oil which is heated above the boiling point of water. Hot oil serves as the heat transferring medium and it aids in heat and mass transfer processes. The major factors affecting the quality of fried product is frying temperature, frying pressure, frying time, type of oil, size and nature of sample (Ophithakorn and Yaeed, 2018). Deep fat frying confers qualities like colour, texture, aroma and taste transferring the food into a well acceptable product. However, it utilizes a very high temperature under atmospheric pressure, thus leading to increased oil uptake in the final product. High oil uptake in fried chips is associated with several health effects such as obesity, cardiovascular diseases, cancer, hypertension and other health problems and is incompatible with recent consumer trends.

The health concerns of modern consumers demand, healthy and tasty snack products with less oil content. In this context, investigation on processing technologies focusing on high quality fried products with less oil and less harmful by products like acrylamide is the need of the hour. Vacuum frying is a promising technology to fulfil these objectives (Dueik *et al.,* 2010). During this process the samples are fried under vacuum (less than 60 Torr-8 kPa) condition, which lowers the boiling point of the oil and water (Maity *et al.,* 2014). The absence of the oxygen inhibits oxidation properties such as enzymatic browning and lipid oxidation which results in good product colour, texture, flavour and nutritional properties. Moreover, there is a decrease in acrylamide content in vacuum fried chips (Tagalpallewar *et al.* 2008). Besides, the vacuum fried oil can be reused efficiently for more than 63 times in subsequent frying events (Ranasalva and Sudheer, 2017).

Vacuum frying technology has been successfully employed for the production of novel snacks from fruits, sea foods, meat and vegetables. The processing conditions such as temperature, pressure and time are the main factors for better acceptance of organoleptic properties in vacuum fried chips.

Adoption of different pre-treatments like blanching cum drying, edible gum coating and freezing improves the product quality and also reduces the oil uptake and acrylamide formation (Setyawan *et al.,* 2013). The selection of the suitable oil for frying plays an important role in the quality maintainece of product and oil. Rice bran oil and palm oil possess high antioxidational properties than other oils (Valantina *et al.,* 2010) and blend of these oils has proved to be better (Ranasalva and Sudheer, 2015).

Adoption of this vacuum frying technology for production of bitter gourd chips has not yet been explored. To bridge the gap, research on development of ready to eat bitter gourd chips using vacuum frying technology was investigated with the following objectives.

1. To optimise the pre-treatment and process parameters for vacuum fried bitter gourd chips.
2. To study the effect of vacuum frying on quality parameters of bitter gourd chips and frying oil and
3. To conduct shelf-life studies of vacuum fried bitter gourd chips

CHAPTER – II

REVIEW OF LITERATURE

The review of literature is one of the important steps to retrieve information about the topic chosen for research. This chapter covers information and literature related to the vacuum frying system, different frying oil properties and fried product properties. The following viewpoints were reviewed in details.

2.1. Bitter gourd and its products

2.2. Frying

2.3. Frying oil

2.4. Deep fat frying

2.5. Vacuum frying

2.6. Pre-treatments for frying

2.7. De-oiling of fried products

2.8. Changes in properties of frying oil

2.9. Product characteristics of vacuum frying

2.10. Sensory analysis

2.11 Packaging and storage studies

2.12 Statistical analysis

2.1 BITTER GOURD AND ITS PRODUCTS:

The bitter gourd (*Momordica charantia*) is consumed throughout year in Asian subcontinent for culinary and medicinal properties. Bitter gourd consists of reducing sugar, saponins, alkaloids, fixed oils, free oils and also good source in vitamin C, Vitamin A, proteins, carbohydrates, crude fibre, thiamine, iron *etc* (Din *et al.* 2011). Table 2.1 represents the proximate composition of bitter gourd (Rani *et al.* 2014). Bitter gourd proteins have inhibitory effect against HIV virus, destroying cells causing leukemia and beneficial effects is lowering blood sugar along with pre-diabetics by slowing string to diabetics. It is very fast growing vegetable and having bitter in wholesome well-venerated vegetable. The fruit has a tonic, carminative, stomachic and cooling effect (Efird *et al.* 2014).

Table 2.1 Proximate composition of Bitter gourd (*Momordica charantia*)

Components	Nutritional amounts
Moisture content	93.20%
Protein	01.00
Energy	17.00 kcal
Lipids	00.77
Fats	00.17 g
Carbohydrates	3.14 g
Fibre	0.80 %
Iron (mg/100g)	02.20
Calcium (mg/100g)	22.00
Magnesium (mg/100g)	17.00

(Rani *et al*. 2014)

Wu *et al.* (2010) conducted study on process optimisation of freeze-dried bitter gourd juice powder. The concentrated juice was produced through an enzymatic process, reverse osmosis, ultrafiltration and vacuum concentration technology. The results indicated that total saponins, total sugars and pH value was decreased in enzymatic process and ultrafiltration. When compared with vacuum concentration process alone, the collective process of the reverse osmosis pursue by vacuum concentration resulted in higher production efficiency and Vitamin C content in concentration juice.

Singh and Sagar (2013) investigate the effect of different drying methods on the nutritional composition of dehydrated bitter gourd rings. In this study compared three different types of drying such as cabinet drying, solar drying, and low-temperature drying. Based on the drying performances and nutrients retention like ascorbic acid, total chlorophyll and β-carotene, cabinet drying method was selected as the best method for bitter gourd drying. Moreover non-enzymatic browning of dehydrated bitter gourd, drying ratio and moisture content of bitter gourd was very less in cabinet drying compared to other drying methods.

Borse and Mishra (2014) studied the effect of different frying temperatures on physico-chemical properties of bitter gourd chips. Bitter gourd was treated in 2% salt, 1% turmeric powder and soaked for 30 min. The treated samples were fried at different temperatures at 140ºC, 160ºC and 180ºC. Based on the physicochemical properties, sensory characteristics and storage studies, sample fried at 160ºC exhibited best quality and high sensory score among others.

Bhattacharjee *et al.* (2016) conducted an experiment on dehydration and rehydration characteristics of bitter gourd. During their study bitter gourd slices were blanched in steam and hot water for duration of 1, 2 and 3 minutes. The blanched slices were dried in a cabinet dryer at a temperature of 55ºC, 60ºC and 65ºC till constant moisture content was achieved. The samples dried at 60ºC with 2 min blanching, exhibited better dehydration quality attributes.

Thakur and Sharma (2016) conducted an experiment on health benefits and value-added products from bitter gourd. During this study, several medicine values such as anti-ulcerogenic, anti-tumour, analgesic, anti-viral, anti-diabetic, antimutagenic, lipolytic and immune modulatory of the bitter gourd were studied. The study showed that bitter gourd proteins (α and β-monorcharin) had some inhibitory effects on the HIV virus and other diseases. A large numbers of value-added products could be prepared from the bitter gourd, such as bitter gourd chips, pickle, dried rings, juice, *etc*. Similarly, Deepa (2015) developed some other value added products from bitter gourd such as ribbons, bitter gourd cutlet and biscuits. The value added products were standardised according to the quality evaluation and sensory scores. The results revealed that the products were well accepted with higher nutrient content.

Singh *et al*. (2017) conducted study on MAP storage of bitter gourd chips. The aim of the study was to determine antioxidant activity of bitter gourd chips by DPPH radical- scavenging activity and ABTS assay. Various MAP gas concentrations were used for the study. The best result was obtained in MAP with 100% N_2:0% CO_2 storage at room temperature.

2.2 FRYING

Frying is a unit operation which mainly used to produce snack foods. Frying is one of the old and popular methods of cooking food in oil. Frying improves the crust, texture and sensory quality of food by a formation of some fragrance compounds (Bognar, 1998). Frying also inactivates enzymes, reduction of micro-organism and moisture content of foods. Orthoefer, (1987) suggested that frying as a fast heating and uniform cooking method than other cooking processes.

Frying involves simultaneous heat and mass transfer of food (Sharma and Mann, 2010). The rate of heat transfer is restrained by the temperature difference between by the surface heat transfer coefficient of oil and food. The thermal conductivity will be inhibited the rate of heat penetration into food during frying. While frying food behaves as a colloid non-porous and non-homogenous anisotropic material (Wu *et al.* 2010).

The frying oil selection depends on several factors viz, resistance and stability of the oil, cost economics and fried products to oxidation (Gadiraju *et al.* 2015). The normal frying temperature of about 150–200˚C or higher temperature tremendously increases unsaturated bonds of the vegetable oils that reduces the frying life and shelf life of food product due to oxidation. Frying could be done by several methods such as deep fat frying, shallow frying, stir-frying and sauteing. Deep fat frying also called as immersion frying in which the process of cooking and dehydration of foods is done at hot oil of temperature 190˚C (Bordin *et al.* 2013). In shallow frying heat is transferred to the food through a thin layer of oil in the form of conduction. Shallow frying is most suitable for products with large surface area. In sauteing, little amount of oil is placed on the base of cooking vessel and frying was done by low flame due to roasting (Blumenthal and Stier, (1991)).

2.3. FRYING OIL

Chatzilazarou *et al.* (2006) reported the various physicochemical changes in olive oil and vegetable oils during frying. The components viz; polyunsaturated fatty acids, iodine value and tocopherol concentration decreased during frying process, whereas peroxide, polar compounds, colour and viscosity increased.

Abiona *et al.* (2011) conducted study on the changes in free fatty acid in vegetable oil and palm oil during deep fat frying. The frying experiment was conducted at a temperature of 180˚C for six consecutive days. During frying period, mono-unsaturated fatty acid and tri-unsaturated free acids decreased with length of usage. The results revealed that, palm oil was the best choice for better quality retention in deep fat frying.

Romano *et al.* (2012) conducted study on evaluation of frying performance of olive oil and palm super olein. Under vacuum condition, frying in palm superolein oil led to increased free fatty acids, total polar compounds, but other parameters had better results than the olive oil.

Debnath *et al.* (2012) conducted experiment on changes in physical, chemical and heat transfer quality of the rice bran oil during deep fat frying of poori. The experiment showed that, first two cycles of frying had increased peroxide, free fatty acids, total polar material but radial scavenging activity was decreased. There was no significant difference ($p>0.05$) in the sensory characteristics of poori prepared in rice bran oil with different frying cycle.

Fan *et al.* (2013) explained frying stability of rice bran oil and palm olein. Study revealed that rice bran oil had lowered free fatty acid value than the palm olein. The p-anisidine value of rice bran oil increased from 11.59 to 31.51 from initial to the 5 day of frying, but in case of palm olein, increased from 11.20 to 59.75. Similarly, at fifth day of frying colour of the rice bran oil was not changed but palm olein had darker in colour. The rice bran oil revealed a high frying stability than the palm olein.

Sengar *et al.* (2014) experimented on degumming of rice bran oil and reported that phospholipids content was the main problem during processing of oil in various applications. The final result shows that application of water, acid and enzymatic degumming reduced the phospholipids present in rice bran oil.

Almeida *et al.* (2017) studied the oxidative stability of crude palm oil after deep fat frying of akara (Fried bean paste). The results revealed that, the techniques used in deep fat frying were main object to control degradation of frying oil and also to improve the quality of palm oil.

2.3.1. Blending of oils

Blending of oil is an economic way of modifying the fatty acid composition and physicochemical characteristics of vegetable oils (Karthickumar *et al.* 2015). Khan *et al.* (2008) studied the properties of coconut oil blends during frying of potato chips. The oil blends selected were coconut oil and sesame oil (blend oil I), coconut olein and sesame oil (blend II) and coconut olein and palm olein (blend III). The results showed that the free fatty acid content and anisidine content decreased during frying process. The sensory evaluation showed that the fried chips in blend I and blend II oils had a bitter taste compared to blend III oil.

Farhoosh *et al.* (2009) studied the frying stability of canola (CAO) oil blended with palm olein (POO), olive (OLO) and corn (COO) oils during frying process. Blends prepared in the ratios of 75:25 ((CAO/POO, CAO/OLO and CAO/COO) and 75:15:10 (CAO/POO/OLO, CAO/POO/COO). Frying stability of CAO improved significantly ($p<0.005$) by blending and tershary blends were found to be better than binary blends.

Mishra and Sharma (2014) observed the changes occurred in rice bran oil and blended with sunflower oil during repeated frying on moist and dried potato chips. The blended oil showed a better stability than pure rice bran oil when used to fry dried and moistened potato chips. The colour of the blended oil had less pure light than rice bran oil during repeated deep fat frying. The p-anisidine value was increased more in rice bran oil as compared to blended oil.

Tiwari *et al.* (2014) blended palm and sesame oil in different ratios to improve the thermal stability of oil during deep fat frying at 180°C for 12 h. The results of their study confirmed that oils blend of palm: sesame (52:48) had high thermal stability with an increase in iodine value from 111.32 to 82.45 meqO_2/kg and decrease in peroxide value ranged from 8.43 to 6.32 meqO_2/kg.

Simon *et al.* (2017) conducted research on nutritional studies and oil blending studies of oil. During the production of the ready-to-eat products the three blends (blend I – soya bean+ sun flower, blend II- soya bean + rice bran oil, blend III – sun flower + rice bran oil) tested. The sample fried in sun flower and soya bean oils blend exhibited the excellent acceptability during sensory evaluation.

Ranasalva and Sudheer (2017a) blended rice bran and palm oil in various ratios to improve the quality of oil during vacuum frying at 100ºC for 10 min. The results of the study confirmed that a blend of rice bran and palm oil (at the ratio 80:20) had a low TPC value (15.7%) and iodine value (86.45 meqO_2/kg) after sixty batches of vacuum frying.

2.4. DEEP FAT FRYING

The deep fat frying also known as immersion frying, the food is fully immersed in hot oil at a temperature of 178˚C to 192˚C. During frying process chemical and physical changes has occurs, such as decrease in moisture content, increase in oil content, increases product temperature and crust formation, denaturation of protein, starch gelatinization and flavour development (Moreira, 2009).

Farkas and Hubbard (2000) reported that the heat transfer during deep fat frying was mainly due to conduction and convection. The heat transfer through convection was governed by heat transfer coefficient while conduction depended on thermal conductivity coefficient. In convection mainly two types, free convection and forced convection. Natural convection took place between submerged food surfaces in oil which was the initial heating stage in frying and forced convection was present at boiling stage. Due to turbulence in frying the heat was transferred from natural convection to forced convection at the second stage of boiling. In the third stage of falling film transfer of heat was initiated through conduction within the inner part of food. Final stage of boiling was bubble endpoint, thickening of crust surface, which decreased the heat transfer, and resulted in the absence of bubbles on the surface of the food.

Morrison *et al.* (1973) compared the different commercial oils with sun flower seed oil based on the tendencies to oxidise after frying and cooking. The sunflower oil was showed better results and it has less prone to oxidation after used than the commercial oils even with lower initial oxygen value.

Brncic *et al.* (2004) investigated the decrease of oil absorption in pre-treatments during deep fat frying of potato strips. In their study oil (sunflower oil, vegetable oil and palm oil) and pre-treatments (blanching in water solutions of calcium chloride, immersion in carboxymethyl cellulose) was tested. The low oil uptake was observed in samples blanched with calcium chloride pre-treatments.

Yildiz *et al.* (2007) determined heat and mass transfer in potato chips during frying of sunflower oil for different temperature (150, 170 and 190ºC). During frying, heat transfer found to be decreased and mass transfer coefficient decreased with increased oil temperature. The moisture diffusivity increased with increased frying temperature. Fig. 2.1 represented the heat and mass transfer during deep fat frying.

Gharachorloo *et al.* (2010) recommended palm oil for the deep fat frying. In their study, compared the quality of frying oils (sun flower, palm and soya bean oil) for its oxidation stability under microwave treatment. The results concluded that, palm oil had greater stability on repeated frying with low percentage of total polar compound (TPC) (21%) after 15 h of frying.

Ahromrit and Nema (2010) used Fickian diffusion theory to explain the heat and mass transfer properties of pumpkin, sweet potato and taro during frying. The results indicated that diffusion theory was simple to determine the heat and mass transfer properties.

Shaker (2015) compared the air frying and traditional deep fat frying for production of healthy potato strips. The changes in physico-chemical substances of fried potato chips were higher in deep fat frying than air frying method, moreover oil content and moisture content of fried potato strip was lower in traditional frying process.

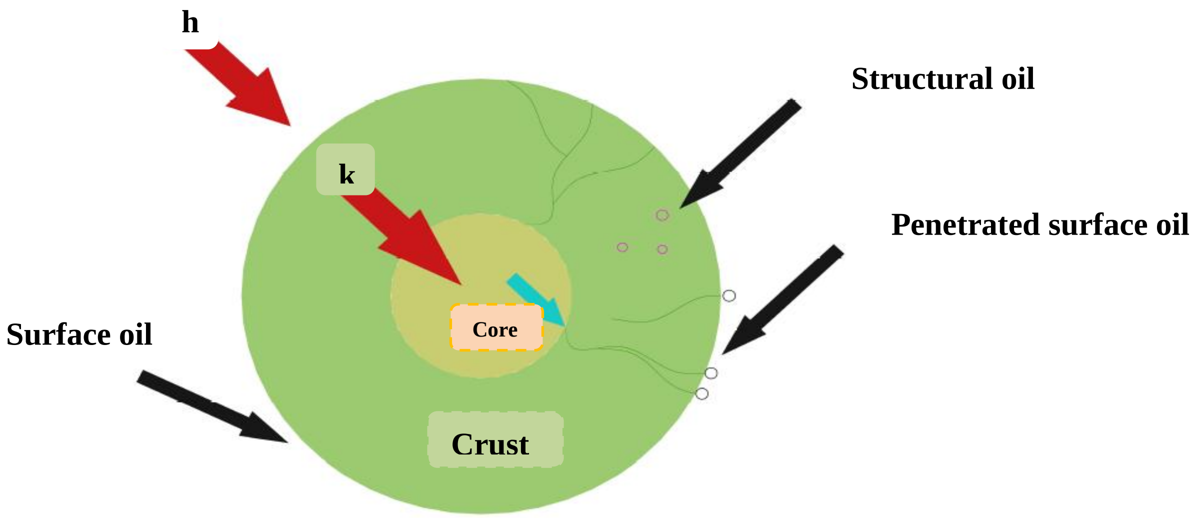

Fig. 2.1. Heat and mass transfer during atmospheric deep fat frying

2.5. VACUUM FRYING

Vacuum frying is a new and promising technology in which samples were fried under low pressure, which lowers the boiling point of the water in foods and smoking point in oil (Shahraki and Mashkour, 2012). Vacuum frying process retains the colour, texture and reduced the production of acrylamide content of fried products. Vacuum frying enhances the organoleptic and nutritional properties in fried products (Jorge *et al.* (2012).

Perez-Tinoco *et al.* (2008) studied physicochemical and nutritional quality of pineapple chips during vacuum frying. The result revealed that the moisture content, water activity and vitamin compounds were decreased, while dehydroascorbic acid and phenolic content were increased during vacuum frying.

Maadyrad *et al.* (2011) developed vacuum fried kiwifruit chips at frying condition of 105ºC, 8 min and 6.2 kPa. The results showed that shelf life of kiwi fruits could extended using vacuum frying process.

Dueik and Bouchon (2011) stated vacuum frying as an ideal frying method for frying carrot, potato and apple chips without significant degradation in nutritive quality when compared to atmospheric frying. The vacuum frying was performed at a pressure of 6.48 kPa; temperature of 98ºC for a period of 4.5 min. Vacuum fried carrot chips were retained 90% of total carotenoids in apple chips and reduced acrylamide formation upto 94% 95% of ascorbic acid (AA) in potato chips.

Diamante *et al.* (2012) studied the vacuum frying of apricot chips at frying condition of 100ºC, 65 min for 2.3 kPa. The results revealed that vacuum frying retains colour and nutritional properties during low temperature and low pressure conditions.

Segovia *et al.* (2016) conducted an experimental study on effects of processing condition for vacuum frying of cassava chips. In their study treatments like blanched, unblanched, processing condition at 17 kPa pressure of 120°C, 130°C and 140°C and compared with atmospheric pressure of 101.3 kPa at a temperature of 165°C. The results revealed that pre blanched chips had a better retention of colour, texture and less oil uptake at 130°C under vacuum condition.

2.5.1. Vacuum frying system

Garayo and Moreira, (2002) conducted an experiment on vacuum frying of potato chips. Vacuum frying system consists of electric pressure cooker of 24 l capacity with vessel of 28 cm inner diameter 0.8 cm and 0.8 cm wall thickness, made of cast aluminium, which could resist an internal pressure of 2 atm. The dual vacuum pump was used for generating 1.33 kPa pressure and a condenser having dry ice trap. The vacuum fried chips had good colour, flavour, texture and less oil content than the atmospheric fried chips.

Yamsaengsung *et al.* (2011) developed vacuum frying system (Fig.2.3) and studied the effect of vacuum frying on structural changes of banana chips. The system comprised of a liquid ring vacuum pump for the production of vacuum in frying chamber. The heat was supplied through the gas cylinder with external flame to heat the oil in frying and storage chambers. The results of SEM showed that frying time slightly increased the size of bananas chips and shape factor.

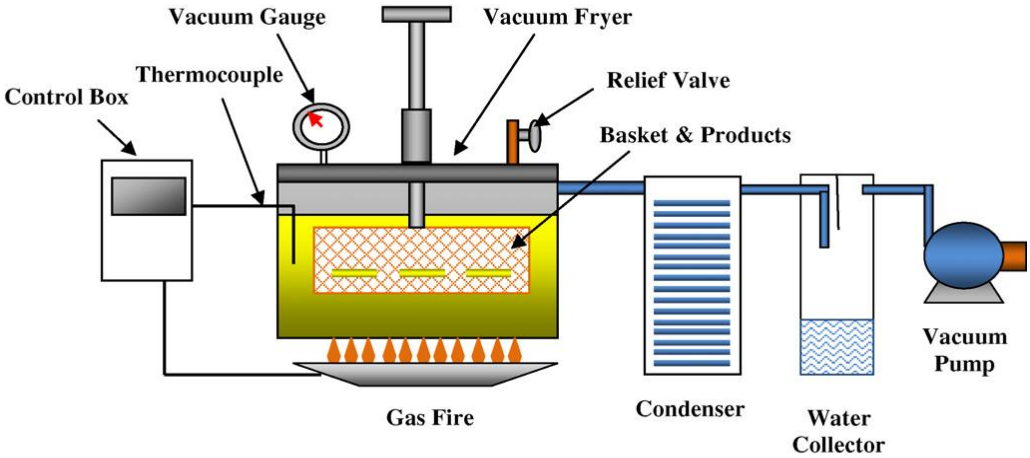

Fig. 2.2 Schematic of the vacuum frying operation

Su *et al*. (2016) developed microwave assisted vacuum frying system to improve the quality of the product and to reduce the oil uptake in potato chips. The microwave devices were uniformly located around the vacuum chamber. The centrifuge was connected at the top of the frying chamber and oil storage chamber. The heating coils were provided for heating the oil at frying and storage chamber. Vacuum pump was used to produce the vacuum in both the chambers. The microwave heating power of vacuum frying was 4000 W. The study revealed that microwave with vacuum fried products had a better result than the vacuum fried potato chips.

Ranasalva and Sudheer (2017a) developed a batch type vacuum frying system for banana chips. This vacuum frying system consisted of two chambers namely; oil storage (length 835 mm and 356 mm diameter) and frying chamber (length 984 mm and 406 mm diameter) were made of stainless steel (SS 316). Vacuum frying system was controlled by a microprocessor and PID (Proportional Integral Derivative) controller. The de-oiling system was mounted inside the frying chamber with frying basket. The vacuum fried banana chips had a good colour, texture, flavour, less oil and acrylamide content.

2.5.2. Process parameters for vacuum frying

The process parameters such as temperature, pressure and time are important parameters to optimise the product quality. Da-Silva and Moreira, (2008) conducted study on vacuum frying of vegetables. Some vegetables like sweet potato, mango, green beans and blue potato were tested at temperature of 120-130ºC with respective time. The vacuum frying at 121˚C temperature produced good quality vacuum fried chips (Potato, green bean, mango and sweet potato) with less oil content, moisture content and water activity.

Garayo and Moreira (2002) evaluated the vacuum frying of potato chips at different temperatures of 118˚C, 132ºC and 144˚C and vacuum pressure of 16.6 kPa, 9.88 kPa and 3.11 kPa. The study revealed that the potato slices vacuum fried at temperature 144ºC and 3.115 kPa pressures had a better colour, texture and less oil uptake than atmospheric fried potato chips.

A study carried out to analyse the effects of vacuum frying and osmotic dehydration to produce a better quality mango chips, showed that a temperature of 120ºC with pre-treated with 65(w/v) osmotic concentrations for 60 min produced best results (Nunes and Moreira, 2009).

Maadyrad *et al.* (2011) standardised the vacuum frying of kiwi fruit by the response surface methodology. Results indicated that vacuum frying at 105°C of 62 bars and 8 min was the best combination for vacuum fried kiwi fruit chips.

Pan *et al*. (2015) illustrated that frying temperature significantly affected the oil absorption and moisture loss in vacuum fried breaded shrimp. The oil content increased with increased temperature (90, 100 and 120°C). The shrimp fried at temperature of 120°C, frying pressure of 20 kPa for 12 min showed highest oil content of 0.25 ± 0.019 g oil/g dry solid.

Suryatman and Ahza (2016) optimised the process parameters for vacuum fried rice –straw mushroom stem chips. For this experiment three temperatures (80˚C, 90˚C and 100˚C), four frying times (3, 6, 9, and 15 minutes) with 2 mm mushroom slices were tested. The results showed that vacuum frying at 100˚C for 3 min generated a good quality chips.

Torres *et al.* (2017) experimented by using response surface methodology to optimise the vacuum frying of eggplant. In this experiment, used a lab scale vacuum frying machine with a fixed vacuum frying pressure of 30 kPa. The results revealed that product fried at 121ºC for 3 min of blanching pre-treatment produced best quality attributes in vacuum fried egg plants.

Ranasalva and Sudheer (2017a) optimised process parameters for vacuum frying of ripe banana chips by response surface methodology. In this experiment, used four temperatures (90, 100, 110 and 120ºC), pressure (10, 15, 20 and 25 kPa) and time (10, 12, 14 and 16 min). The results revealed that product fried at 105ºC and 18 kPa for 13 min produced a novel healthy snack with less oil content.

2.6. PRE-TREATMENTS OF VACUUM FRYING

Pre-treatment is to reduce the oil absorption in the fried product and it improves the quality of the fried products. For research purposes blanching cum drying, edible gum coating and freezing can be used as pre-treatments (Ranasalva and Sudheer, 2017b).

2.6.1 Blanching cum drying

Blanching is a pre-treatment method, which inactivates the enzymes present in the fruits and vegetables. Drying is a convective heat transfer process in which moisture from the product is removed. Blanching and drying is an important pre-treatment to improve the quality and shelf life of the dried product.

Debnath *et al*. (2003) studied the effect of pre-drying on the kinetics of water loss and oil absorption during deep fat frying of chickpeas flour. The results showed that vacuum frying at 175ºC decreased the kinetic coefficient of moisture transfer (0.056-0.039/s) as well as oil transfer (0.063-0.035/s).

Pedreschi and Moyano (2005) studied the effect of pre-drying on quality of potato chips. The samples were blanched in hot water at 85°C for 3.5min and then fried at 180°C. The oil uptake was 50% less in pre-treated sample compared to untreated sample.

Mariscal and Bouchon (2008) stated that pre-dried vacuum fried apple slices absorbed 50% less oil compared to that of atmospheric fried apple chips.

Hasimah *et al.* (2011) studied the different pre-treatments to produce high-quality vacuum fried pineapple snacks, blanched at 100°C for 3 min by steam cabinet blancher. The results showed that pre-treated vacuum fried pineapple produced less than 30% oil uptake and moisture dropped from 3.4% to 2.1%.

Pahade and Sakhale (2012) studied the effect of blanching for reduction of oil uptake from French fries. The results revealed that water blanching at 85°C for

6 min and drying at 150°C for 3 min in a conventional oven led to less oil uptake and better sensory attributes in vacuum fried product.

Garcia-Segovia *et al.* (2016) stated that water blanching of cassava chips and subsequent frying at 70ºC for 10 min had a better retention of colour and less oil uptake. Hong-Wei *et al.* (2017) stated that thermal blanching as an important operation to inactivate the polyphenol oxidase (PPO), peroxidase (POD).

2.6.2. Freezing

Fan *et al.* (2005) conducted pre-treatment of carrot with a combination of 30% mixed aqueous solution of malt and dextrin (2:1) for 1 h and stored overnight at -18°C. The results revealed that pre-treatment of freezing at -18ºC was an alternative method for improving quality of the product. The vacuum fried apricot chips were pre-treated with freezing at -18°C in a chest freezer for 24 h and soaking in 70% maltodextrin (MD) at 20°C (Diamante *et al*., 2011).

Shyu *et al*. (2005) observed the effect of pre-treatment and process parameters on the quality of vacuum fried carrot chips. The carrot slices were treated in freezer at -30°C for overnight. The study revealed that frozen vacuum fried product had high oil content, high water activity but good textural property.

Hasimah *et al.* (2011) was optimised the sensory qualities of vacuum fried pineapple stack. Pre-treatment of freezing at -20°C for 20 h resulted in a vacuum fried product with good textural property and better quality. The oil content of frozen product was higher than maltodextrin pre-treated sample in potato chips (Diamante *et al.* 2011).

Ophithakorn and Yaeed (2016) observed that microstructure change occurs in fish tofu during vacuum frying. Before frying samples were frozen at -20°C until defrosting and defrosted at 4°C overnight in the refrigerator. The frozen fish tofu of vacuum frying had less microstructure changed due to rapid formation of the microstructure pores during evaporation of the ice crystals during frying.

2.6.3. Edible gum coating

The edible film coating is like a wax that in applied to the fruits for better retention of quality, to prevent loss of moisture, to create shine on fruits. Moreover, the main intention is to preserve the colour, texture, reduces oil uptake and increases the shelf life of product. In food industry hydrocolloids have wide varieties of application and it posse's good barrier properties to lipids, carbon dioxide and oxygen. The edible coating materials have a number of natural flavours and substances such as protein, cellulose derivatives, polysaccharides, starches, pectin, plasticisers, and lipids are used for the purpose. It mainly depends on its barrier and mechanical behaviour of foods (Raghav *et al.* 2016). The edible coating was applied by dipping, spraying or casting. The hydrocolloids used as eating materials are gellam gum, pectin (three types), k-carrageenan-konjac-blend, soy protein isolate (SPI), sodium caseinate, methylcellulose (MC), gelatin, microcrystalline cellulose, locust bean gum, whey protein isolate (WPI) and vital wheat gluten. The double layer and multiple coating were most effective in reducing oil absorption than single layer coating but retention of water was higher (Albert and Mittal (2002).

Kim *et al.* (2011) studied the effect of hydrocolloids on the oil absorption and heat transfer during frying. The hydrocolloid coated (gellan and guar gum) samples fried at 170°C and the coating significantly reduced the heat transfer and oil content in the fried sample.

Singthong and Thongkaew (2009) studied the effect of different hydrocolloid (alginate, pectin and carboxymethylcellulose) coated on deep fat fried matured banana (*Musa sapientum Linn*.) Pectin was reported to reduce oil content by 23 g/100 g and had a higher sensory score in all quality attributes.

Sahin *et al.* (2005) studied the use of different gum type (hydroxyl propyl methyl cellulose (HPMC), guar gum, xanthan gum, and gum Arabic) coated in chicken nuggets for deep fat frying. Coated sample was fried at 180°C for 3, 6, 9 and 12 min. Results revealed, that HPMC and xanthan gum reduces the oil uptake and moisture content of fried chicken nuggets compared to other gums.

Bouaziz *et al.* (2016) studied the quality of fried potato by treating with almond gum. Potato was treated with almond gum of concentration (0 to 20 g/l) and dried for 2 h. Results showed that oil content of fried potato chips by was reduced 34%.

Norizzah *et al.* (2016) studied the effect of hydrocolloids (xanthan gum and carrageenan) on the oil uptake during repeated frying of banana fritters. Sliced banana was dipped in 1% carrageenan, 1% xanthan gum, and control and fried at 170°C for 3min. They results showed that banana fritters with batter containing xanthan gum and moisture treated sample had better quality product than other treated sample.

Angor (2016) demonstrated the effects of coated films (carboxymethylcellulose and soy protein) on the reduction of oil fried in potato pellet chips. Results revealed that all coated products had less fat absorption and moisture retention. Moreover, 10% coated solution produced the most desirable effect on oil uptake in SPI (Soy protein isolate) and CMC (Carboxy methyl cellulose).

2.7 DE-OILING OF FRIED PRODUCTS

The de-oiling is centrifugation process, to remove surface oil resulting in very low oil content in the final product. De-oiling is a unit operation for all kinds of fried products (Pandey, 2009).

Moreira *et al.* (2009) reported the effect of de-oiling on vacuum fried potato chips. In their study potato chips were fried at 120ºC, 130ºC and 140ºC for 6 min and de-oiled at 750 rpm for 40 s. The results indicated that vacuum frying with de-oiling could reduce the oil content to 80-90%.

Sothornvit (2011) evaluated the effect of centrifugation speed and edible gum coating of vacuum fried banana chips. The study revealed that combination of centrifugation speed and edible gum coating had significantly reduced the oil content and improved the quality of fried banana chips.

Ranasalva and Sudheer, (2017a) studied the effects of post centrifugation (de-oiling) on quality of vacuum fried banana chips. The effects of centrifuging speed (400, 600, 800 and 1000 rpm) and time (0, 3, 5, 7, 9 min) on vacuum fried banana chips at 100ºC for 12 min. The oil content of de-oiled chips reduced to 90.9% in vacuum fried banana chips at a speed of 1000 rpm for 5 min.

2.8. CHANGES IN PROPERTIES OF FRYING OIL

During frying several chemical changes occurs in frying oil, leading to significant variations in total polar compounds, colour values, peroxide values, viscosity and free fatty acids.

2.8.1. Viscosity

Kusucharid *et al.* (2009) reported the viscosity of vacuum frying oil from the beginning to last day of frying. Results showed no significant change ($p > 0.05$) with a range of 71.13 to 72.13 cp.

Rani *et al.* (2010) reported the quality changes of trans and trans free fat product during frying. Viscosity increased with the hydrogenation level and the rate of change of non-hydrogenated oil. Viscosity was strongly affected by its degradation products. The trans fat had high changes of viscosity in different time 0.0395 Pa s (4 min), 0.0421(8 min), 0.0445 Pa.s (12min), 0.0667 Pa.s (16 min), 0.0986(20 min) and 0.1416 Pa.s (24 min). The samples got darker and viscosity increased with time of heating.

Rubalya-Valantina *et al.* (2010) studied the viscosity and stability in rice bran and palm oil. The result indicated that unheated rice bran oil had less viscosity than heated rice bran oil and similarly in case of palm oil. Finally, after heating with the desired temperature of rice bran and palm oil, the rice bran had less viscosity changes than palm oil.

Probir *et al.* (2012) observed an increase in viscosity from 56 to 84.48 m Pa s in soya bean oil after eight times of deep fat frying. Lioumbas *et al.* (2012) conducted study on palm and olive oil viscosity during vacuum frying. After 40 times of frying no significant change in viscosity was observed in olive oil.

2.8.2. Total polar compounds

Aladedunye and Przybylski (2009) studied the degradation of nutritional qualities of oil during frying. Total polar compounds content during frying at

180ºC were 19.8% and reached 38% at the end of frying. The oxidative deterioration was very high at 215ºC (0.9653) of heating compared with frying at 180ºC (0.8690).

Kusucharid *et al.* (2009) found the characteristics changes of palm oil during vacuum frying and atmospheric frying of sweet potato chips. In palm oil initial (fresh) total polar compounds was 6.25% which increased from 10.26 to 26.12% under atmospheric frying and 12.57% but under vacuum frying at 8th day of drying.

Amany *et al.* (2012) conducted experiment to obtain high-quality potato chips and fried oil. Initially polar compound of sunflower oil was 0.01%. During frying, some fats and oils undergo oxidation and hydrolysis process to the polar compound. The result showed after 24 h of vacuum frying, sunflower oil liberated less than 25% of total polar compounds.

2.8.3. Peroxide

Gopala Krishna *et al.* (2005) studied the frying performance of processed rice bran oil. Initially the peroxide value was in the range of 3.34 meq/kg to 12.50 meq/kg which increased to 12.30 meq/kg at final frying. The peroxide value increased due to oryzanol content in the frying oil.

Kusucharid *et al.* (2009) studied the comparative effects of vacuum frying and atmospheric frying of sweet potato chips in palm oil. From day one to fourth day of frying peroxide value (4 meq/kg) was increased but after fourth day it decreased in both the frying.

Amany *et al.* (2012) conducted experiment on vacuum frying of potato chips with sunflower oil for better quality production. The peroxide value was increased to 42.12 meq/kg oil under vacuum frying and 45.13 meq/kg oil under atmospheric frying after 24 h.

Nayak *et al.* (2016) assessed the effect of quality of mustard oil during deep fat frying. The peroxide value of mustard oil had increased beyond average oxidation after 20-25 h of deep fat frying.

2.8.4. Free Fatty Acids

Kusucharid *et al.* (2009) documented the palm oil quality parameters during vacuum and atmospheric frying of sweet potato chips. Initially quality of free fatty acid of 0.46 mg KOH/g. After frying it increased to 1.23 mg KOH/g in vacuum frying and 3.82 mg KOH/g in atmospheric frying from the day one to 6th day of frying.

Amany *et al*. (2012) stated that the free fatty acid of sunflower oil was increased during atmospheric as compared to vacuum frying of potato chips.

Ismed, (2016) studied the effects of frying time and temperature on properties of carrot chips by using vacuum frying. Frying time and the temperature had less effect on rice bran oil during vacuum frying. Less free fatty acids were produced during vacuum frying.

Nayak *et al.* (2016) evaluated the quality of mustard oil during deep fat frying. During deep fat frying, FFA of mustard oil increased from 0.73 to 4.38% after 30 h of frying.

2.8.5. Colour values

Kusucharid *et al.* (2009) showed that colour values (L*, a*, b*) was changed during the first day to final day of vacuum and atmospheric frying of sweet potato chips. The L* value decreased while a* and b* values increased with frying time.

Tarmizi *et al*. (2013) substantiated that, the colour values of fried oil were relatively less in the oil drained at vacuum condition than atmospheric condition. Since drainage at vacuum condition employed 50% low temperature than atmospheric condition, a reduction of 46.7% darkness was noted in L* value in vacuum drained fried oil than atmospheric drainage.

Nayak *et al.* (2016) studied the quality assessment of mustard oil during frying. The L*, a* and b* value decreased and after 30 hours of frying a* turned out to be negative. This indicated that the colour changed from reddish to dark compared to fresh oil. The changes in colour values of oil mainly depend on heating temperature and time.

2.9. PRODUCT CHARACTERISTICS OF VACUUM FRYING

2.9.1. Moisture content

Shyi-Liang and Hwang (2001) studied the effect of process condition on vacuum fried apple chips. The results showed that after frying at 90ºC for 5 min moisture content of VF-apple chips increased to 8% and frying at 100ºC for 20 min reduced the moisture content to 2%.

Maity *et al.* (2014) stated that temperature and time significantly affected the moisture content of vacuum fried jack fruit chips.

Su *et al.* (2016) studied the moisture content of novel micro-assisted vacuum fried potato chips. The moisture content of both vacuum fried and micro-assisted vacuum frying potato chips reduced from 80% to 6%, because of the application of microwave energy.

Ren *et al.* (2018) investigated the effects of pre-treatments on vacuum fried shiitake mushroom chips. The results revealed that combination of blanching-osmotic-freezing produced low moisture content (2.52 kg/kg db) compared to other pre-treated vacuum fried shiitake mushroom chips.

2.9.2. Oil content

Fan *et al.* (2006) studied the effects of pre-treatment on vacuum fried carrot chips. The study showed that the blanching-cum-osmotic (0.23 kg/kg db) fried pre-treated sample had minimum oil uptake than other pre-treated VF-carrot chips.

Mariscal and Bouchon (2008) conducted study on comparison of vacuum frying and atmospheric frying of apple slices. Their results showed that the highest oil uptake was observed for atmospheric fried apple chips, whereas the lowest was for pre-dried vacuum fried apple chips.

Sothornvit, (2011) stated that oil content of coated banana slices had less oil uptake compared to control. The hydrocolloids of guar gum coating produced greater oil absorption (25.22%) than xanthan gum coating in banana chips (17.22%).

Yagua and Moreira (2011) studied the physical and chemical changes during vacuum frying of potato chips. Results showed that the potato chips fried at higher temperature had higher total oil content than those fried at lower temperature and also the final internal oil content was found to be lower at higher temperature.

Maity *et al.* (2017) did experiment on vacuum frying of jackfruit by using different pre-treatments. Result showed that, the oil uptake of partially dried jackfruit chips, pre-frozen sample and control (untreated) were 28.3%, 33.1% and 30%, respectively.

2.9.3. Water activity

The threshold limit of water activity for the microbial growth in dehydrated products is 0.6. Perez-Tinoco (2008) found that, water activity of vacuum fried pineapple chips was less than 0.29 a_w.

Dueik *et al.* (2010) reported that, the water activity of vacuum fried carrot chips was 0.44 a_w which is well below the tolerance limit. Sothornvit (2011) studied the effect of post frying and edible coating on vacuum fried banana chips. The result revealed that gum coated with high centrifuge speed had less water activity than other pre-treated vacuum fried banana chips.

Ren *et al.* (2018) stated the water activity of pre-treated (Blanching + osmotic + coating) vacuum fried Shiitake mushroom chips was 0.25 a_w which was less than the other pre-treated sample.

2.9.4. Bulk and true density

Yauge and Moreira (2011) stated that, bulk density decreased from initial value of 1103 kg/m^3 to 453 kg/m^3, while true density increased from 1088 kg/m^3 to 1404 kg/m^3 in vacuum fried potato chips.

Ravli *et al.* (2013) conducted two stage vacuum frying of sweet potato chips. The results revealed that during single stage frying bulk and true density were decreased and increased under the dual stage vacuum frying.

2.9.5. Colour values

Mariscal and Bouchon, (2008) observed the major changes in colour values of L* (Lightness) and a*(red-green chromaticity) during atmospheric frying and vacuum frying. The overall L* and a* values decreased during atmospheric frying with increased frying time.

Perez-Tinoco, (2008) reported that vacuum fried pineapple chips at 112ºC produced a better colour values of L*(81.2), a*(9.12) and b*(41.29) than at other frying temperatures.

Dueik and Bouchon (2011) studied the colour values of vacuum fried carrot, apple and potato chips. The results revealed that L* value of vacuum fried chips was consistently higher than atmospheric fried chips. Similar trend was observed in case of a* (redness) and b* (yellowness) values.

Goswami *et al.* (2015) stated the lightness of the fried chips is important criteria for consumer acceptance. Maity *et al.* (2017) reported effects of pre-treatments on physico-chemical properties of vacuum fried jackfruit chips. The results revealed that untreated and frozen pre-treated sample had good colour values than other pre-treated vacuum fried jack fruit chips.

2.9.6. Texture

The textural property is important parameter for all food products, especially in fried products. The chips produced from the vacuum and atmospheric frying had no significant difference in texture. However, pre-treatments like blanching cum drying, gum coated created difference in textural changes in fried products (Sahin *et al.*, 2005).

Yamsaengsung *et al.* (2011) revealed that during storage the hardness value of vacuum fried potato chips increased due to presence of moisture. In this study during storage hardness value ranged from 16.51 N to 11.79 N at fourth day of studing.

Dueik and Bouchon (2011) experimented on vacuum and atmospheric frying of carrot chips and results concluded that the frying technology significantly ($p<0.05$) affected the textural properties of products.

García-Segovia *et al.* (2016) stated that vacuum frying increased temperature brought decreases the area under the force versus displacement curve and increased the hardness value of 5.1 N in potato chips.

Wexler *et al.* (2016) stated the vacuum fried papaya chips fried at 117 ºC had4 N of hardness value, while in atmospheric fried at 150ºC had 7.79 N of hardness value. The high hardness value indicated the less crispy product.

2.9.7. Thickness Expansion

Yamsaengsung *et al.* (2011) studied the, structural changes of vacuum fried banana chips. The study found the highest degree of expansion at 110ºC, 8 kPa and 20 min. Ravli *et al.* (2011) stated that, thickness expansion of the sweet potato chips in single stage of vacuum frying was suddenly reduced to negative values for the early times of frying and then increased slowly to reach a constant thickness expansion value.

2.9.9. Acrylamide content

The acrylamide is one of the hazardous compounds formed from high starch foods and frying under high temperature products. Tareke *et al.* (2002) opined that formation of acrylamide content is mainly temperature dependent and fresh or untreated food does not exhibit acrylamide content.

Powers *et al.* (2017) stated the acrylamide content increased with increased temperature of 120-170ºC in potato chips. Granda *et al.* (2004) stated the acrylamide formation was high in potato chips during sample were fried under high temperature of 150ºC compared to other temperature.

Granda and Moreira (2005) studied the effect of frying methods on acrylamide formation in potato chips under vacuum (118ºC) and traditional frying

(165ºC). The study reveals that, 94% of acrylamide content was reduced under vacuum condition in potato chips. Moreover, atmospheric fried chips had 193 ppb of acrylamide content but in vacuum condition found only 25 ppb.

Bekas *et al.* (2006) examined the acrylamide content of 32 commercial deep fat fried potato chips samples available in local market of Poland. The acrylamide content ranged from 380µg/kg to 861µg/kg, which was identified to be safe when consumed occasionally.

Daniali *et al.* (2010) compared the acrylamide content in various deep fat fried banana snack products. The results found that the banana fitters had the highest acrylamide content of 7468.8 µg/kg compared to other snacks.

Barutcu *et al.* (2009) studied the acrylamide formation in different batter formulations during microwave frying. The microwave frying provides less production of acrylamide content and lighter colour, as compared to fried in traditional frying for 5 min.

Abdel-Monem *et al.* (2013) studied that impact of pre-treatment on acrylamide formation in fried chips and result found that blanched, soaked fried chips produces less acrylamide content than control (un-treated) products.

Pedreschi *et al.* (2016) reported the pre-dried sample increased the acrylamide formation in fried potato chips and those soaked in Nacl solution had less acrylamide content.

2.10. SENSORY EVALUATION

A nine point Hedonic scale was used by Kusucharid *et al,* (2009), Ravli *et al.* (2013), Crosa *et al,* (2014), Segovia *et al.* (2016) and Ranasalva and Sudheer (2017a) to perform the sensory evaluation of fried food products.

2.10.1. Fuzzy logic on sensory evaluation

Fuzzy logic is an important tool by which vague and imprecise data could be analysed and important conclusions regarding acceptance, rejection, ranking, strong and weak attributes of food could be drawn. Fuzzy sets could be used for the analysis of sensory data instead of average scores to compare the sample attributes (Shinde and Pardeshi, 2014).

Jaya and Das (2003) conducted the sensory evaluation of reconstituted mango drink and three other commercial branded mango drinks (Real, Slice and Frooti) using fuzzy logic. The mango drink of brand ‘Slice’ ranked first of (0.24) for taste, ‘Real’ brand of (0.227) for taste, reconstituted mango drink (0.215) for mouthfeel and ‘Frooti’ with (0.205) for taste.

Lazim and Suriani (2009) selected three types of coffee product (Nesc, Indoc, Incom) for sensory evaluation. The coffee product of Indoc had a ranked first of 0.950 for taste, Nesc product (0.820) for taste, Incom coffee product (0.700) for taste. The results indicated that best sensory attributes obtained by Indoc coffee product for taste and overall acceptability.

Routray and Mishra (2012) conducted a sensory evaluation for dahi drink for which is available in the standard market. In this study, selected three types of sample for evaluation, sample 1((S1), dahi powder and water), sample 2 ((S2), dahi powder, guar gum, locust bean gum and water) and sample 3 ((S3) dahi powder, guar gum, locust bean gum, vanilla essence and water). The result found that S3 and S2 are well designated than the S1. So the ranking of drink was S3>S2>S1.

Mukhopadhyay *et al.* (2013) conducted sensory analysis for 5 samples of chhana podo. The analysis was done on a five-point Hedonic scale with 120 sensory panels. These sensory results were validated with its ranking of attributes using Fuzzy logic. Among these, the sample that ranked first had the following scores in each attributes i.e., aroma (0.845), colour (0.835), mouth feel (0.802) and taste (0.792).

Shinde and Paradeshi (2014) conducted a sensory evaluation of commercially available jam samples by using fuzzy logic model. The result indicated that the sample X4 (0.7163) was ranked highest followed by X3 (0.6556), X2 (0.6559) and X1 (0.6559). Based on the values ranking of jam sample was X4>X3>X2>X1.

Kaushik *et al.* (2015) conducted sensory analysis of high pressure processed mango pulp and litchi juices compared with the untreated and thermally treated sample by using fuzzy logic. Results revealed that high pressure processed samples ranked first in taste than thermally processed mango and litchi juice.

Ranasalva and Sudheer (2017a) conducted sensory analysis of pre-treated vacuum fried banana chips compared with untreated and atmospheric fried sample by using fuzzy logic. The results revealed that untreated vacuum fried banana chips sample ranked first in colour and taste than other pre-treated vacuum fried banana chips.

2.11. PACKAGING AND STORAGE STUDIES

Illeperuma and Jayasuria (2002) used nitrogen flushing in aluminum pouches laminated with polyethylene for osmotic dehydrated bananas and extended its shelf life upto eight months of storage without affecting its sensory attributes.

Fan *et al.* (2007) studied the storage stability of carrot chips. They stored the chips in 25 µm low-density polyethylene (LDPE) film with 95% of nitrogen gas flushed and had a shelf life of 6 months.

Presswood (2012) reported that vacuum fried beef could stored up to 32 weeks at 15-25ºC temperature under aluminium foil laminated pouches with reduced water vapour transmission rate.

Esana *et al.* (2015) reported that sweet potatoes fried at 108ºC for 9 min and vacuum packed in polyethylene bags had a shelf life of 30 days.

2.12. STATISTICAL METHOD

The optimisation of the vacuum fried chips was done by researchers using different statistical tools. Fan *et al.* (2005) selected RSM for designing of vacuum fried dehydrated carrot chips and analysed data by SPSS version 10. Diamante *et al*. (2011) used completely randomised design for the design of vacuum frying of apricot slices and analysed by design expert version 9.0. Presswood, (2012) studied the vacuum fried beef strips by using RSM. Wexler *et al*. (2016) used the response surface methodology to compare vacuum and atmospheric frying of papaya chips impregnation with blackberry juice. Ranasalva and Sudheer (2017a) used the response surface methodology (RSM) for vacuum frying of banana chips and analysed by design expert version 7.0.0. However, selection of standardisation design was based on the levels and treatments factors.

CHAPTER-III

MATERIALS AND METHODS

This chapter constitutes the detailed description about materials used and the methods adopted for the "Development and evaluation of process protocol for vacuum fried bitter gourd chips (*Momordica charantia*)". This study was a part of the state network project, Centre of excellence in Post Harvest Technology under Kerala Agricultural University. A detailed modus operandi of the research has been explained under the consecutive subheadings.

3.1 Sample preparation

3.2 Vacuum frying system

3.3 Vacuum frying process

3.4 Optimisation of pre-treatment for vacuum frying of bitter gourd chips

3.5 Standardisation of process protocol for vacuum frying

3.6 Product quality parameters

3.7 Oil quality parameters

3.8 Sensory evaluation

3.9 Packaging studies

3.10 Storage studies

3.11 Stastical analysis

3.12 Cost economics

3.1 SAMPLE PREPARATION

The green coloured matured bitter gourd (CV: *Priya*) was used for the study and it is showed in Plate 3.1. The bitter gourds of medium long (25-30 cm) and thickness of 5-6 cm were procured from local market. The procured bitter gourds were stored at 10ºC temperature and 75-80% relative humidity (Lastriyanto *et al.*, 2013). Bitter gourds were cleaned manually and sliced into slicer of thickness ranging from 1.5 to 2.0 mm using slicer (Balakrishna Engineering, Coimbatore, India) with stainless steel blade (SS 304). The average diameter of bitter gourd slices was 39.07 mm. The thickness and diameter of sliced bitter gourd was measured by vernier calliper (RSK Digital Caliper, China).

Plate 3.1 Raw bitter gourd

3.2 VACUUM FRYING SYSTEM

Batch type vacuum frying system of 3 kg capacity was used for preparation of fried bitter gourd chips. The vacuum frying system consists of two chambers i.e. frying and oil storage chamber. Frying chamber and oil storage chamber were made of stainless steel (SS 316) and chambers were provided with heaters of 3 kW and 1.5 kW. Vacuum frying system was controlled by a microprocessor and PID (Proportional Integral Derivative) controller. A de-oiling system was mounted inside the frying chamber with frying basket holder (Ranasalva, 2017).

3.2.1 De-oiling system

De-oiling system consisted of 0.5 hp motor (Make: Prime motors, India) with 6 poles and rotates at 1000 rpm. The motor was mounted at the top of the frying chamber and connected to frying basket holder at the other end. The frying basket holder was fastened with a screw mechanism to contain the frying basket during frying and de-oiling. Frying basket was made of stainless steel (SS 316) with curved bottom (30º) provided with closure. The curved bottom of frying basket aided in the easy draining of oil after frying (Ranasalva, 2017).

3.2.2 Pressure system

The Pressure system was constructed with pressure transmitter (Make: SETRA, India) and its measuring range was 0 to 250 kPa. The pressure was maintained by 2 hp water ring vacuum pump (Make: Sabara, India) of 30 m^3/kg capacity. The compound dial gauge type of instrument was used for measurement of pressure (-1 to 4 kg/cm^2) in storage and frying chamber. In frying basket two separate pneumatically operated spherical disc butterfly valves (Make: AIRA, India) were attached with each chamber to create a vacuum inside the chambers. The pressure difference was created through vent valves by using nitrogen gas, between the chambers, to transfer oil. Nitrogen gas was used to maintain the oil quality, as creation of pressure gradient using air enhances the chance of oxidative rancidity. The oil was transferred from the storage tank to frying tank and vice versa through SS ball valves. Plate 3.2 represents the vacuum frying system used for the present study (Ranasalva, 2017).

3.2.3 Cooling system

The cooling system included a cooling tower of 10 L capacity attached with 1 hp water pump (Make: Protech, India) with a head flow of 5 to 10 lpm. Vapour removed during frying was condensed using shell and tube heat exchanger. The vapour was collected through a closed basin fitted with a ball valve (Ranasalva, 2017).

3.3 VACUUM FRYING PROCESS

The vacuum frying process could be divided into four stages *viz*, Depressurisation, frying and de-oiling, pressurisation and cooling (Garayo and Moreira, 2002; Ranasalva and Sudheer, 2017a) (Table. 3.1). The step involved in vacuum frying process is illustrated below.

3.3.1 Sample loading

The prepared samples were weighed initially and loaded into frying baskets. The two frying baskets were loaded with equal quantity (approx. 1050-1100 g each) of samples in order to have a balance during de-oiling. The loaded frying baskets were kept inside frying chamber using basket holder and chamber was closed tightly.

Plate 3.2. Vacuum frying system for bitter gourd chips

1.	Compressor	2.	Nitrogen cylinder	3.	De-oiling motor
4.	Oil storage chamber	5.	Cooling tower	6.	Control panel
7.	Vacuum valve	8.	Condenser	9.	Oil flow valve
10.	Frying chamber				

(Ranasalva, 2017)

3.3.2 Frying oil

The blended oil (Rice bran and palm oil at the ratio 80:20) was used as frying oil for vacuum frying (Ranasalva and Sudheer, 2017a). Blended oil was filled into the storage chamber by opening its top lid. This oil was preheated for a period of 15-20 min before frying.

3.3.3 Depressurisation phase

Depressurisation phase is basically a creation of low pressure inside the storage and frying chambers. A Low pressure of 6-13 kPa (Dueik and Bouchon

(2011); Maity *et al.* (2014); Maadyrad *et al.* (2011)) was created by opening the vacuum valve connected with storage and frying chambers. Simultaneously, the frying chamber was heated to the desired frying temperature (Ranasalva, 2017).

3.3.4 Frying and de-oiling phase

Frying was performed when vacuum frying chamber attained the set temperature and pressure. The following pressure changes occurred during this phase within the storage and frying chambers. The vent valve of storage chamber was opened to increase the pressure by using nitrogen gas and then the oil inlet valve was also opened. Due to pressure gradient created between storage chambers (high pressure) and frying chamber (low pressure) oil gets transferred into frying chamber through oil inlet valve. The vent valve and oil inlet were then closed. The loaded bitter gourd slices were immersed in oil for a set frying time. During frying process, the frying basket was rotated at 40 rpm using a de-oiling motor attached to it. After the completion of frying, the pressure gradient was created to transfer the oil from frying chamber to storage chamber. The vent valve of a frying chamber and oil inlet valve was opened favouring the creation of pressure gradient (storage chamber with low pressure and frying chamber with high pressure) to facilitate the movement of oil from frying chamber to storage chamber. The vent valve and oil inlet valve were then closed. The pressure was reduced again inside the frying chamber prior to de-oiling. The de-oiling motor was then set to higher rpm (1000 rpm) for desired time (Ranasalva, 2017). The removal of surface oil from fried bitter gourd chips was effected through a centrifugation process.

3.3.5 Pressurisation and cooling phase

The vacuum was then released in the frying chamber using vent valve. The product was unloaded and allowed to cool till it reaches room temperature (Ranasalva, 2017). The vacuum fried bitter gourd chips were packed in laminated aluminium flexible pouches, LDPE and stand up zipper pouches with aluminium foil back (One side silver and other side transparent) packaging with nitrogen (N_2) flush and stored at room temperature for further analysis.

Table 3.1 Stages of Vacuum Frying

Stages		Characteristics
Phase 1	Depressurisation	Reduction in pressure and increase in temperature to desired level was achieved in storage and frying chambers.
Phase 2	Frying and de-oiling	Frying was carried out at standardized temperature, pressure and time. De-oiling was done by centrifugation of fried samples to remove its surface oil.
Phase 3	Pressurisation	Fried and de-oiled product was brought to atmospheric pressure.
Phase 4	Cooling	Product temperature was brought down to room temperature before packaging and storage.

(Ranasalva, 2017)

The performance evaluation of vacuum frying of bitter gourd chips and blend of rice bran (brand: PAVIZAM, Kerala, India) and palm oil (brand: PALMSON, Kerala, India) (80:20) was done. The procedure is explained under various experiments, *viz.*, Experiment I – Optimisation for pre-treatments for vacuum frying of bitter gourd chips, Experiment II – Standardisation of process and product parameters for vacuum frying of bitter gourd chips and Experiment III – Packaging and shelf life studies of vacuum fried bitter gourd chips.

EXPERIMENT I

3.4 OPTIMISATION OF PRE-TREATMENTS FOR VACUUM FRYING OF BITTER GOURD CHIPS

Based on the preliminary studies of vacuum frying of bitter gourd, a combination of temperature (100ºC) (Shyi-Liang and Hwang, (2001); Diamante *et al.* (2012)), pressure (6 kPa) (Dueik *et al.* (2010); Maity *et al.* (2014)) and time (12 min) (Ranasalva and Sudheer (2015); Tarzi *et al.* (2011)) for the pre-treatment study was selected. The various pre-treatments were adopted for reducing oil uptake and to improve the quality parameters of the fried product. Pre-treatments like edible gum coating, blanching cum drying and freezing were selected for this study. The experimental design for the vacuum frying of bitter gourd with different pre-treatments are described in Table 3.2 and movement flow sheet is lit up in Fig 3.1

Table 3.2. Experimental design of vacuum frying of bitter gourd chips with different pre-treatments

Independent variables	Dependent variables
• Atmospheric fried chips • Blanching cum drying • Control (un-treated) • Edible gum coating • Freezing	Vacuum fried bitter gourd chips properties (Moisture content, water activity, oil content, bulk density, true density, thickness expansion, texture, colour values and sensory analysis)

(Ranasalva, 2017)

3.4.1 Blanching cum drying

The sliced bitter gourd samples of 1.44 mm thickness were water blanched for 2 min at 95ºC (Zhu *et al.* 2015) and dried at 70ºC for 1 h 30 min (Abdulla *et al.* 2013).

3.4.2 Freezing

The sliced bitter gourd samples of 1.44 mm thickness were kept in a freezer at -30ºC for 8 h (Arlai *et al.* 2014).

3.4.3 Edible gum coating

The guar gum coating was prepared by dissolving 1.5% of guar gum in distilled water at 90ºC for 30 min (Sothornvit, 2011). The application of gum on a sliced bitter gourd was performed by dipping and the thickness of the coating was controlled by the duration of dipping. The percentage weight gain was determined by weighing the gum sooner than and subsequently coating. The ratio of a coating solution to bitter gourd slices was maintained at 5:4 and the slices were soaked for seven min within the gum solution.

3.4.4 Atmospheric frying

The atmospheric frying was carried out by immersing the sample in the hot oil, at a frying condition of temperature 165ºC, pressure of 101 kPa and time of 15 min. After each frying process, the samples were removed from the frying vessel and hold in stainless steel sieve to facilitate draining of oil.

3.4.5 Stastical design for pre-treatment of vacuum fried bitter gourd chips

The vacuum frying of matured bitter gourd slices was performed with blended oil (Rice bran and palm oil, 80:20). The pre-treated vacuum fried samples were tested for their quality parameters. These pre-treatments were statistically analysed using ANOVA general two factorial methods (OPSTAT software). Optmisation of pre-treatments was done and the best treatment was selected for further studies.

EXPERIMENT II

3.5 STANDARDISATION OF PROCESS PARAMETRS FOR VACUUM FRYING OF BITTER GOURD

The standardisation of vacuum fried product was done by three different combinations of temperature, pressure and time. The detailed description of the process parameter design has been explained under the experimental design section 3.5.1 and 3.5.2.

3.5.1 Experimental design

To conduct the experiment design in a systematic and economical manner, the experimental work was optimised by completely randomised design. The completely randomised design is a basic special factor design with this design; subjects are randomly assigned to treatments (Fisher and Feynman, 2007). The main advantage of this design is that the analysis of data is simplest as compared to other statistical designs. The independent variables and dependent variables are discussed in section 3.5.2.1 and 3.5.2.2.

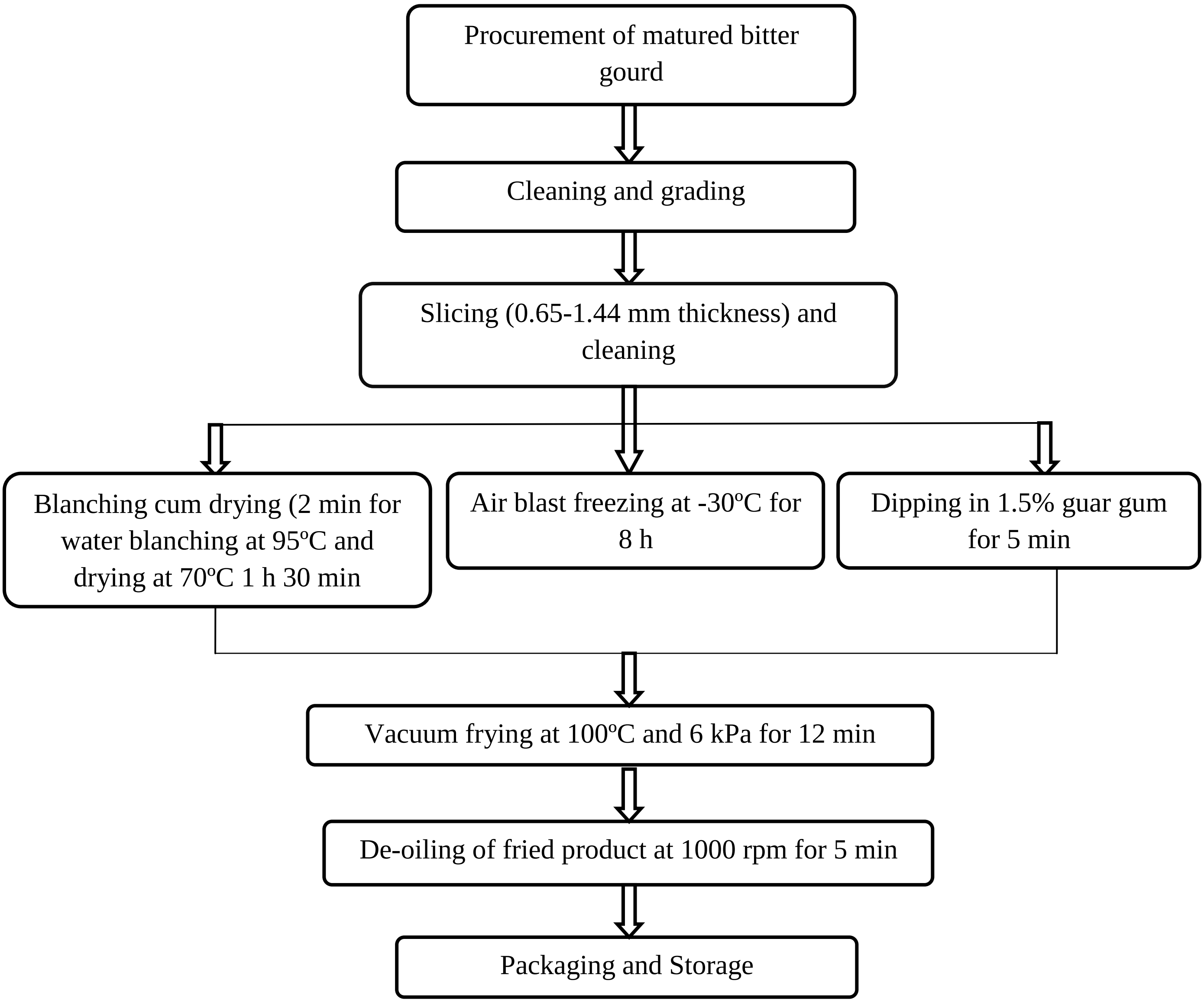

Fig. 3.1 Process flow chart for vacuum frying of bitter gourd chips with different pre-treatments

3.5.2 Vacuum frying parameters

3.5.2.1 Independent variables

The independent variable for the optimisation of process parameters are following below

B_1: Frying temperature (100-120ºC) - 100, 110 and 120 ºC

B_2: Frying pressure (9-13 kPa) - 9, 11 and 13 kPa

B_3: Frying time (10-14 min) - 10, 12 and 14 min

3.5.2.2 Dependent variables

The dependent variable for the optimisation of process parameters is given in Table 3.3

Table 3.3 Dependent variable for optimisation of process parameters

Product quality	Oil quality
Moisture content, oil content, water activity, bulk density, true density, colour values, texture values, energy values, acrylamide content and sensory analysis.	Total polar compound (TPC), peroxide value (PV), colour values, viscosity and free fatty acid value (FFA).

3.5.2.3 Stastical analysis for vacuum fried process parameters

The optimisation of process parameters was done in vacuum fried bitter gourd samples. The obtained results were statistically analysed by using ANOVA general factorial method (WASP software version.2) and standardisation of process parameter was done. The optimised processing condition was selected for further studies.

3.6 QUALITY PARAMETERS OF VACUUM FRIED BITTER GOURD CHIPS

3.6.1 Moisture content

The moisture content of the vacuum fried bitter gourd chips was determined by gravimetric method. Moisture content was calculated by weight loss after drying 3 g of coarsely ground sample in hot air oven dryer at 105ºC for 24 h (AOAC, 1986). The test was pre-formed in triplicates.

3.6.2 Water activity

The water activity of the vacuum fried bitter gourd chips were determined by using water activity meter (Model: Aqua lab, Decagon Devices Inc., Pullman (Wa), USA) (Perez-Tinoco *et al.*, 2008). The water activity meter showed in Plate 3.3.

3.6.3 Oil content

Oil content of vacuum fried bitter gourd chips as analysed by Soxhlet apparatus (Pelican Equipments, Soc plus model: SOCS 06 ACS, India) and test was performed in triplicates (Garayo and Moreira, 2002). The Soxhlet apparatus is shown in Plate 3.4. The oil content of vacuum fried bitter gourd chips was determined by the following equation;

$$\%\ \text{Oil content} = \frac{W_2 - W_1}{W} \times 100 \qquad \textbf{............ (3.1)}$$

Where,

W- Weight of thimble with sample, g

W_1- Weight of empty beakers, g

W_2- Weight of beaker with final extracted oil, g

3.6.4 Thickness expansion

The thickness expansion of vacuum fried chips was determined by using the equation 3.2 (Yagua and Moreira 2011). The thickness of chips was measured by using vernier calliper.

$$L = \frac{l_o - l_{(t)}}{l_o} \times 100 \qquad \textbf{.......... (3.2)}$$

Where,

l_o - Initial thickness of the raw sample, (mm)

l(t) -Thickness of the sample at frying time t. (mm)

3.6.5 Bulk density

The bulk volume of vacuum fried bitter gourd chips was determined by liquid displacement method (Da-Silva and Moreira, 2008). In an experiment, five bitter gourd chips were weighed and the volume in the apparatus was recorded with and without sample. The bulk density of chips was then determined by dividing the weight of the chips by its bulk volume. The bulk density of vacuum fried bitter gourd chips was determined by using following equation (Ravli *et al.*, 2013).

$$\rho_t = \frac{W_s}{V_b} \qquad \textbf{......... (3.3)}$$

Where,

W_s – Weight of the de-oiled sample, g

V_b – Bulk volume of sample, ml

Plate 3.3 Water activity meter

Plate 3.4 Soxhlet apparatus

3.6.6 True density

The true density of vacuum fried bitter gourd chips was determined as per the method recommended by Deshpande and Poshadri (2011) and was calculated by the following equation 3.4.

$$\rho_t = \frac{M_s}{V_t} \qquad \textbf{........... (3.4)}$$

Where,

M_s - Weight of de-oiled sample, g

V_t - True volume of the sample, ml

3.6.7 Acrylamide content

The acrylamide formation in vacuum fried bitter gourd chips was determined using the modified high-performance liquid chromatography (HPLC)–diode array detector (DAD) method (NIIST, Thiruvananthapuram) (Shamla and Nisha, 2014).

3.6.8 Texture analysis

Hardness is a measure of force required to rupture the food products and it is deliberated in Newton (N). The Texture Analyser (TA.XT Texture anlyser, stable micro system) was used for the determination of crispiness and hardness of vacuum fried bitter gourd chips and it is shown in plate 3.5.

In texture analyser test were conducted for individual bitter gourd chips and the required values are obtained from a graph. During testing process, the probe is allowed to move from a top portion to downwards to fracture the sample for a specified distance of 20 mm. Once the probe touched the sample, the maximum force required to rupture the chips were observed and compared between the samples. The crispiness test for vacuum fried bitter gourd chips test was conducted in triplicates in texture analyser. The TA settings used for the test is given below

TA settings

Test Mode	: Measuring force in compression
Option	: Return to start
Pre-test speed	: 1.50 mm/sec
Test speed	: 2.00 mm/sec
Post-test speed	: 10.00 mm/sec
Distance	: 20.00 mm

Trigger type	: Auto (force)
Trigger force	: 5.0 g
Probe	: Blade set (HDP/BS)

3.6.9 Protein content

The protein content of vacuum fried bitter gourd chips was determined according to AOAC standard procedure (AOAC, 2005).

Plate 3.5 Texture analyser

3.6.10 Crude fibre content

The crude fibre of the vacuum fried bitter gourd chips was estimated by using moisture and fat-free samples by (AOAC, 1980)

$$\text{Crude fibre g/100g} = \frac{[100 - (\text{moisture} + \text{fat}) \times (W_e - W_a)}{(\text{Weight of the sample (moisture and fat content))}} \times 100$$

.... (3.5)

Where,

We- Pre-weighed ashing dish, g

Wa- Weight of the dish after ashing, g

3.6.11 Carbohydrates content

Carbohydrate content of bitter gourd chips was determined by following equation

$$\text{Carbohydrates (g/100)} = 100 - [\text{Protein (g)} + \text{Fat (g)} + \text{Moisture (g)} + \text{Ash (g)} + \text{Fiber (g)}$$

.... (3.6)

3.6.12 Energy content

The energy content of the vacuum fried bitter gourd chips was determined by standard equation (Ekanayake *et al.*, 1999) which involves the fat content, protein, and carbohydrate content.

$$\text{Energy (kJ/100 g)} = [(\text{Protein (g)} \times 4) + (\text{Carbohydrates (g)} \times 4) + (\text{Fat (g)} \times 9)]$$

.... (3.7)

3.6.13 Colour values

The colour of the vacuum fried bitter gourd chips was determined by using a Hunter lab Colourimeter – Colour flex EZ diffuse model. It works on the principle of focusing the light and measures energy reflected from the sample across the entire visible spectrum. Colourimeter having standard observer curves such as red, green and blue colours. The primary lights required matching a series of colours across the visible spectrum and mathematical model used to describe the colours are called Hunter model. This colorimeter expressed the colours on L*, a*, and b*. The L* value represents lightness it's ranging from, 0 (blackness) to 100 (whiteness), a* represents +ve (redness) and –ve (greenness) and b* represents +ve 60 (yellowness) and –ve 60 (blueness) (Maity *et al.,* 2014). The colour of the bitter gourd chips measured by using CIELAB scale at 10˚ observer at D65 illuminant with 50 mm diameter measuring space. Before measuring colour instrument should standardise by placing black and white standard tiles. The deviation from colour of the samples with the standard was also observed and recorded in the computer interface.

The total colour difference (ΔE) between raw (L_0*, a_0*, b_0*) and fried bitter gourd chips (L*, a*, b*) was determined using the equation 3.8 which is adopted by Afjeh *et al.* (2014). Hunter lab colourimeter showed in Plate 3.6.

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad \textbf{....... (3.8)}$$

3.7 OIL QUALITY PARAMETERS

3.7.1 Total polar compounds

The total polar compounds of oil measured by using Testo 270º (Make: Italy) instrument. In this instrument measures, TPC based on the dielectric constant of oil and value is directly converted into percentage weight of TPC (Guillén and Uriarte, 2012). The oil to be tested was pre-heated to 40ºC in a glass beaker. The probe with a sensor of Testo 270º was inserted into pre-heated oil sample. Care should be taken to avoid touching of the sensor at the bottom of the beaker. The digital display on the instrument shows the TPC in percentage. The Testo 270º instrument used for the measurement of TPC is shown in Plate 3.7.

3.7.2 Colour values

The colour values of blended and fresh oil with definite interval of frying were measured by using a colourimeter. The detail procedure of colourimeter is explained under the section 3.6.13.

3.7.3 Viscosity

The viscosity of oil measured by using viscometer (Model: Brookfield DVE Viscometer, United State; plate 3.8). It is a measure of resistance to flow and expressed in (Ns/m^2). The equipment consisted of a bubble stage to avoid experimental error due to dislodgement. The spindle (No.2) was fixed in screw present under viscometer to conduct the test. The oil sample (500 ml) was taken in a glass beaker and placed below the spindle and the spindle was lowered carefully without touching the sides or bottom of the beaker. The measurement was taken in auto range. The motor was then switched on and the spindle rpm was adjusted till 100% torque. The reading of viscometer was displayed in cP (centipoises). A similar procedure was followed for subsequent tests.

3.7.4 Oxidation stability (Peroxide and free fatty acids value)

The free fatty acids expressed in oleic acid percentage and peroxide value (PV) expressed in active oxygen per kilogram (meq O_2/kg). These two parameters are very important parameters for determination of oxidation stability of the edible oil. These two parameters were determined by using rapid analysis equipment (CDR FoodLab, Italy). This instrument is acquiescent with Association of official analytical chemist's (Kwon *et al.* 2016).

According to photometric readings, the equipment performs the test samples and test solution. The equipment contains 16 incubation cells to test solution or warm sample with cuvetters and four cells to execute the test. The manufacturer provided a different kit of test solutions with label R1 and R2. The sample size and test kits vary depending on the attribute. The entire test was done with following general procedure.

The test tubes containing reagent R1 were placed in one of the incubation cells and let to warm for 5 min. The cuvette was gently shaken for 2 - 3 times and kept in the cell marked with blue light and the read button was pressed to obtain readings for blank. Then the homogenised sample was drawn with the pipette tube 2 or 3 times and released it on the blotting paper before collecting for the test. Then 2.5 µl of sample was collected for FFA value and 5 µl for PV values. The pipette tip was cleaned carefully with blotting paper, avoiding contact between the extremity of the tip and paper. The sample was then placed in the cuvette, keeping the tip immersed in the reagent. The cuvette with the sample was shaken gently for 2 - 3 times and placed in the cell marked with blue light. The read button was then pressed to execute the test.

In case of peroxide test, 10 µl of R2 solution was collected and added along with R1 and sample in the cuvette. The cuvette was then incubated for three minutes after gentle shaking of the contents. Later, the cuvette was placed in cell marked with blue light and the read icon was pressed to obtain the photometric reading. The respective test results were displayed and recorded. The CDR FoodLab instrument used for analysis of FFA and PV is showed in Plate 3.9

3.8 Sensory analysis

The sensory analysis plays an important role for examination of product through evaluation of the attributes such as texture, colour, flavour, taste and overall acceptability (Piana *et al*, 2004). A nine point Hedonic scale was used for sensory evaluation and score card given to bring out inherent characteristics of vacuum fried bitter gourd chips. The vacuum fried chips were evaluated for texture (crispiness), colour (appearance), flavour, taste and overall acceptability by a panel of 30 judges. The score card model is given in Appendix A.

3.8.1 Fuzzy logic

The sensory analysis done subjectively was ranked based on the characteristics preference mathematically using fuzzy comprehensive model (Lazim and Suriani, 2009). The score collected from 30 untrained judges were taken and their grammatical judgment was converted to numerical ranking using fuzzy model. The characteristics assigned to respective values based on the preference given by sensory panel.

Plate 3.6 Colourimeter

Plate 3.7 Testo 270º

Plate 3.8 Brookfield viscometer

Plate 3.9 Rapid analysis equipment FoodLab

The score assigned for the vacuum fried bitter gourd chips were texture- 0.3, colour and appearance- 0.2, taste- 0.2, flavour- 0.1 and overall acceptability – 0.2. The sensory analysis by using fuzzy logic involved following three sets.

I. **Factor set (F_f)** – Quality characteristics of vacuum fried bitter gourd chips (texture, colour and appearance, flavour, taste and overall acceptability)

II. **Evaluation set (E_f)** - Scale factors for quality attribute (Excellent (EX), Good (GD), Medium (MD), Fair (FR) and Not Satisfactory (NS))

III. **Transformation set (T_f)** - Numerical values for the evaluation set (EX =1, GD = 0.9, MD = 0.7, FR = 0.4, NS = 0.1)

The fuzzy model for sensory analysis was done through the membership functions represented below.

- **Fuzzy membership function (FMF) -** Determined by a adding the individual linguistic term given to each of the quality characteristics of the product and divided by the number of judges tested the product.

- **Normalized Fuzzy membership function (NFMF) -** It is the function obtained by multiplying FMF and scale factor allotted to respective membership function.
- **Normalized Fuzzy membership function matrix** – It is the matrix formulated by adding NFMF with its respective scale factors.
- **Judgment membership function matrix (JMFM)** – This is the deciding matrix for ranking. It could be obtained by adding the column values of all matrix and divide with highest total column value.
- **Judgment subset (JS)** – It is the final ranking of samples evaluated along with attributes preference of judges. The model calculation along with sets and matrix table are given in detail in appendix B.

EXPERIMENT III

3.9 PACKAGING STUDIES

The optimised vacuum fried bitter gourd chips were packed into three different packages (Plate 3.10). The vacuum fried chips were packed in LDPE stand up pouches (M1) of 400 gauge thickness, zipper pouches with aluminum foil back (one side silver other side transparent (M2)) and laminated aluminum foil flexible pouches (M3) of 0.006-0.008 mm thickness. The packaging was done using nitrogen flush packaging machine (Model: QS 400 V, Sevana packaging solutions, Kerala, India) with 95% of N_2 flushing (Fan *et al.*, 2007). The Packed samples were stored at room temperature for storage studies. The packaging studies were conducted for selecting suitable packaging material for vacuum fried bitter gourd chips. The packaging studies were conducted for 60 days and quality analysis was performed at a regular interval of 30 days. The best packaging material was selected for storage studies.

3.10 SHELF LIFE STUDIES

The laminated aluminium flexible packaging material was selected for storage studies**.** The storage studies were conducted for optimised vacuum fried bitter gourd chips which were stored under ambient temperature (25±5ºC) and relative humidity (70±10%). During storage studies the changes in the physical and biochemical qualities of vacuum fried bitter gourd chips were analysed at regular intervals of 30 days. The studies were conducted up to 90 days of storage. All the experiments carried out in triplicates and mean values were taken for analysis.

Plate 3.10. Different packaging materials used for vacuum fried bitter gourd chips

3.11 Analysis data

The stored samples were tested for quality evaluation. Nine samples with high sensory scored were statistically analysed by Agricultural Stastical Software Package (WASP software version.2) and optimisation of the storage studies was done. A significant difference of treatments was defined as p≤ 0.0001.

3.12. Economic analysis

The cost economics was done for the optimised vacuum fried product for commercialisation of the product. The cost was determined by standard method with reasonable assumptions. The assumptions like life span of machine, annual working hours (H), salvage value (S), interest on initial cost, repair & maintainece, insurance & taxes, electricity charges, labour wages/person, skilled assistants and manager are used. The details of the cost analysis are given in Appendix C.

CHAPTER-IV

RESULTS AND DISCUSSION

This chapter deals with the result of optmisation of different pre-treatments, vacuum frying process and product parameters of ready-to-eat vacuum fried bitter gourd chips. The second phase of study consists of quality evaluation, packaging and shelf life studies of selected vacuum fried bitter gourd chips. The salient observations are discussed with relevant literature.

EXPERIMENT I

4.1 OPTMISATION OF PRE-TREATMENTS FOR VACUUM FRYING OF BITTER GOURD CHIPS

The blend of rice bran and palm oil (80:20) was selected as the frying oil for experimental purpose. In experiment I, standardisation of pre-treatments was done to produce good quality vacuum fried bitter gourd chips. Pre-treatments like freezing, blanching cum drying and edible gum coating were carried out for vacuum frying of bitter gourd at processing condition of frying temperature (100ºC), frying pressure (6 kPa) and frying time (10 min). Subsequently the untreated vacuum fried bitter gourd taken as the control. The VF-bitter gourd chips of different pre-treatment are represented in Plate 4.1. The specific quality parameters of pre-treated and control samples were compared with consequent atmospheric fried matured bitter gourd chips. The complete details of the pre-treatments are given in appendix-D1 (Table D1.1).

4.1.1 Effects of pre-treatments on quality parameters of vacuum fried bitter gourd chips

The quality attributes of the pre-treated vacuum fried bitter gourd chips namely, moisture content, water activity, oil content, bulk density, true density, hardness, colour values (L*, a* and b*) are discussed here.

Plate 4.1 Pre-treated vacuum fried bitter gourd chips

4.1.2 Moisture content

The moisture content of pre-treated VF- bitter gourd chips significantly ($p<0.0001$) varied with different pre-treatments. The moisture content of VF-bitter gourd chips is graphically represented in Fig. 4.1 and its details shown in appendix-D1. The highest moisture content (2.304%) was observed in edible gum coated pre-treatment. The bitter gourd chips pre-treated with guar gum solution form a thin layer over the surface of chips and led to gain higher moisture content. The obtained results were in accordance with the findings of Sothornvit (2011) for guar gum coated banana chips during vacuum frying. The blanching cum drying pre-treatment had less moisture content of 0.210%. The initial moisture removal of bitter gourd slices through drying contributed to low moisture content in the VF-bitter gourd chips. Similarly low moisture content was observed in fried potato strips that were air dried prior to frying (Dehghannya *et al*., 2015). The moisture content of the control and frozen pre-treated VF-bitter gourd chips were 0.264% and 0.269%, respectively. The higher moisture removal was seen in the control and frozen pre-treatment. This was due to uniform removal of moisture on vacuum frying of frozen sample with high temperature difference. Fan *et al.* (2006) stated similar trend of moisture reduction in the frozen pre-treated vacuum fried carrot chips. The atmospheric fried bitter gourd chips had moisture content of 2.014% which is higher than control and frozen pre-treated sample.

4.1.3 Water activity

Water activity of the pre-treated vacuum fried bitter gourd chips significantly ($p<0.0001$) changed with different pre-treatments. The Fig. 4.2 depicts the water activity of VF-bitter gourd chips and values are tabulated in appendix–D1. The water activity of the VF- bitter gourd chips was ranged between 0.192 and 0.276 a_w and it is recognised as safe limit. The water activity of blanching cum drying (0.192) pre-treated sample was the least followed by atmospheric (0.238), control (0.250), frozen (0.251) and edible gum coated

(0.276a_w) VF-bitter gourd chips. Perez-Tinoco *et al.* (2008) represented similar results of a_w values for vacuum fried pineapple chips.

4.1.4 Oil content

The pre-treatment significantly ($p<0.0001$) affected the oil uptake of the VF-bitter gourd chips. Oil content was considerably less in vacuum fried bitter gourd chips than atmospheric fried bitter gourd chips (Fig. 4.3). The highest oil content of 20.32% was noticed in atmospheric chips followed by frozen (8.51%) pre-treated VF-bitter gourd chips. The rapid formation of microstructure pores during the evaporation of ice crystals on frying promote high oil uptake. The result was in agreement with Ranasalva and Sudheer (2017b), who observed a high oil uptake in vacuum fried banana chips pre-treated with freezing. The lowest oil uptake of 3.26% was observed in VF-bitter gourd chips pre-treated with blanching cum drying. This is because the product was dried before frying and the loss of moisture is directly related to oil absorption. Moyanoa and Pedreschi (2006) observed the lowest oil content in drying pre-treated deep fat fried potato chips. The least oil absorption was observed in guar gum coated VF-bitter gourd chips followed by control (untreated) sample. Accomplishment of low moisture content was main reason for less oil absorption in edible gum coating samples. The edible coating forms a thin layer on surface of sample that resist the mass transfer in the product (Freitas *et al.* 2009). A comparable result was reported on basil gum pre-treated deep fat fried shrimp (Naimeh *et al.,* 2016). Among the above treatments the control (untreated) sample gave comparatively less oil content and better organoleptic quality.

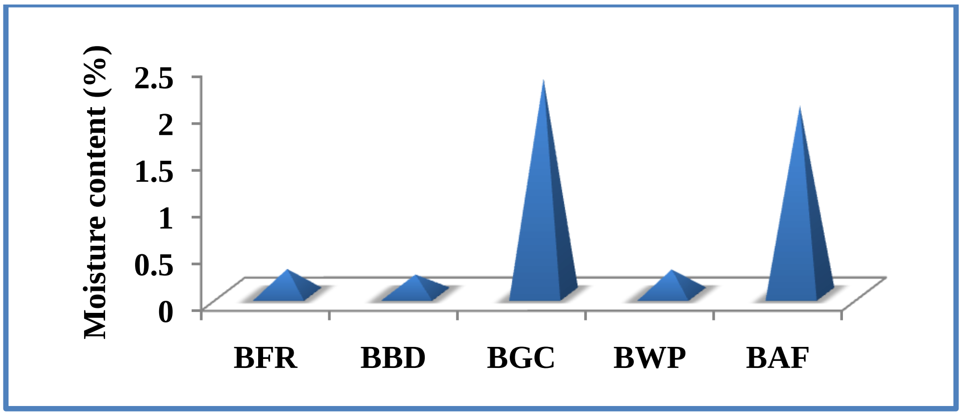

Fig.4.1 Moisture content of pre-treated vacuum fried bitter gourd chips

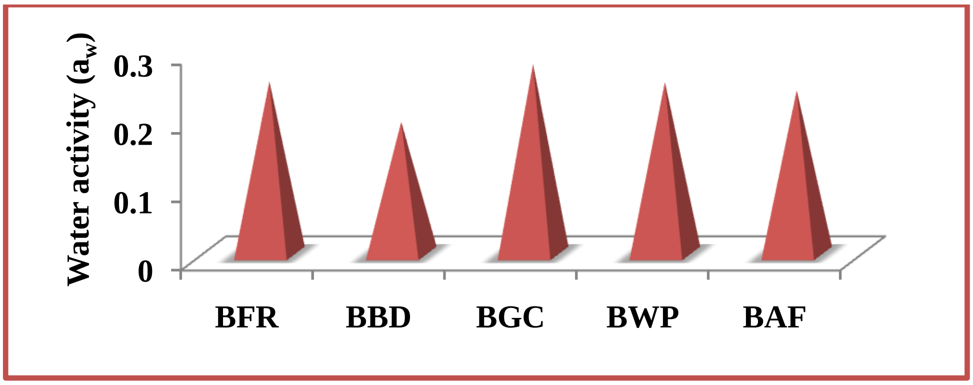

Fig.4.2 Water activity of pre-treated vacuum fried bitter gourd chips

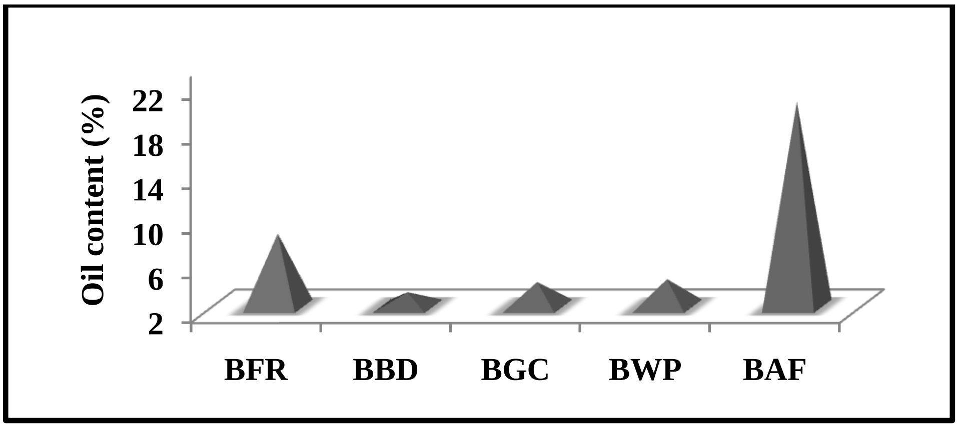

Fig. 4.3 Oil content of pre-treated vacuum fried bitter gourd chips

BFR-Freezing **BBD-**Blanching cum drying **BGC-** Edible gum coated

BWP- Control **BAF-** Atmospheric frying

4.1.5 Bulk and True density

The bulk and true density exhibited significant difference ($p<0.0001$) among the pre-treated VF-bitter gourd chips (Fig. 4.4 and Fig. 4.5). Lower bulk and true density of 0.368 g/cm^3 and 1.191 g/cm^3 were observed in the frozen pre-treated bitter gourd chips. The frozen food products had high oil content which increases the bulk weight of the chips. Similar results were obtained in vacuum fried shiitake mushroom chips pre-treated with freezing (Ren *et al.,* 2018). The bulk and true density values of guar gum pre-treated VF bitter gourd chips were on par with frozen pre-treated sample.

The blanching cum drying pre-treatment of VF-bitter gourd chips led to a bulk density of about 0.395 g/cm^3 and true density of 1.401 g/cm^3. The bulk and true densities of control (untreated) sample showed a modest variation with corresponding blanching gum drying pre-treatment. Troncoso *et al.* (2009) described similar results of bulk and true density for blanching cum drying pre-treated vacuum fried potato slices. The bulk and true densities of atmospheric fried bitter gourd chips were found to be higher than the untreated vacuum fried sample and blanching cum drying pre-treatment.

4.1.6 Thickness expansion

The thickness expansion of pre-treated vacuum fried bitter gourd chips significantly ($P<0.0001$) changed with pre-treatment (Fig. 4.6). VF- bitter gourd chips pre-treated with freezing showed higher amount of the thickness expansion (-72.33%) followed by blanching cum drying and edible gum coated pre-treatments. Kawas and Moreira (2001) reported that thickness expansion of blanching cum drying and edible gum coated pre-treated tortilla chips were less than frozen pre-treated sample.

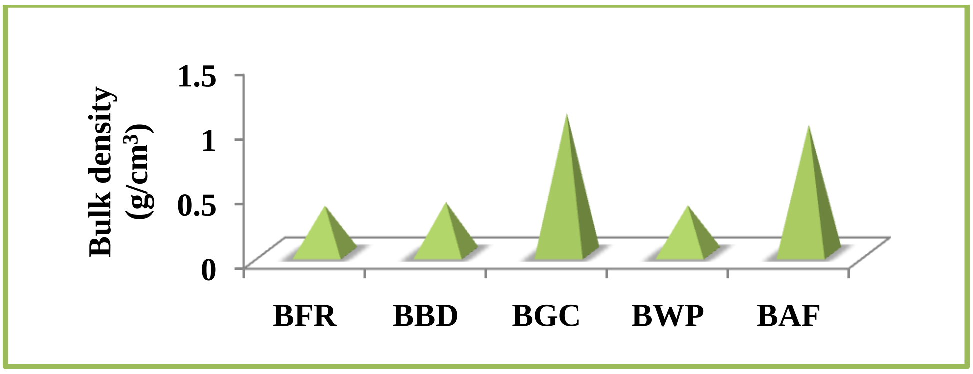

Fig. 4.4 Bulk density of pre-treated vacuum fried biter gourd chips

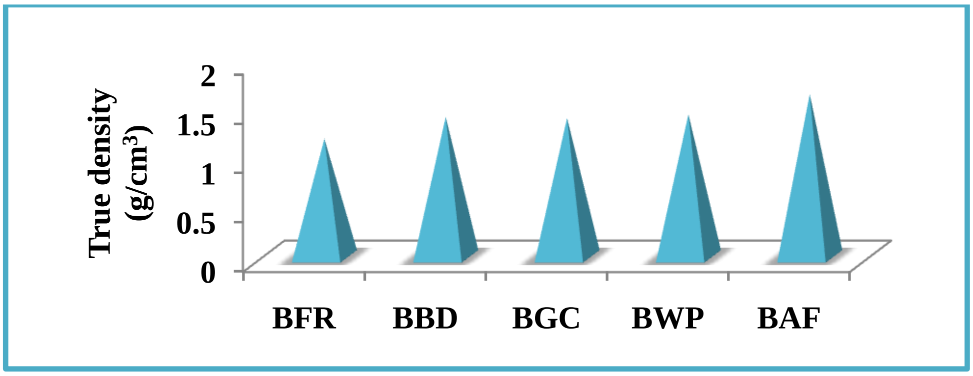

Fig. 4.5 True density of pre-treated vacuum fried bitter gourd chips

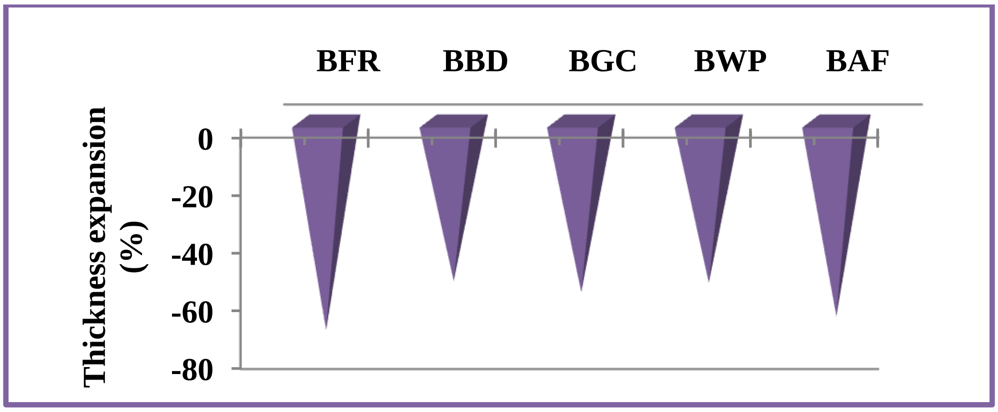

Fig. 4.6 Thickness expansion of pre-treated vacuum frying bitter gourd chips

BFR-Freezing **BBD-**Blanching cum drying **BGC-** Edible gum coated

BWP- Control **BAF-** Atmospheric frying

The frozen pre-treated sample had high thickness expansion due to the high temperature and pressure gradient. Thickness expansion of guar gum coated pre-treated chips was -59.17, which was greater than the control sample. This was due to an additional guar gum layer above the chips.

4.1.7 Colour values

The colour aspects showed significant difference ($p<0.0001$) with pre-treatments. The colour values of VF- bitter gourd chips are illustrated in Fig. 4.7. The maximum L* of 51.13 was obtained in freezing pre-treated sample followed by control (50.47) and edible gum coated (46.28) sample. The minimum L* value of 31.19 was observed in atmospheric fried chips followed by blanching cum drying pre-treated chips (42.58). Thus frozen bitter gourd produced light coloured chips, which is a desirable character. However, dark coloured product was obtained from blanching cum drying pre-treatment. The drying process in blanching cum drying pre-treatment led to darken colour of fried product. Fan *et al.* (2006) also reported higher L* value of vacuum fried carrot chips pre-treated with freezing.

The a* and b* value of vacuum fried bitter gourd showed significant variation ($p<0.0001$) with pre-treatments. The a* value of VF-bitter gourd chips pre-treated with freezing had the greatest negative value of -4.30, which indicates the high green colour in the product. While, the product from blanching cum drying pre-treatment had a minimum a*value (-2.61) due to drying process. In blanching cum drying colour was changed mainly because of drying process. The untreated (-4.13) and edible gum coated (-3.24) bitter gourd chips obtained had better a* value compared to blanching cum drying pre-treatments. A similar result was obtained for vacuum fried peas pre-treated with blanching cum drying (Zhu *et al.*, 2015).

The highest b* value was recorded in frozen pre-treated vacuum fried bitter gourd chips (26.47) followed by control (un-treated) (26.78) sample. The atmospheric fried bitter gourd chips had a minimum b* value and product became darker in colour. The colour degradation of atmospheric fried chips mainly due to high temperature and frying in open air led to contact with oxygen.

The ΔE (colour difference) value of pre-treated VF-bitter gourd chips showed significant difference ($p<0.0001$) in different pre-treatments. The colour change (ΔE) with respect to fresh samples was lowest in freezing pre-treatment (11.02) followed by control samples (11.66). The detailed colour value of pre-treated vacuum fried bitter gourd chips was illustrated in the appendix-D1. The colour variation on vacuum frying was comparatively less than atmospheric fried VF- bitter gourd chips. Troncoso *et al*, (2009) reported similar results on the colour analysis of vacuum and atmospheric fried potato slices.

4.1.8 Textural changes

The textural changes of pre-treated VF-bitter gourd chips exhibited significant difference ($p<0.0001$). The higher hardness value of 2.146 N was noted in VF-bitter gourd chips pre-treated with blanching cum drying. The removal of moisture prior to frying made the product compact and hard (Debnath *et al.* 2003) in blanching cum drying pre-treated sample. Fan *et al.* (2005) reported that lower breaking force correspond to higher crispiness and Fan *et al.* (2006) confirmed that crispiness value was higher in case of the drying compared to atmospheric fried and other pre-treatments of vacuum fried carrot chips. The VF-bitter gourd chips pre-treated with freezing had the lowest hardness value of about 1.273 N, followed by control (1.422 N) and edible gum coated (1.691 N) products. The retention of moisture in the frozen bitter gourd slices increased the rate of mass transfer with high oil absorption that favoured crispiness in the product. Arlai *et al.* (2014) had also reported that hardness value of vacuum fried okra chips was less when pre-treated with freezing. The hardness value of the guar gum coated vacuum fried bitter gourd chips was less compared with control and atmospheric fried products. Garmakhany *et al.* (2011) reported a similar trend of textural changes for hydrocolloids coated of French fries.

4.1.9 Sensory analysis

The consumer acceptability of pre-treated vacuum fried bitter gourd chips is explained here. The sensory score of VF-bitter gourd chips of different pre-treatments are specified in Fig. 4.9. The VF-bitter gourd chips had higher sensory score than the atmospheric fried bitter gourd chips. The fuzzy logic comprehensive model also reveals similar trend. The untreated (8.8) and frozen (8.7) pre-treated vacuum fried bitter gourd recorded the maximum overall acceptability followed by other pre-treatments like gum coating (8.2) and blanching cum drying (7.0). Freezing pre-treated and control sample had same sensory score for colour and appearance (9.0), flavour (8.5) and taste (8.5), but in case of texture, control had higher score of 9.0 compared with frozen pre-treated sample (5.5). The atmospheric fried bitter gourd chips had a least score of 6.2 for overall acceptability when compared with other treatments. The ranking of the pre-treated vacuum fried bitter gourd chips is represented in Table 4.1. The fuzzy logic ranking for pre-treated VF-bitter gourd chips were BFR=BWP>BGC=BBD>BAF (Frozen pre-treated=untreated> Edible gum coating=blanching cum drying>atmospheric). The quality characteristics of the freezing pre-treated vacuum fried bitter gourd chips were similar to the control (untreated) sample. The control (untreated) VF-bitter gourd chips had a better quality attribute compared to other pre-treated bitter gourd chips.

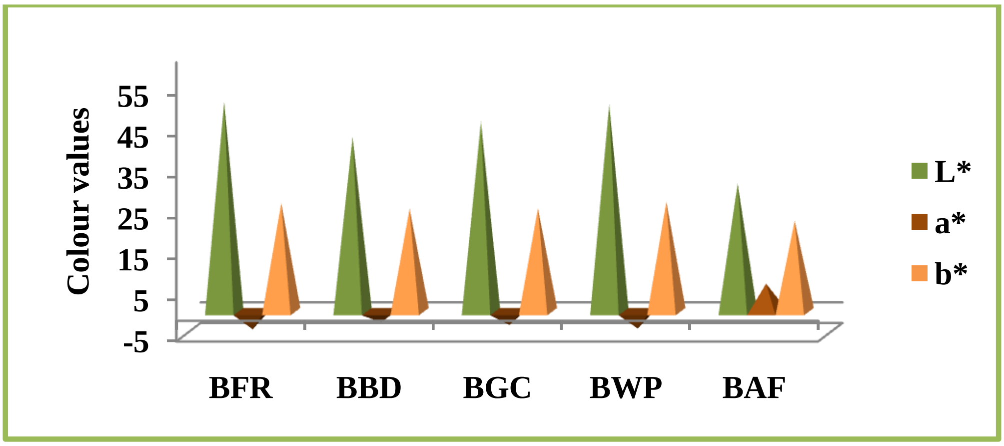

Fig. 4.7 Colour values of pre-treated vacuum fried bitter gourd chips

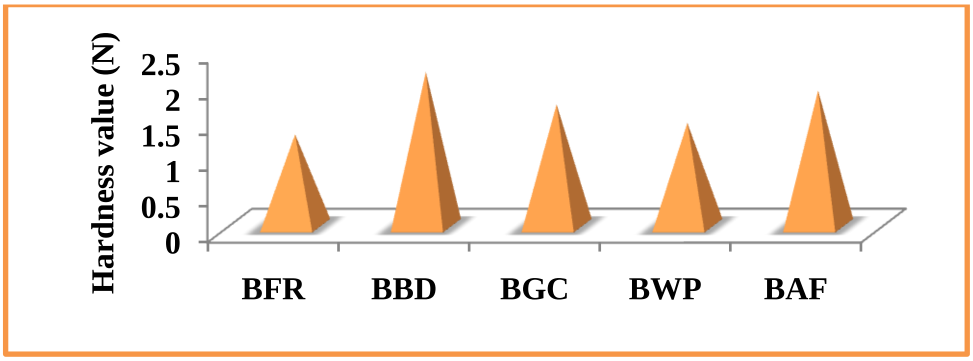

Fig. 4.8 Hardness value of pre-treated vacuum fried bitter gourd chips

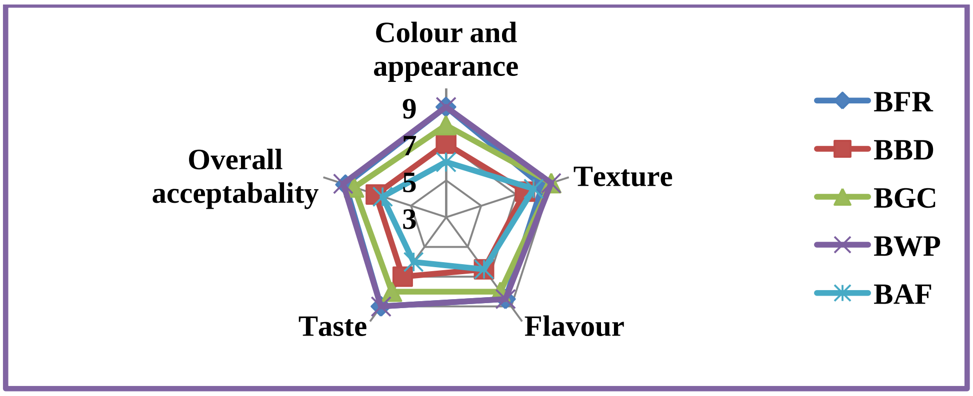

Fig. 4.9 Sensory evaluation of pre-treated vacuum fried bitter gourd chips

BFR-Freezing **BBD**-Blanching cum drying **BGC-** Edible gum coated

BWP- Control **BAF-** Atmospheric frying

Table 4.1 Fuzzy ranking of pre-treated vacuum fried bitter gourd chips

Treatments	Ranking of the sensory attributes
BFR	C&A=Texture > OA =Taste =Flavour
BBD	C&A=Texture > OA =Taste =Flavour
BGC	C&A= Texture> OA> Flavour >Taste
BWP	C&A>OA= Taste>Texture=Flavour
BAF	Taste> Flavour>Texture>OA>C&A

OA-overall acceptability, C&A- Colour and appearance

By considering the results of quality parameters of pre-treated bitter gourd chips and sensory scores of pre-treated chips, further experiment was conduct using the control (untreated) sample to optimise the vacuum frying process parameters.

EXPERIMENT - II

The experiment II was performed for the optimisation of process parameters *viz*, temperature, pressure and time of frying for the production of vacuum fried bitter gourd chips. Based on the preliminary studies and previous studies, blended rice bran and palm oil in the ratio of 80:20 was selected for vacuum frying. De-oiling was carried out by centrifugation at a speed of 1000 rpm for 5 min. The experiment consisted of 27 treatments in 3 replications. Plate 4.2 depicts vacuum fried bitter gourd chips obtained at different processing conditions.

4.2 EFFECTS OF PROCESS PARAMETERS ON THE PHYSICAL PROPERTIES OF VACUUM FRIED BITTER GOURD CHIPS

The results of the analysis of quality attributes such as moisture content, water activity, oil content, bulk density, true density, hardness, colour changes, energy content and acrylamide content of vacuum fried bitter gourd chips are shown in Table E1.2.

4.2.1 Moisture content and water activity

The moisture content of VF-bitter gourd chips obtained from different processing conditions is shown in Fig. 4.10. The results indicated that frying conditions affected the moisture content. The moisture content ranged from 0.437% to 3.852% in vacuum fried bitter gourd chips at different frying parameters. Moisture content decreased with increased frying temperature and frying time. The low moisture content of 0.437% was noticed in VF-bitter gourd chips at frying conditions of 120ºC, 13 kPa and 14 min (BT27). At higher temperature, moisture removal was very fast due to water evaporation and that led to less moisture content. Since the food is heated under the vacuum condition which decreases the boiling point of water and oil, moisture removal was instantaneous in bitter gourd slices without warm-up phase. High moisture content of 3.852% was observed in VF-bitter gourd chips at frying temperature of 100ºC, frying pressure of 9 kPa and frying time of 10 min. Similar results were observed in the vacuum frying of carrot chips at frying temperature of 118ºC (Garayo and

Moreira, 2002). There was significant ($p<0.0001$) difference in moisture content of VF-bitter gourd chips subjected to different frying condition. The same phenomena were also observed for vacuum fried banana chips (Ruttanadech and Chungcharoen, 2015), vacuum fried carrot chips (Fan *et al*., 2005) and for vacuum fried apple chips (Shyi and Hwang, 2001).

The R^2 value of moisture content of VF-bitter gourd chips was 95%, the first order linear model was found to be sufficient to determine the effect of process parameters on moisture content.

The surface plot for water activity of VF-bitter gourd chips with different frying conditions is represented in Fig. 4.11. Water activity is an important property that can be used to predict the stability and safety of food with respect to microbial growth rate. The safe level of water activity for any fried product was less than 0.6 (Fontana, 1998). In present study, all the bitter gourd chips had water activity of less than 0.5, which indicated that vacuum frying method maintain the quality and prolong the shelf life of products. The higher water activity value of 0.498 was noted in VF- bitter gourd chips with frying condition of 100ºC, 9 kPa and 10 min (BT1). This may due to high moisture retention at the respective frying temperature, pressure and time. The lower water activity value of 0.121 was obtained at frying condition of 120ºC, 13 kPa and 14 min (BT27). Similar results were observed for vacuum fried carrot chips (Dueik *et al.*, 2010) and vacuum fried shiitake mushroom chips (Ren *et al*, 2018). The R^2 value of water activity for VF-bitter gourd chips was 98.5%. The process parameters have significantly ($p<0.0001$) effect on water activity of VF-bitter gourd chips.

4.2.2 Bulk and true density

The bulk density of VF-bitter gourd chips with different frying conditions was shown in Fig. 4.12. The bulk and true density of VF-bitter gourd chips significantly varied ($p<0.0001$) with processing condition.

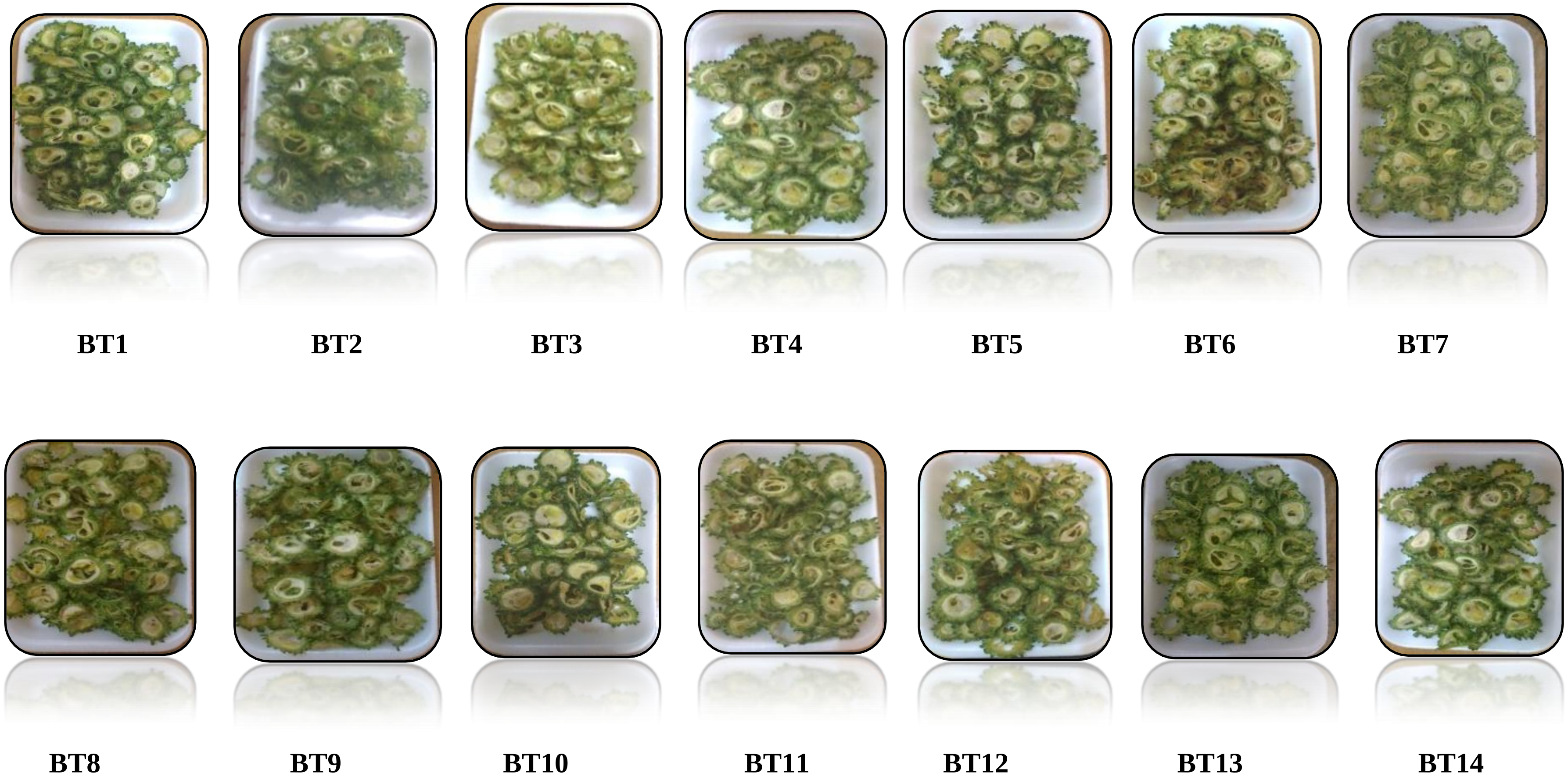

Plate 4.2a Vacuum fried bitter gourd chips under different process conditions

BT15 **BT16** **BT17** **BT18** **BT19** **BT20** **BT21**

BT22 **BT23** **BT24** **BT25** **BT26** **BT27**

Plate 4.2 b Vacuum fried bitter gourd chips under different process conditions

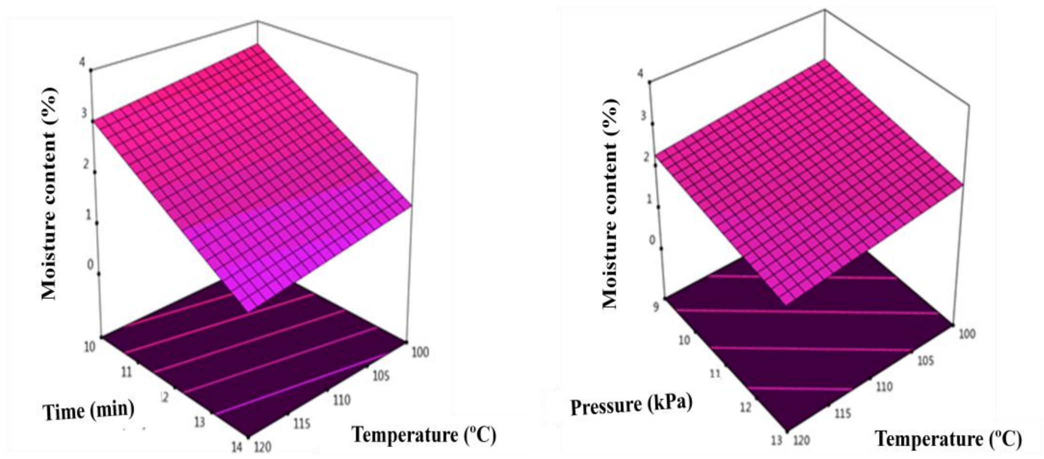

Fig. 4.10 Changes in moisture content of VF-bitter gourd with process parameters

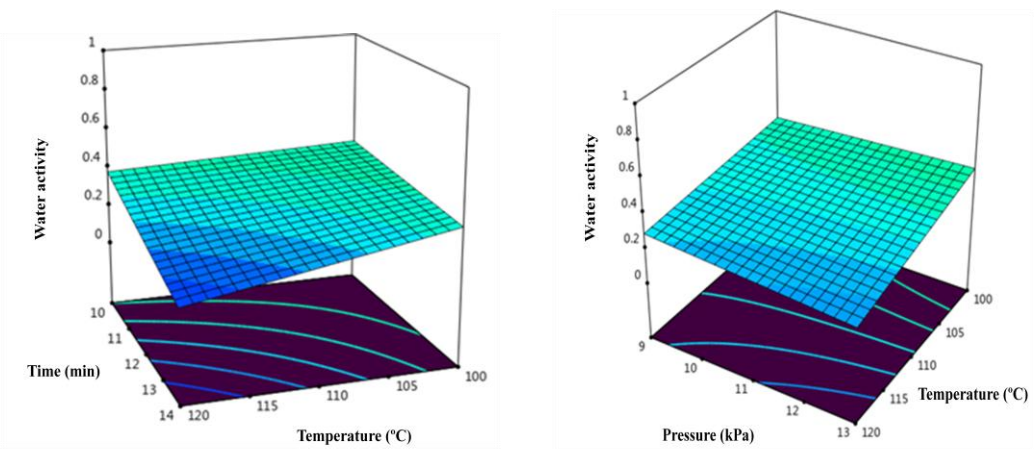

Fig. 4.11 Changes in water activity of vacuum fried bitter gourd chips with process parameters

The bulk density of VF-bitter gourd chips ranged between 0.239 g/cm^3 to 0.578 g/cm^3. Lower bulk density of 0.239 g/cm^3 was observed at frying condition of 120ºC, 13 kPa and 14 min (BT27). The vacuum fried product obtained at 100ºC, 9 kPa and 10 min (BT1) was found to be higher bulk density compare to other frying temperatures. The variation in temperature and oil content was played very important role in the frying process. The bulk density value was initially high at temperature of 100ºC and it decreased with increase in temperature. The increase in bulk density value during low frying temperature was because of high moisture content. These results were in agreement with the observation of Yagua and Moreira (2011) for bulk density of VF potato chips in different thermal condition. The R^2 value of bulk density in vacuum fried bitter gourd chips was 89.7% at different frying condition.

The true density of VF-bitter gourd chips with different processing conditions was depicts in Fig. 4.13. The higher true density of 1.325 g/cm^3 was noticed at the frying condition of 120ºC, 13 kPa and 14 min. The increase in true density during frying has been attributed to mass transfer phenomena as a result of water loss. Lower true density of 0.688 g/cm^3 was obtained at the frying temperature of 100ºC, frying pressure 9 kPa and frying time of 10 min. Moreira *et al.* (2009) reported similar trends for true density of vacuum fried carrot chips. All the three process parameters significantly ($p<0.0001$) affected the true density of vacuum fried bitter gourd chips. The R^2 value of 97.9% for true density in VF-bitter gourd chips at different processing conditions.

4.2.3 Oil content

Effect of processing condition on oil content of VF-bitter gourd chips is shown in Fig. 4.14. The oil content of VF-bitter gourd is ranged from 4.011 to 10.65% at different frying conditions. The maximum oil content of 10.65% was noted in vacuum frying condition at 120ºC, 13 kPa and 14 min (BT27). The minimum oil content of 4.011% was observed in VF-bitter gourd chips with frying temperature of 100ºC, frying pressure of 9 kPa and frying time of 10 min.

The oil uptake increased due to increased frying temperature and frying time. The same phenomenon was also observed by Segovia *et al,* (2016) for vacuum fried cassava chips at different frying temperature and frying time and Ranasalva and Sudheer (2017) for vacuum fried banana chips. An increase in oil content was found to be related to the loss of moisture in the product. This was because of the diffusion gradient created by the loss of moisture due to drying of surface (Shyi and Hwang, 2001). The R^2 value of oil content for vacuum fried bitter gourd was 99% at different processing condition. The frying conditions were significantly ($p<0.0001$) effect on oil content of the vacuum fried bitter gourd chips.

4.3.4 Thickness expansion

The thickness expansion of vacuum fried bitter gourd chips at different processing conditions is represented in Fig. 4.15. There was significant difference ($p<0.0001$) in thickness expansion with process parameters. At the end of the frying, thickness expansion was higher at 120ºC, because it causes the product surface, thus producing increased resistance to thickness change. The thickness of the vacuum fried chips was decreased rapidly, and which further increased. The maximum thickness expansion of -61.48% was observed in the VF- bitter gourd chips at frying temperature (120ºC), frying pressure (13 kPa) and frying time (14 min) (BT27). The minimum thickness expansion of -52.12 % was reported at processing condition of 100ºC, 9 kPa and 10 min (BT1). Thickness expansion ranged between -52.12 to -61.48% at different frying temperature (100, 110 and 120ºC). Garayo and Moreira (2002) reported the same trend in the thickness expansion with different physical and thermal properties of potato chips. The R^2 value of thickness expansion for VF-bitter gourd was 98% at different processing conditions. Among the individual term the temperature and time showed a positive effect. However the moisture content, oil uptake and pressure showed a negative effect on thickness expansion (Ravli *et al.,* 2013)**.**

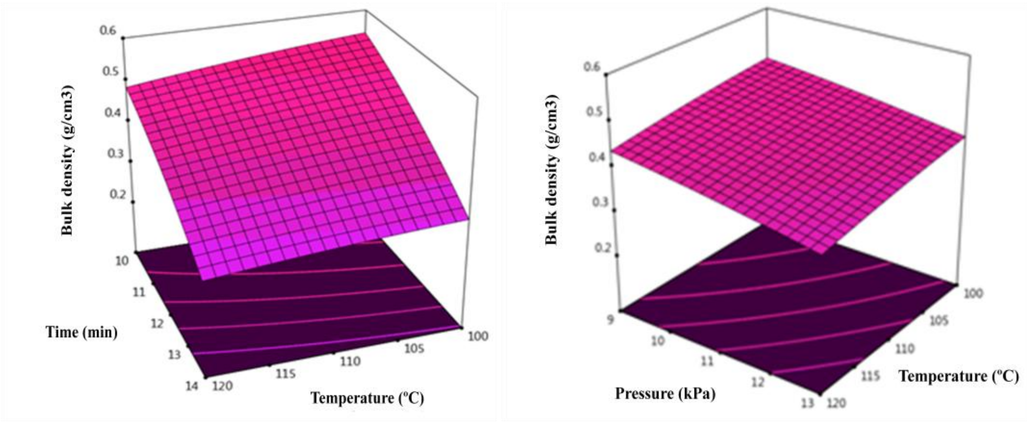

Fig. 4.12 Changes in bulk density of vacuum fried bitter gourd chips with process parameters

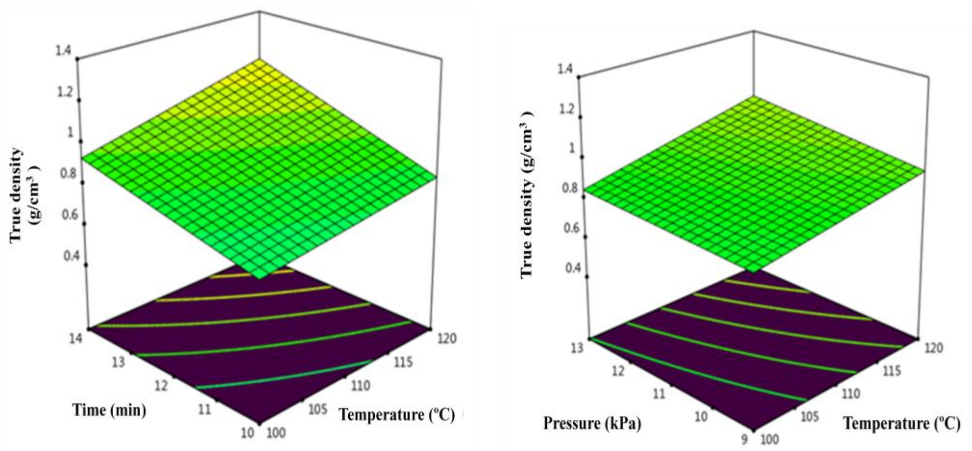

Fig.4.13 Changes in true density of vacuum fried bitter gourd chips with process parameters

4.3.5 Colour values

The L* values of vacuum fried bitter gourd chips obtained from different experiment is shown in Fig. 4.16. The colour values of VF-bitter gourd chips significantly ($p<0.0001$) varied with different process parameters. The L* values of the vacuum fried bitter gourd chips ranged from 33.72 to 50.19. The colour values were inversely proportional to the frying temperature. A higher L* value of 50.19 was observed in VF-bitter gourd chips at frying condition of 100ºC, 9 kPa and 10 min (BT1). Lower L* value of 33.72 was observed in the VF-bitter gourd chips at processing conditions of 120ºC, 13 kPa and 14 min (BT27). When frying time was further extended, the L* value decreased at all frying temperatures. Similarly, dark coloured chips were observed in the vacuum fried apple slices at higher temperature due to Millard reaction (Mariscal and Bouchon, 2008). The R^2 value of L* for VF-bitter gourd was 98.7% at different process parameters.

The a* value of VF-bitter gourd chips with different processing conditions shown in Fig. 4.17. The a* value of VF-bitter gourd chips ranged between -0.97 to -5.3 in three different frying temperature (100, 110 and 120ºC), pressure (9, 11 and 13 kPa) and time (10, 12 and 14 min). The maximum a* value of -0.97 was observed in the VF- bitter gourd chips at frying condition of 120ºC, 13 kPa and 14 min (BT27). The minimum a* value of -5.3 was found in the VF-bitter gourd chips at lower frying condition of 100ºC, 9 kPa and 10 min (BT1). In VF-bitter gourd chips, green colour was increased with a high negative value at lower frying temperature, whereas at high frying temperature, a* value changed from green to red colour due to browning reaction. The a* value of VF- bitter gourd chips significantly ($p<0.0001$) varied with different frying conditions. The R^2 value of a* for VF-bitter gourd chips was 95.4 % at different processing conditions.

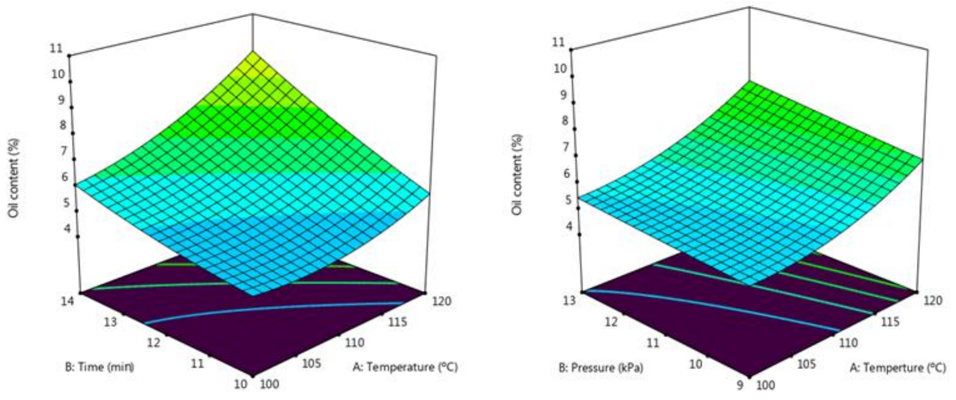

Fig. 4.14 Changes in oil content of vacuum fried bitter gourd chips with process parameters

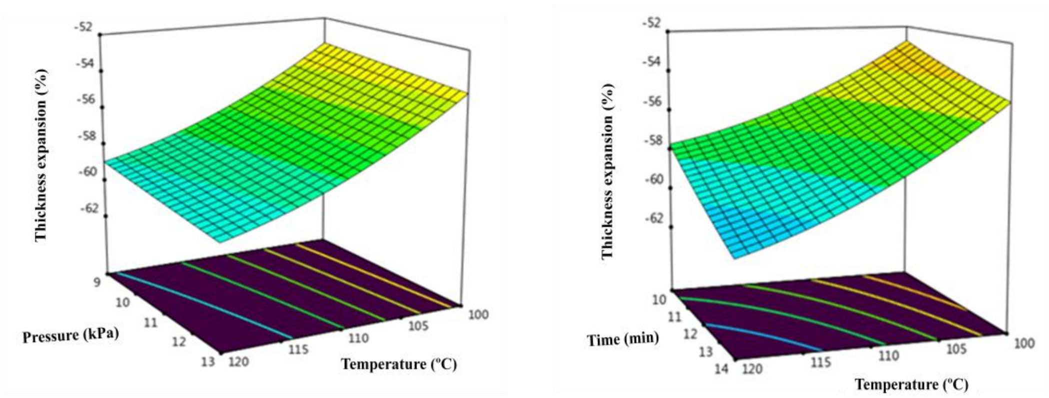

Fig. 4.15 Changes in thickness expansion of vacuum fried bitter gourd chips with process parameters

The b* value of vacuum fried bitter gourd chips with different frying conditions is depicts in Fig. 4.18. The b* value ranged from 19.46 to 27.68 in VF-bitter gourd chips at different processing conditions. Higher b* value (27.68) was noted in VF-bitter gourd chips at frying condition of 100ºC, 9 kPa and 10 min (BT1). Lower b* value (19.46) was noticed in VF-bitter gourd chips at frying temperature (120ºC), frying pressure (13 kPa) and frying time (14 min). The higher temperature provided the lower b* value. The same phenomenon was also observed, for vacuum fried chicken nugget (Teruel *et al.,* 2014). The b* value significantly ($p<0.0001$) varied at frying temperature, pressure and time. The R^2 value for b* for VF-bitter gourd chips was 97.9% at different processing conditions.

4.3.6 Textural changes

The hardness value of VF-bitter gourd chips affected by different frying parameters is shown in Fig 4.19. In VF-bitter gourd chips hardness value significantly ($p<0.0001$) varied with frying temperature and time. The results suggested that hardness value of VF-bitter gourd chips increased when frying at high temperatures. Hardness value of vacuum fried chips ranged between 1.411 N to 3.915 N at different frying temperature (100ºC, 110ºC and 120ºC), frying pressure (9, 11 and 13 kPa) and frying time (10, 12 and 14 min). The higher hardness value of 3.915 N was observed in VF-bitter gourd chips at frying condition of 120ºC, 13 kPa and 14 min (BT27). The lower hardness value of 1.411 N was noted in VF-bitter gourd chips at frying condition of 100ºC, 9 kPa and 10 min (BT1). In case of the VF- bitter gourd chips, the hardness value was inversely proportional to the crispiness. The hardness value, increased due to loss of moisture was high at higher temperature during frying. Similar results were observed for increased hardness value of vacuum fried banana chips at 120ºC for 14 min (Yamsaengsung *et al.* 2011) and vacuum fried potato chips at 144ºC (Garayo and Moreira, 2002). The R^2 value of 99% was observed in hardness of VF-bitter gourd chips at different processing condition.

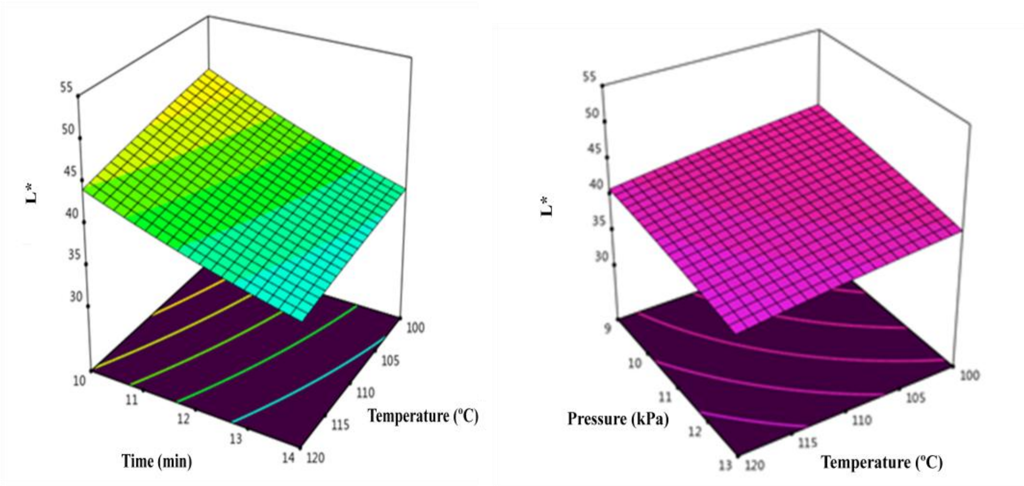

Fig. 4.16 Changes in L* of vacuum fried bitter gourd chips with process parameters

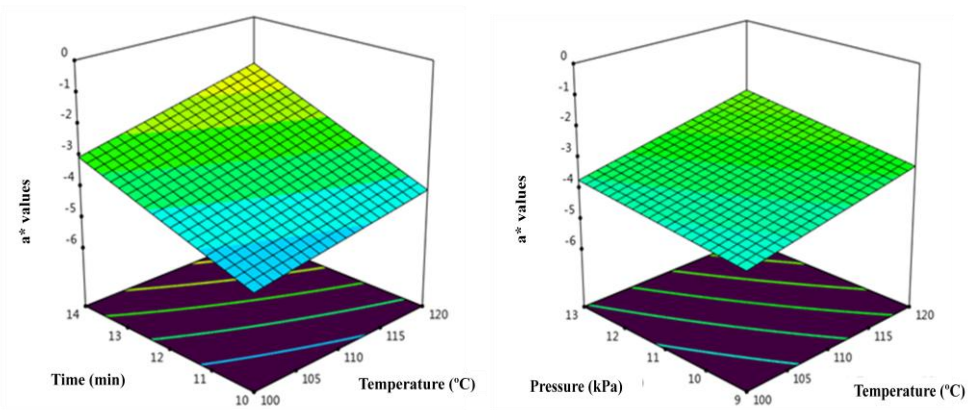

Fig. 4.17 Changes in a* of vacuum fried bitter gourd chips with process parameter

4.3.7 Energy content

The energy content of VF-bitter gourd chips at different frying condition is shown in Fig. 4.20. The energy content of fried bitter gourd chips was determined by using the standard formula (Ekanayake *et al*., 1999). The major nutrients like carbohydrates, protein, fibre and fat were estimated and energy content calculated for VF-bitter gourd chips. The energy value ranged from 1042.3 kJ/100g to 1441.12 kJ/100g was observed in VF-bitter gourd chips at different frying temperature, time and pressure. The higher energy value of 1444.13 kJ/100g was observed in the VF-bitter gourd chips at frying condition of 120ºC, 13 kPa and 14 min (BT27). The lower energy value of 1042.3 kJ/100g was noted in VF-bitter gourd chips at processing condition of 100ºC, 19 kPa, and 10 min (BT1). The energy content is directly proportional to the oil content of the chips (Stubbs *et al.*, 1995). The lower energy content in fried chips represented less oil content product. The R^2 value of 97% was observed in energy content of VF-bitter gourd chips at different frying conditions. The process parameter has directly relationship on energy values of vacuum fried bitter gourd chips.

4.2.8 Acrylamide content

The acrylamide content is formed in a wide range of fried foods, especially high starch products. The acrylamide content of VF-bitter gourd chips was determined by using high performance liquid chromatography with DAD method. The lower acrylamide content was reported in vacuum fried chips compared to atmospheric frying. The acrylamide content of VF-bitter gourd chips at different processing conditions is represented in Fig. 4.21. The higher acrylamide content of 326.14 ppb was obtained in VF-bitter gourd chips at processing conditions of 120ºC, 13 kPa and 10 min (BT27). A lower acrylamide content of 56.52 ppb was observed in VF-bitter gourd chips at frying conditions of 100ºC, 9 kPa and 10 min (BT1). Lower acrylamide content produced in VF-chips was due to reduced temperature and less Milliard reaction in the product (Granda *et al*, 2004). Granda and Moreira, (2005) reported an acrylamide content of 524.79 ppb in vacuum

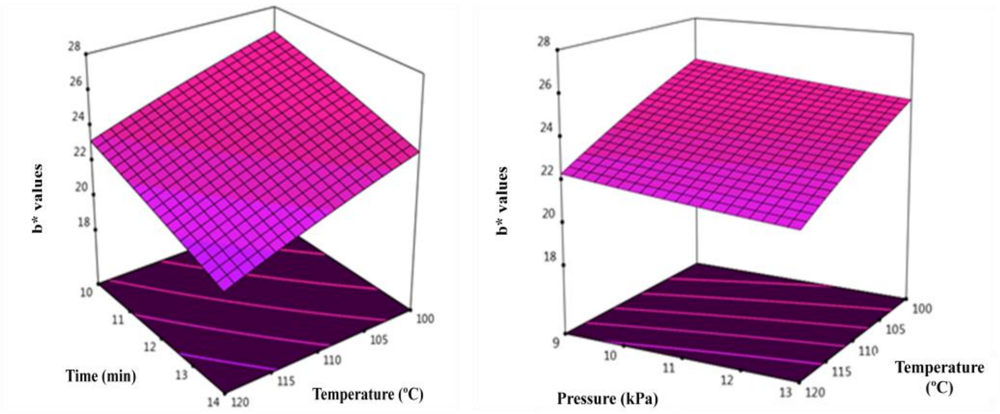

Fig. 4.18 Changes in b* of vacuum fried bitter gourd chips with process parameters

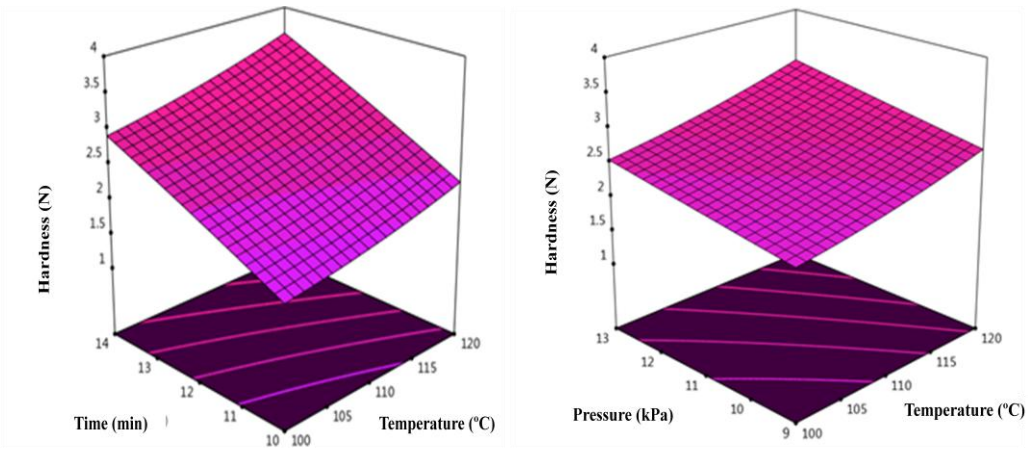

Fig. 4.19 Changes in hardness of vacuum fried bitter gourd chips with process parameters

fried potato chips at 140ºC. The oxidative degradation of frying oil also contributes to acrylamide formation in chips.

4.3.9 Sensory evaluation

The sensory evaluation of vacuum fried bitter gourd chips with different processing conditions was done in a 9-point Hedonic scale and is represents in Table 4.2.

The sensory evaluation displayed good consumer preference for the product treated at a temperature of 100ºC, pressure of 9 kPa and time of 10 min. The vacuum fried chips at 110ºC and 120ºC had a dark colour and less consumer preference. The atmospheric fried bitter gourd chips had overall acceptability of 6.2 due to its browning. According to sensory evaluation the treatments that had a good sensory attributes were BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 with sensory score of 8.7, 9.0, 8.5, 9.0, 8.5, 8.6, 8.5, 8.5 and 8.5, respectively.

The fuzzy logic attributes had the same sensory score. The samples BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 ranked first in overall acceptability followed by BT2, BT3, BT5, BT6, BT7, BT9, BT10, BT11, BT12, BT14, BT16, BT17, BT18, BT19, BT21, BT23, BT24 and BT27. The preference between the sensory attributes of BT1 was colour and appearance>texture>overall acceptability>taste >flavour. The higher sensory score of above nine samples due to its green colour and good textural property. Those treatments that scored high in the nine-point hedonic scale and fuzzy logic comprehensive model were selected for storage studies.

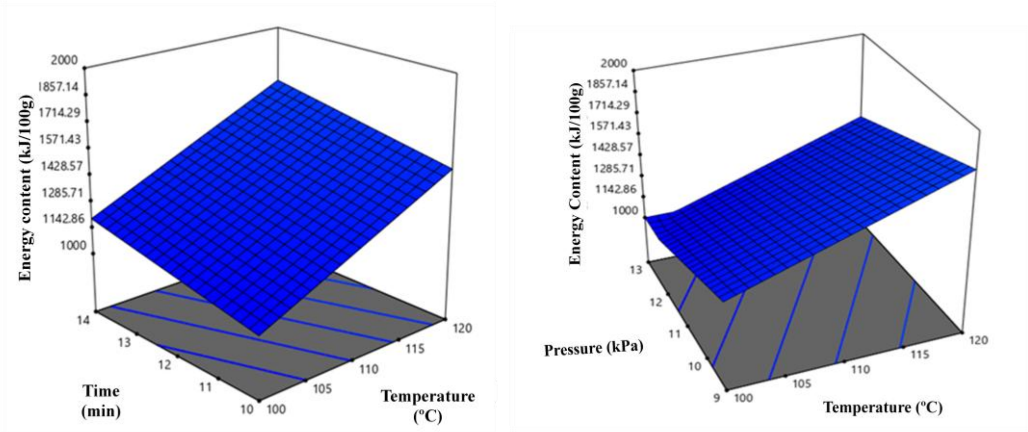

Fig. 4.20 Changes in Energy values of vacuum fried bitter gourd chips with process parameters

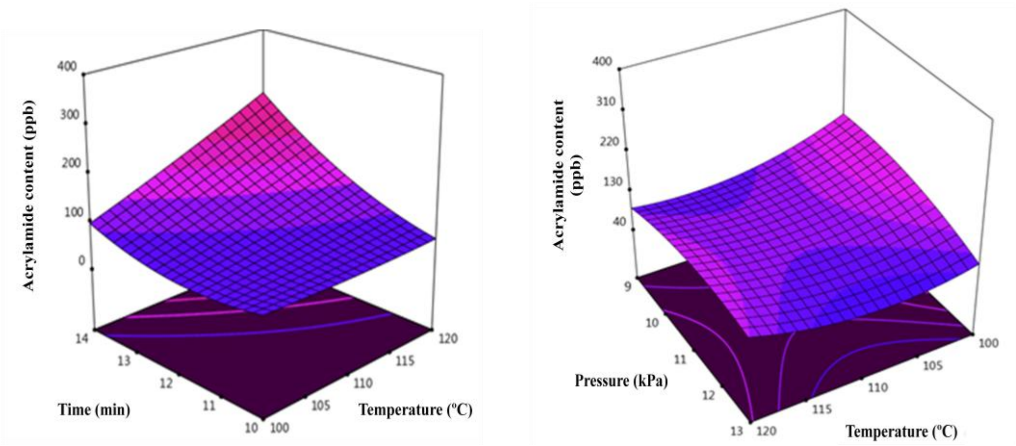

Fig. 4.21 Changes in acrylamide content of vacuum fried bitter gourd chips with process parameters

Table 4.2 Mean sensory score for vacuum fried bitter gourd chips

Treatments	Colour and appearance	Texture	Flavour	Taste	Overall acceptability
BT1	8.7	9.0	8.7	8.4	8.7
BT2	7.0	7.5	8.3	8.0	7.5
BT3	8.0	6.5	7.5	8.5	8.1
BT4	9.0	8.5	8.5	9.0	9.0
BT5	8.0	8.3	7.4	8.0	7.5
BT6	8.0	7.5	7.5	7.5	7.5
BT7	7.5	8.0	8.0	8.0	8.0
BT8	8.5	9.0	8.5	8.5	8.5
BT9	8.2	8.0	8.0	7.5	8.0
BT10	8.5	8.2	7.0	7.5	8.0
BT11	7.0	8.2	8.0	7.5	7.5
BT12	7.5	7.6	7.2	7.7	7.5
BT13	9.0	9.0	9.0	9.0	9.0
BT14	7.5	7.5	8.0	8.5	8.0
BT15	8.5	8.5	8.0	8.2	8.5
BT16	8.0	7.5	7.4	7.7	7.4
BT17	8.0	8.0	7.5	8.0	8.2
BT18	8.4	8.5	8.7	8.4	8.5
BT19	7.5	7.9	8.2	8.3	8.0
BT20	8.6	8.5	8.0	7.4	8.1
BT21	7.2	7.5	7.9	8.0	7.5
BT22	9.0	8.6	8.8	8.5	8.6
BT23	8.2	7.4	7.5	7.5	7.5
BT24	7.2	7.0	7.2	7.4	7.5
BT25	8.5	8.5	8.7	8.5	8.5
BT26	9.0	8.7	8.0	8.1	8.5
BT27	7.5	7.6	7.4	7.2	7.7

EXPERIMENT III

4.3 PACKAGING STUDIES

The study was conducted for 60 days to analyse the suitability of different packaging materials such as low density polyethylene stand up pouches (M1), zipper pouches with aluminium foil back (one side silver other side transparent; M2) and laminated aluminium flexible pouches (M3) for VF-bitter gourd chips. The experiment was conducted at frying temperature (100ºC), frying pressure (9 kPa) and frying time (12 min) for vacuum frying of bitter gourd chips during 60 days of studies. Based on the quality changes of VF-bitter gourd chips during storage period, best packaging material was selected.

4.3.1 Effect of different packaging materials on quality parameters of vacuum fried bitter gourd chips

The quality parameters like moisture content, hardness, thickness expansion, water activity, colour values and sensory parameters are evaluated for 60 days with 30 days interval.

4.3.1.1 Moisture content

The effect of different packaging material on moisture content of vacuum fried bitter gourd chips is displays in Fig. 4.22. As the storage period was increased the moisture content of the chips was increased from 2.150% to 3.374% in low density polyethylene (M1); 2.150% to 3.019% in stand up zipper pouch of aluminium back (M2) and 2.150 to 2.986 % in laminated aluminium flexible pouch (M3) at 0th to 60th day of storage. The moisture absorption of the vacuum fried bitter gourd chips packed in laminated aluminium foil packaging found to be significantly less compared to other packaging materials. The obtained moisture content was conformation with the results on deep fat frying of jackfruit chips (Sathish Kumar *et al.,* 2016).

4.3.1.2 Water activity

The effect of different packaging material on water activity of vacuum fried bitter gourd chips is represented in Fig. 4.23. The initial water activity of the vacuum fried chips was 0.317. During storage period water activity was increased from 0.317 to 0.495 in LDPE (M1); 0.317 to 0.402 in stand up zipper pouch with aluminium back (M2) and 0.317 to 0.381 in laminated aluminium flexible packaging at 0^{th} to 60^{th} day of storage. The water activity of vacuum fried bitter gourd chips was significantly increased in all packaging materials but comparatively less in laminated aluminium flexible packaging.

4.3.1.3 Hardness

The effect of different packaging material on hardness of vacuum fried bitter gourd chips is shown in Fig. 4.24. The higher hardness value indicated the low crispy product. During storage studies hardness value had increased due to water absorption. The hardness value of the vacuum fried bitter gourd chips increased from 2.05 N to 3.17 N in LDPE (M1); 2.05 N to 3.10 N in stand up zipper with aluminium back packaging (M2) and 2.05 N to 2.74 N in laminated aluminium flexible packaging (M3). The hardness value was high in stand up zipper with aluminium back packaging and LDPE compared to laminated aluminium pouches. On 60^{th} day lower hardness value of 2.74 N was recorded on laminated aluminium flexible pouches. The same phenomena were observed by Molla *et al.* (2008) for deep fat fried jackfruit chips.

4.3.1.4 Thickness expansion

The effect of different packaging materials on thickness expansion on vacuum fried bitter gourd chips is represented in Fig. 4.25.

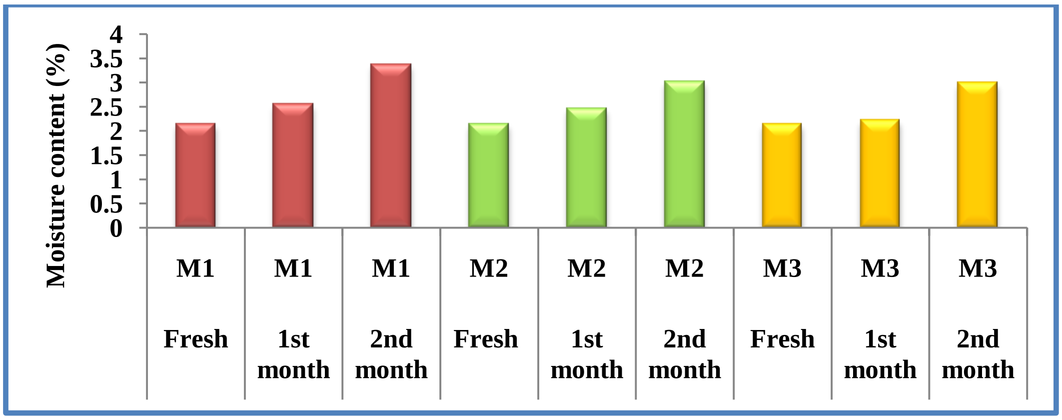

Fig. 4.22 Effect of different packaging material on moisture content of vacuum fried bitter gourd chips

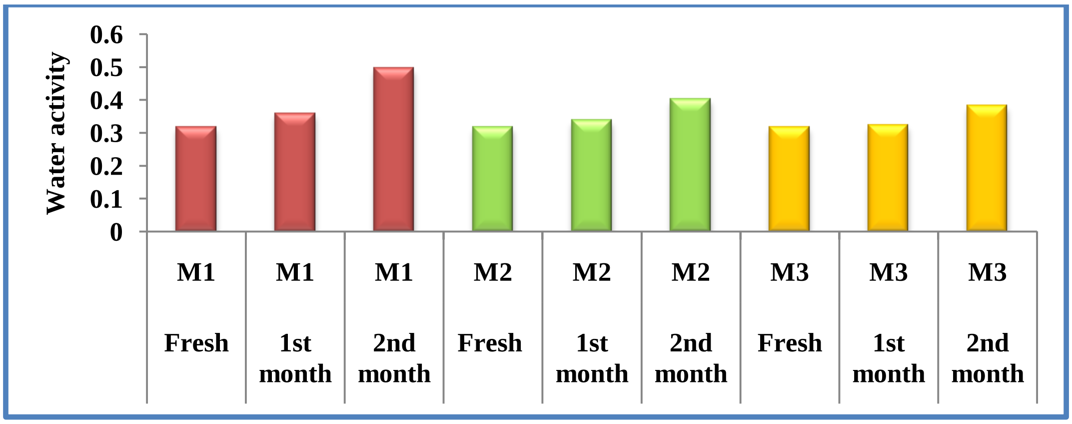

Fig. 4.23 Effect of different packaging material on water activity of the vacuum fried bitter gourd chips

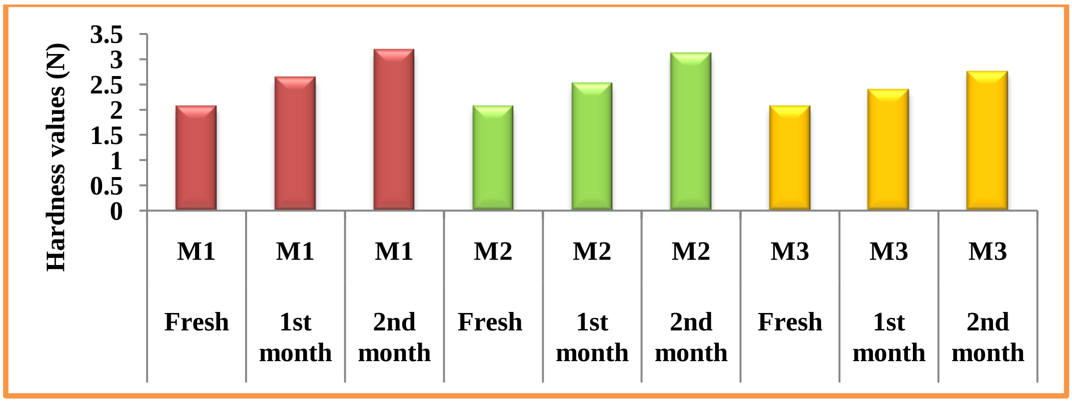

Fig. 4.24 Effect of different packaging material on hardness value of vacuum fried bitter gourd chips

The thickness value decreased from -53.26 to -52.32% in LDPE (M1); -53.26 to -52.74% in stand up zipper with aluminium back packaging (M2) and -53.26 to -53.01% in laminated aluminium flexible pouches (M3) at 60th day of storage period. Packaging material had less significant effects on thickness expansion during storage period. The same phenomena were observed by Krishnankutty *et al.* (1981) for deep fat fried banana chips during storage.

4.3.1.5 Colour values

The L* values of vacuum fried bitter gourd chips were graphically represented in Fig. 4.26. The L* values was significantly decreased from 50.42 to 38.26 in LDPE (M1); 50.42 to 40.2 in stand up zipper with aluminium back packaging (M2) and 50.42 to 43.16 in laminated aluminium flexible pouches (M3) at 60th day of storage. The L* value of vacuum fried bitter gourd chips were significantly decreased in all packaging material. Laminated aluminium flexible packaging found to be good as compare to other packaging material due to less variation of L* value.

The effect of different packaging material on a* values of vacuum fried bitter gourd chips is illustrated in Fig. 4.27. Initially a* value was -4.35 and it indicated that high colour retains in vacuum fried bitter gourd chips. The a* value increased from -4.35 to -0.68 in LDPE (M1); -4.35 to -1.04 in stand up zipper with aluminium back packaging (M2) and -4.35 to -2.13 in laminated aluminium flexible pouches (M3). The a* value was significantly increased during storage period. The laminated aluminium flexible pouches preserve the colour when compared to other packaging materials.

The effect of different packaging material on b* value of vacuum fried bitter gourd chips is represented in Fig. 4.28. The b* value was decreased from 26.6 to 23.21 in LDPE (M1); 26.6 to 23.45 in stand up zipper with aluminium back packaging (M2) and 26.6 to 24.53 in laminate aluminium flexible packaging material (M3). The b* value of the vacuum fried bitter gourd chips was significantly difference with different packaging materials.

The colour difference (ΔE) of the vacuum fried bitter gourd chips stored in different packaging materials were graphically represented in Fig. 4.29. The ΔE value of the vacuum fried bitter gourd chips was significantly changed with different packaging materials. The ΔE values was varied from 10.72 to 23.01 in LDPE (M1); 10.72 to 21.80 in stand up zipper with aluminium back packaging (M2) and 10.72 to 18.51 in laminated aluminium flexible pouches (M3). During packaging studies the laminated aluminium flexible packaging resulted with less colour difference after 60th day of storage.

4.3.1.6 Sensory evaluation

The vacuum fried bitter gourd chips were packed in three different packages namely, low density polyethylene stand up pouches, zipper pouches with aluminium foil back (one side silver other side transparent) and laminated aluminium flexible pouches and stored for 60 days in ambient condition. These samples were subjected to sensory evaluation by un-trained panel of judges for every 30 days once. Organoleptic properties include colour and appearance, texture, flavour, taste and overall acceptability. Fig. 4.30 depicts the effect of different packaging materials on sensory properties of vacuum fried bitter gourd chips. The colour and appearance of vacuum fried bitter gourd chips was decreased from 8.5 to 6.4 in LDPE (M1); 8.5 to 6.8 in zipper pouches with aluminium foil back (M2) and 8.5 to 7.5 in laminated aluminium flexible pouches (M3) on 60th day of storage. Texture of vacuum fried bitter chips was decreased from 8.5 to 6.3 in LDPE (M1); 8.5 to 7.0 in zipper pouches with aluminium foil back (M2) and 8.5 to 7.2 in laminated aluminium flexible pouch (M3). The flavour value decreased from 8.6 to 6.4 in LDPE (M1); 8.6 to 7.2 in zipper pouches with aluminium foil back (M2) and 8.6 to 7.4 in laminated aluminium flexible pouches (M3).

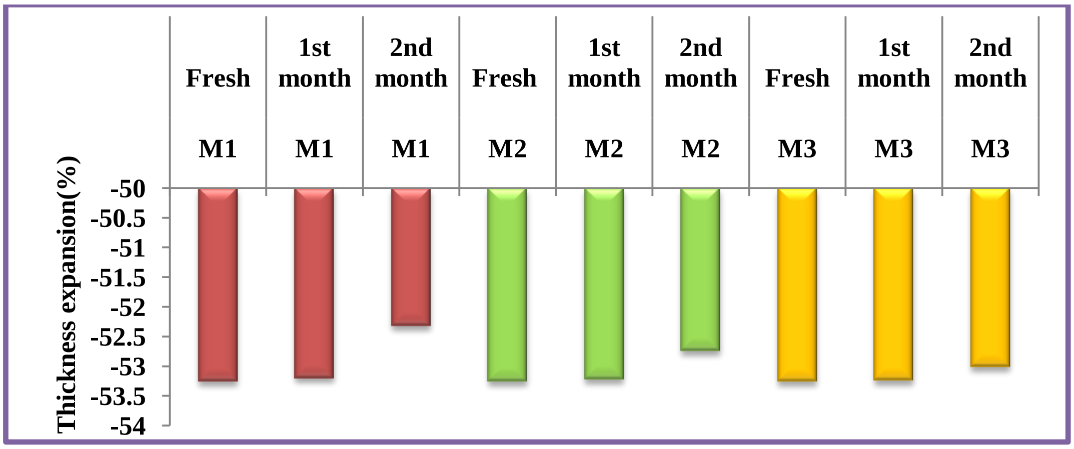

Fig. 4.25 Effect of different packaging materials on thickness expansion of vacuum fried bitter gourd chips

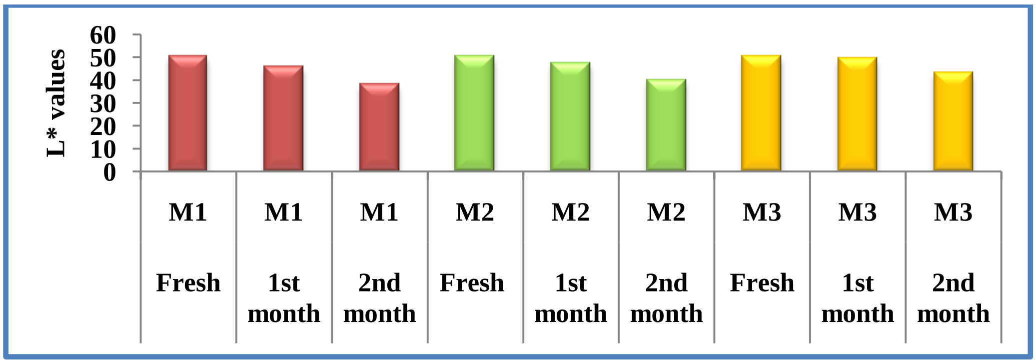

Fig. 4.26 Effect of different packaging material on L* values of vacuum fried bitter gourd chips

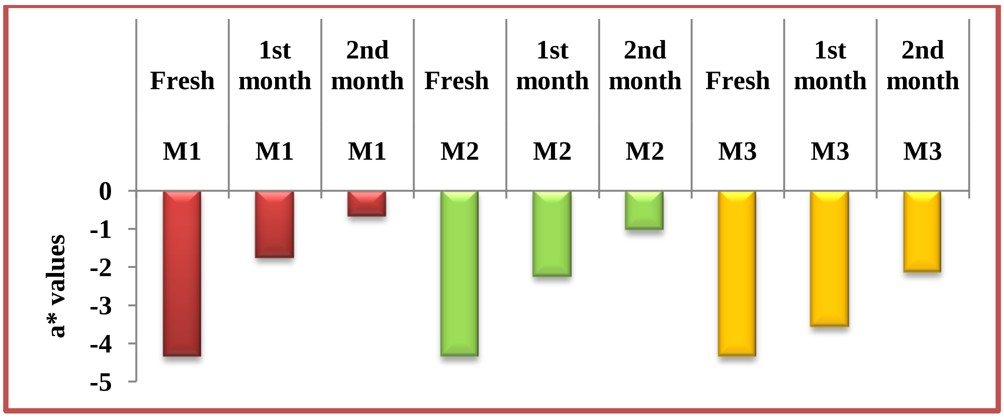

Fig. 4.27 Effects of different packaging materials on a* values of vacuum fried bitter gourd chips

Taste of vacuum fried bitter gourd chips was decreased from 8.4 to 6.2 in LDPE (M1); 8.4 to 6.7 in zipper pouches with aluminium foil back (M2) and 8.4 to 7.1 in laminated aluminium flexible pouches (M3). Similarly, overall acceptability of vacuum fried bitter gourd chips decreased from 8.5 to 6.2 in low density polyethylene stand up pouches (M1); 8.5 to 7 in zipper pouches with aluminium foil back (M2) and 8.5 to 7.5 in laminated aluminium flexible pouches (M3).

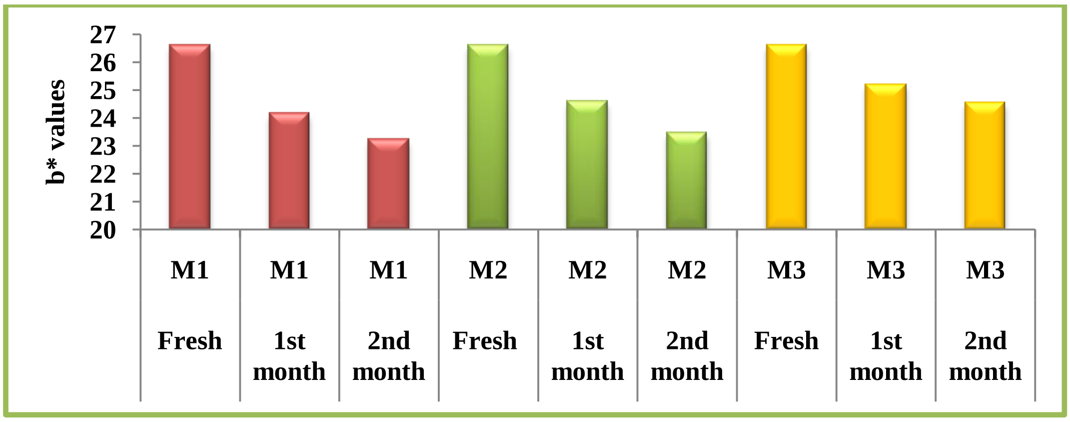

Fig. 4.28 Colour values of b* of vacuum fried bitter gourd chips with different packaging materials

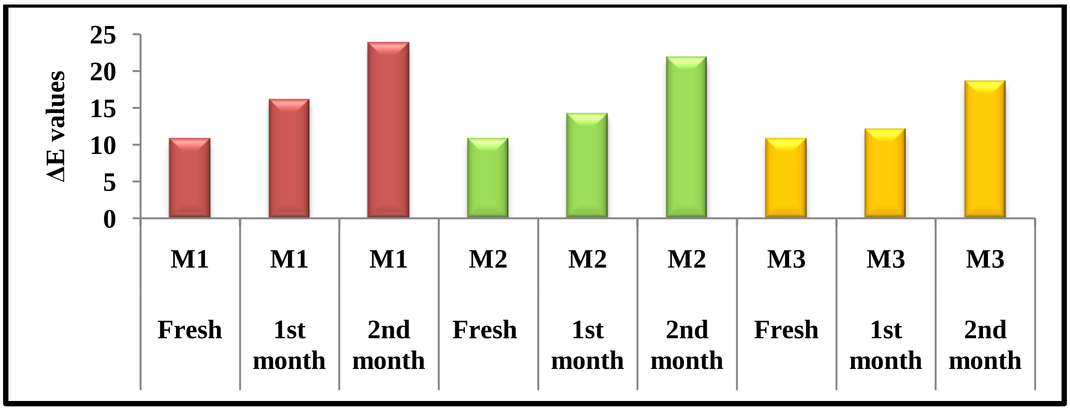

Fig. 4.29 Effect of different packaging materials on colour difference on vacuum fried bitter gourd chips

Considered the sensory scores, vacuum fried bitter gourd chips packed in laminated aluminium flexible pouches had higher sensory score. The aluminium flexible packaging material was selected for storage studies of vacuum fried bitter gourd chips obtained at different processing condition and stored for 90 days at ambient conditions.

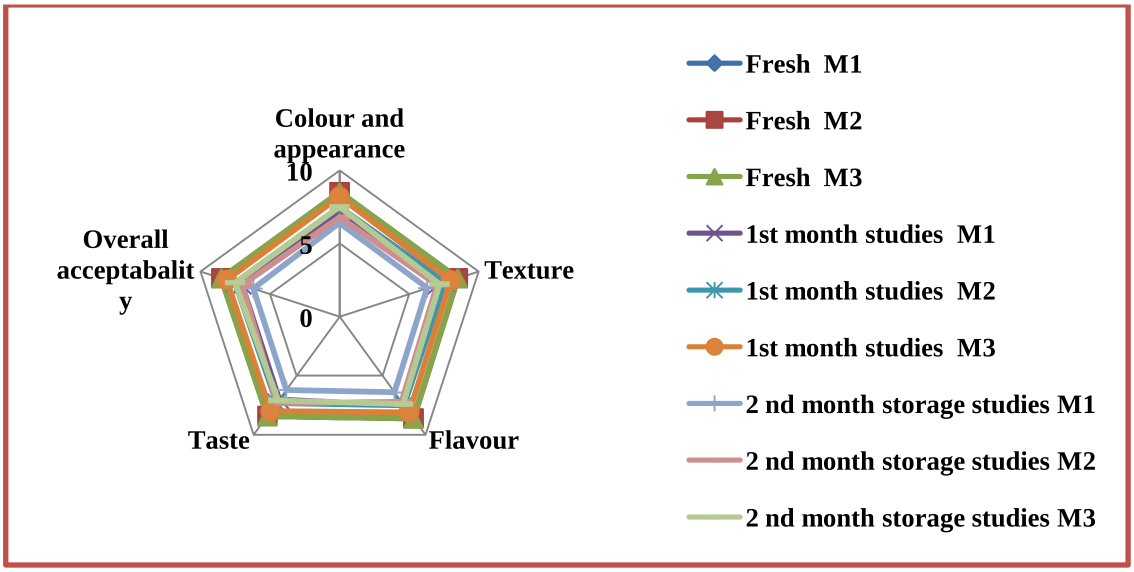

Fig. 4.30 Effect of different packaging materials on organoleptic properties of vacuum fried bitter gourd chips

M1 - Low density polyethylene stands up pouches

M2 - Zipper pouches with aluminium foil back (one side silver other side transparent

M3 - Laminated aluminium flexible pouches

4.4 STORAGE STUDIES

The storage study was conducted for vacuum fried bitter gourd chips that score high in sensory analysis obtained at different frying condition. The quality analyses of nine selected treatments are BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were carried out in 30 days interval for 90 days of storage periods. The vacuum fried bitter gourd chips were packed into nitrogen flushed laminated aluminium flexible pouches and stored in ambient condition.

4.4.1 Moisture content and Water activity

The moisture content of the vacuum fried bitter gourd chips were significantly increased ($p<0.0001$) with storage periods. Fig. 4.31 shows the moisture content of vacuum fried bitter gourd chips during storage period. The moisture content of the vacuum fried bitter gourd chips were gradually increased during storage. The final moisture content of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were 4.492, 4.214, 2.912, 4.027, 1.853, 3.102, 3.961, 3.324and 2.421% respectively. The moisture content of the stored vacuum fried bitter gourd chips ranged from 3.5 to 4.5 % at 90th day of storage studies. The increased moisture content was due to absorption of moisture from atmosphere through package (Molla *et al.*, 2009). Similar results were observed by (Satishkumar *et al*., 2016) in laminated aluminium packed jackfruit chips.

The water activity of the vacuum fried bitter gourd chips during storage represented in Fig. 4.32. The water activity of the vacuum fried bitter gourd chips were significantly ($p<0.0001$) increased during storage period. The final water activity of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were 0.538, 0.468, 0.352, 0.467, 0.282, 0.335, 0.471, 0.379and 0.228, respectively. The water activity of the vacuum fried bitter gourd chips increased during storage due to the moisture absorption. The water activity of stored VF- bitter gourd increased from 0.25 to 0.54 a_w at the 90th day of storage. The maximum water activity of 0.538 was observed in vacuum fried bitter gourd chips at 90th day of storage period.

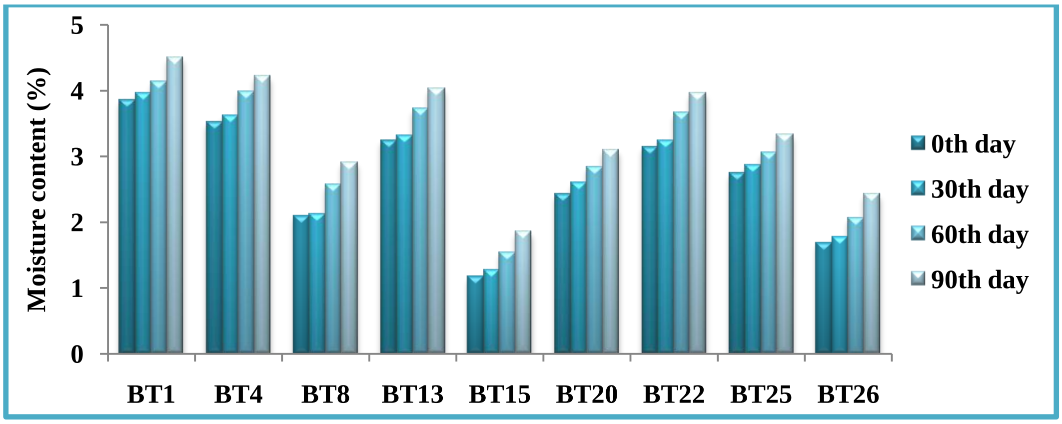

Fig. 4.31 Moisture content of the vacuum fried bitter gourd chips during storage studies

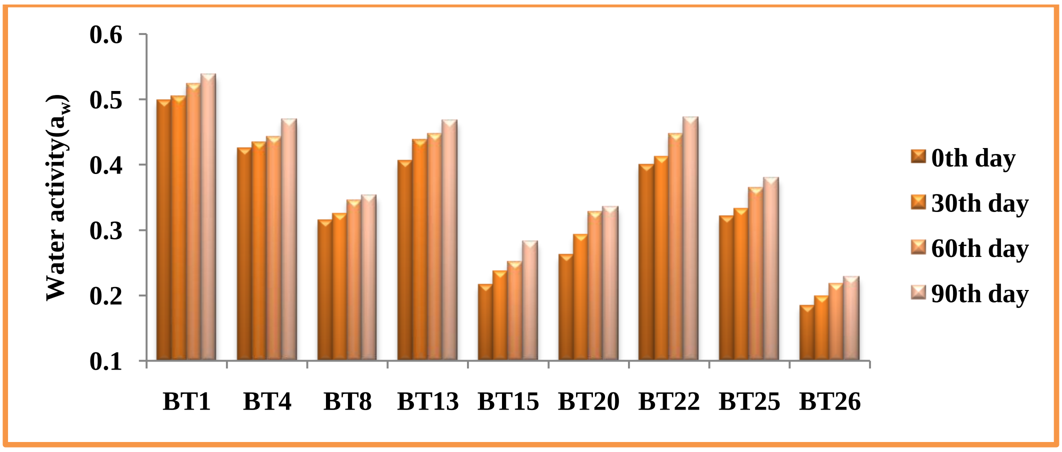

Fig. 4.32 Water activity of the vacuum fried bitter gourd chips during storage periods

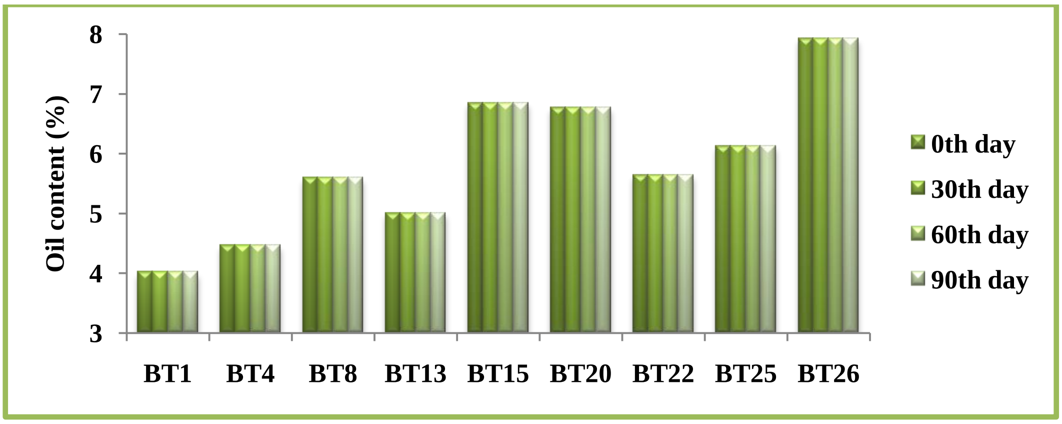

Fig. 4.33 Oil content of the vacuum fried bitter gourd chips during storage studies

4.4.2 Oil content

The oil content of the vacuum fried bitter gourd chips during storage is represented in Fig. 4.33. The storage studies no significant difference on oil content of vacuum fried bitter gourd chips. The initial oil content of BT1, BT4, BT8, BT13, BT15, BT20, BT22 and BT25, BT26 were 4.011, 4.458, 5.581, 5.004, 6.851, 6.769, 5.642, 6.124 and 7.924% respectively. In the present study, the quality of bitter gourd chips was maintained due to the usage of nitrogen flushed package. During storage period the oil content of the vacuum fried bitter gourd chips were unchanged. Sonia, 2014 also observed the no significant difference in oil content of laminated aluminium stored banana chips.

4.4.3 Bulk density and True density

The bulk density of the vacuum fried bitter gourd chips during storage was depicts in Fig. 4.34. The final bulk density of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were 0.619, 0.597, 0.501, 0.583, 0.394, 0.505, 0.537, 0.510 and 0.443g/cm^3. During storage period the slight increases of the bulk density due to the moisture absorption and oil content. The bulk density of the stored vacuum fried bitter gourd chips ranged between 0.619 to 0.578 g/cm^3. There is no significant variation in the bulk density during storage periods, when sample was frying at same processing condition.

The true density of vacuum fried bitter gourd chips during storage period is represented in Fig. 4.35. The final true density of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were 0.797, 0.795, 0.978, 0.885, 1.073, 0.992, 0.921, 0.987 and 1.092 g/cm^3. The true density values of stored samples were ranged between 0.972 to 1.092 g/cm^3 after 90th day of storage periods. The true and bulk density of the vacuum fried bitter gourd chips were slightly increased during storage period. The results were confirmed by Maneerote *et al.* (2009) for increased bulk and true density of vacuum fried potato chips during storage.

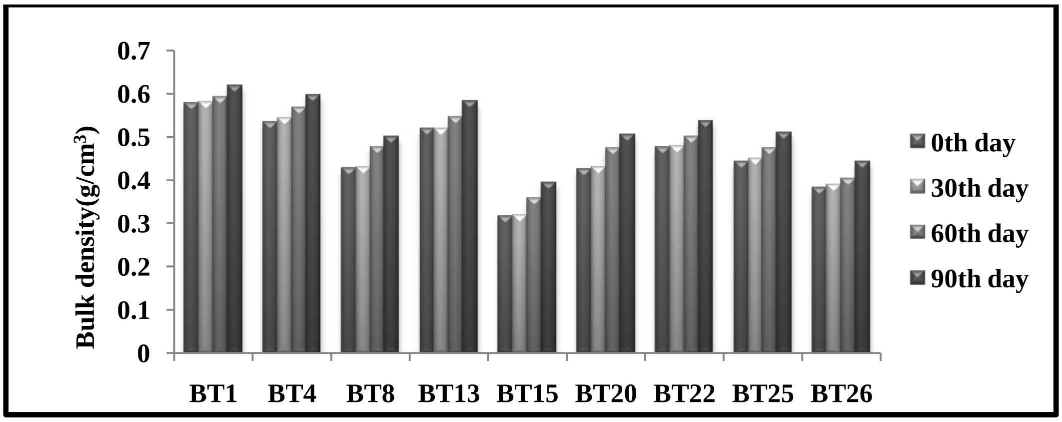

Fig. 4.34 Bulk density of the vacuum fried bitter gourd chips during storage studies

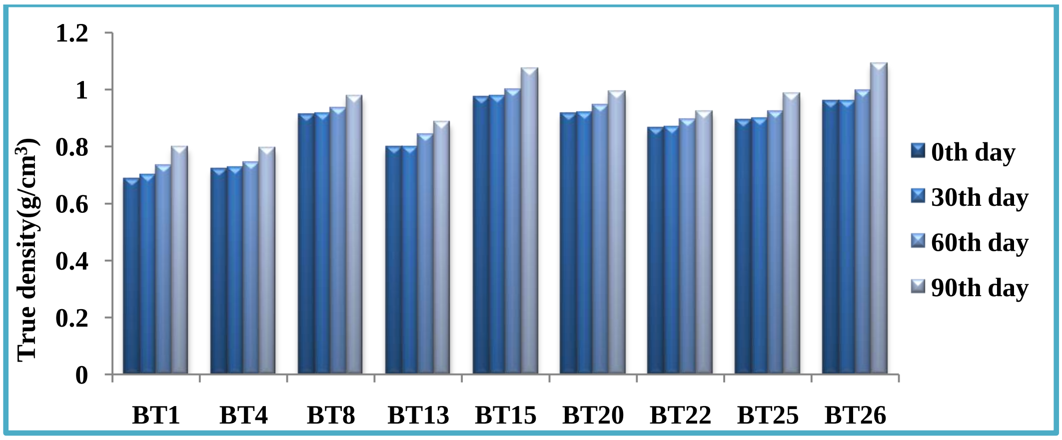

Fig. 4.35 True density of the vacuum fried bitter gourd chips during storage studies

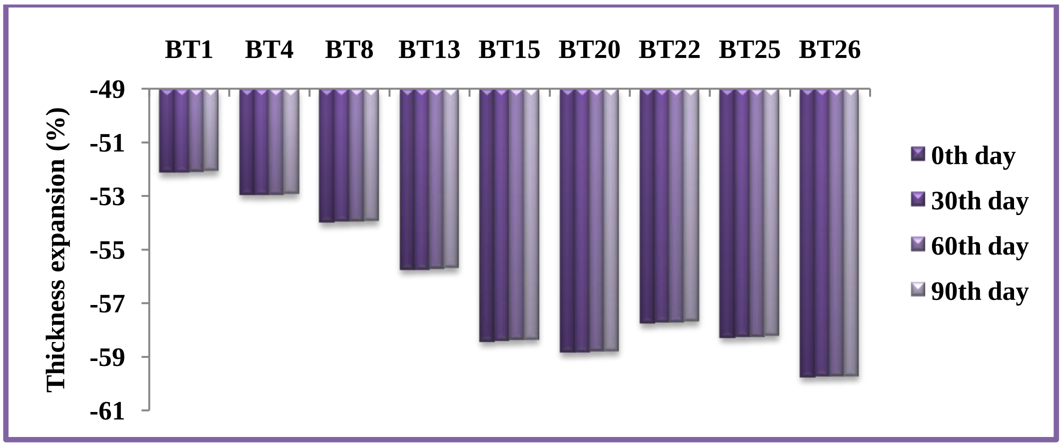

Fig. 4.36 Thickness expansion of the vacuum fried bitter gourd chips during storage periods

4.4.4 Thickness expansion

The thickness expansion of VF-bitter gourd chips during storage period represented in Fig. 4.36. The initial value of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were -52.12, -52.95, -53.99, -55.74, -58.42, -58.84, -57.75, -58.28 and -59.76, respectively. The thickness expansion of the stored samples BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were –52.07, -52.93, -53.93, -55.69, -58.36, -58.36, -58.78, -57.69, -58.22 and -59.71% respectively, at 90th day of storage. The similar trends were observed in storage of deep fat fried banana chips (Krishnankutty *et al.,* 1981).

4.4.5 Textural changes

The texture of the vacuum fried bitter gourd chips during storage period was represented in Fig. 4.37. During storage periods, the hardness of the vacuum fried bitter gourd chips were significantly increased ($p<0.0001$) with treatments. The final hardness of BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 were 2.687, 2.842, 3.826, 3.025, 4.311, 3.462, 3.210, 3.276 and 4.104 N, respectively, at 90th day of storage. The hardness value was increased during storage studies, due to the moisture absorption that made the texture of vacuum fried bitter gourd tough and rubbery. The hardness value of the bitter gourd chips were ranged between 1.5 to 4.20 N was observed at 90th day of storage period. The increased in hardness value indicated the reduction of the crispiness in the chips (Maity *et al.,* 2014).

4.4.6 Colour values

The colour value (L*) of the vacuum fried bitter gourd chips were significantly varied during storage periods and it is represented in Fig. 4.38. The higher L* value indicated the lightness in colour and which is attractive to consumers. The L* was ranged from 50.01 to 39.22 in fresh vacuum fried bitter gourd chips. The L* value decreased with increased storage period. The L* values of the stored VF-bitter gourd chips were ranged from 50.0 to 24.15 at 90th day. The same trend was observed in vacuum fried peas during storage period (Zhu *et al.,* 2015).

The a* and b* value of VF-bitter gourd chips during storage was illustrated in Fig. 4.39 and Fig. 4.40. The initial a* and b* value of vacuum fried bitter gourd ranged from -5.3 to -2.25 and 27.68 to 21.52. At 90th day of storage, a* and b* values were significantly ($p<0.0001$) decreased from -5.3 to -1.0 and 27.68 to 11.95. Sample kept in laminated aluminium pouches had less reduction in a* and b* value. Similar results were reported by Ammawath *et al.* (2002) for banana chips.

4.4.7 Sensory evaluation

The sensory evaluation was done for vacuum fried bitter gourd chips in fuzzy logic comprehensive and 9-point Hedonic scale. Before going to sensory evaluation, each stored sample was checked for microbial contamination through total plate counts (TPC). A high sensory score with good acceptance was observed upto 60th day of storage (> 8.0 Hedonic scale). However the score reduced to a sensory score of 7.0 after 90th day of storage with appreciable consumer acceptance. During storage period the considered the all sensory scores, the BT1 had good sensory scores than other treatments. Fig. 4.41 shows the sensory scores of vacuum fried bitter gourd chips during storage. The reduced degree of crispness and colour of the VF-ripe with increase in storage duration affected the consumer preference.

The fuzzy logic compressive of the VF-bitter gourd was done for BT1, BT4, BT8, BT13, BT15, BT20, BT22, BT25 and BT26 with 30 days of interval up to 90th day and it is represented in appendix-F2. Based on the sensory attributes of vacuum fried bitter gourd chips during storage studies the fuzzy logic ranking was done. The fuzzy logic of the VF-bitter gourd chips were Fresh = 30th day > 60th day > 90th day.

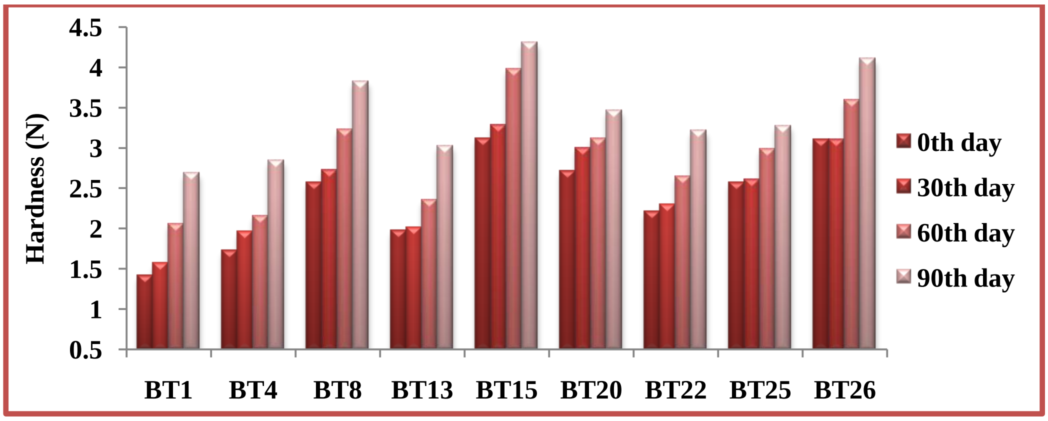

Fig. 4.37 Hardness value of vacuum fried bitter gourd chips during storage studies

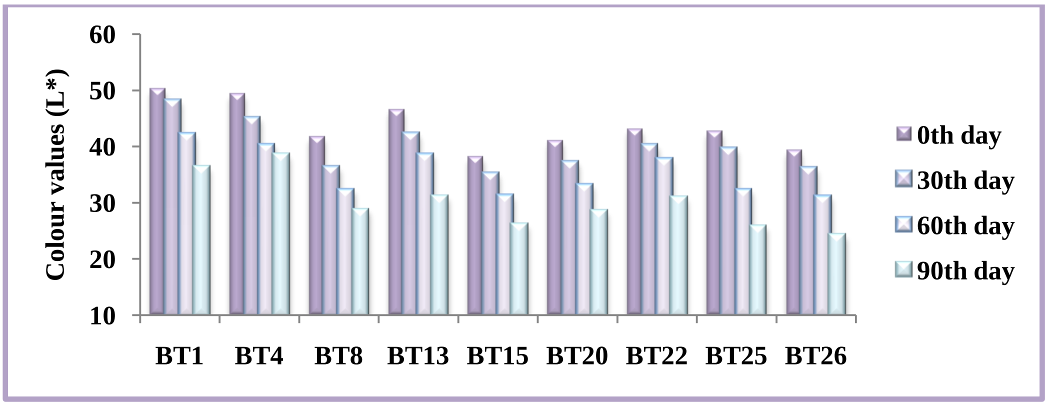

Fig. 4.38 L* values of vacuum fried bitter gourd chips during storage studies

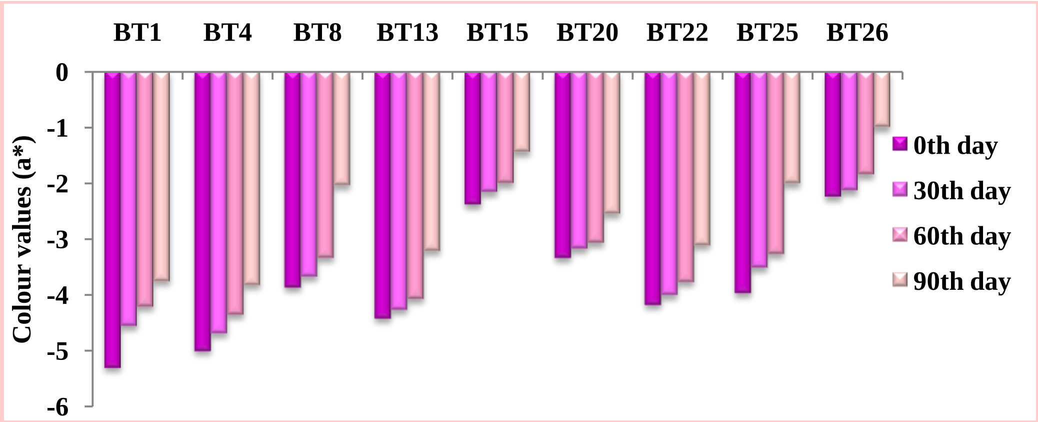

Fig. 4.39 a* values of vacuum fried bitter gourd chips during storage studies

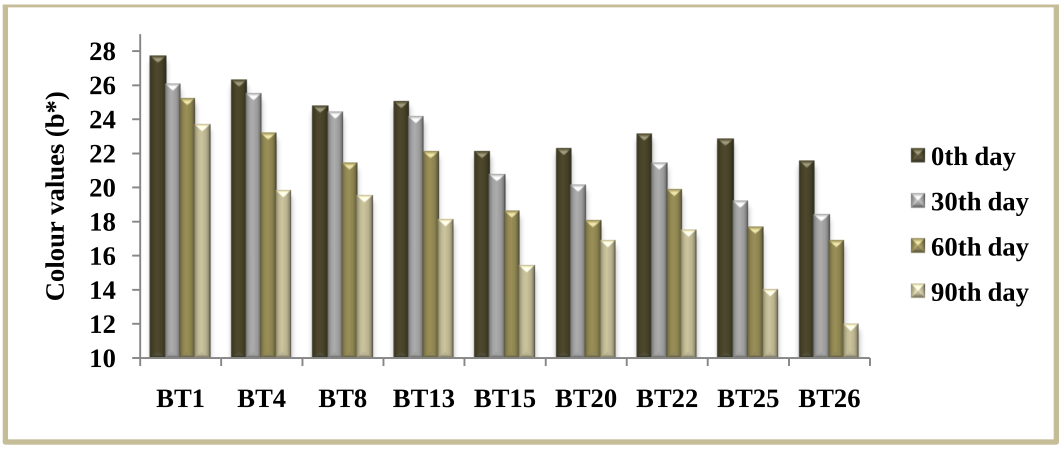

Fig. 4.40 b* value of VF-bitter gourd chips during storage studies

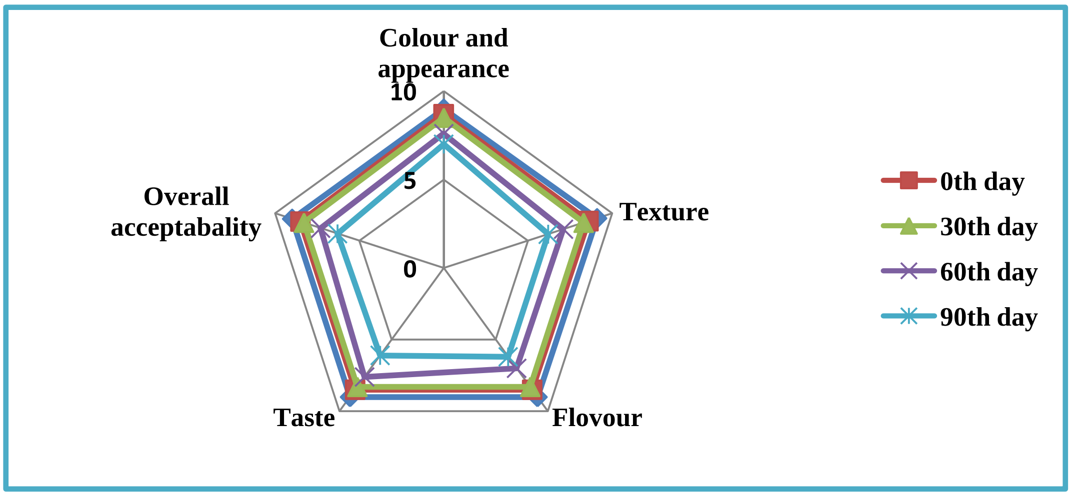

Fig. 4.41 Sensory score of VF-bitter gourd chips during storage studies

4.5 CHANGES IN THE BLENDED OIL QUALITY PARAMETERS DURING VACUUM FRYING

The blends of rice bran and palm oil were evaluated for oil quality parameters after its repeated use for several batches of vacuum frying. After every batch of vacuum frying, the product properties was analysed during the optimisation of the process parameters of bitter gourd chips. Similarly, after every batch of frying, oil was tested for its quality evaluation. The changes in quality parameters *viz.* total polar compounds, peroxide, free fatty acids, colour values and viscosity were analysed. During the optimisation process oil was heated under temperature of 100ºC, time of 10 min and pressure of 9 kPa. The cooling time of 15 min given to oil for after every batch of vacuum frying. Quality parameters of frying oil are discussed below.

4.5.1 Viscosity

The viscosity of the blended oil increased linearly with increased number of vacuum frying. The initial viscosity value of blended oil was 0.35 Ns/m^2, which was significantly increased from 0.35 to 1.66 Ns/m^2 after sixty-six times of vacuum frying. Fig. 4.42 depicts the changes in viscosity values of blended oil during vacuum frying. When frying oil used continuously over a long period, oxidation reaction leads to the formation of carbonyl or hydroxyl groups bonded to carbon chain making flux among molecules that increases viscosity (Abbas-Ali *et al.*, 2013). Viscosities of the oils increased periodically and were highly influenced by frying temperature than frying medium (Tyagi and Vasishtha, 1996). The increase of viscosity value is significantly less when frying under vacuum condition compared to atmospheric frying.

4.5.2 Total polar compounds

The determination of total polar compounds in frying oil contributes the most important measure of the extent of oxidative deterioration.

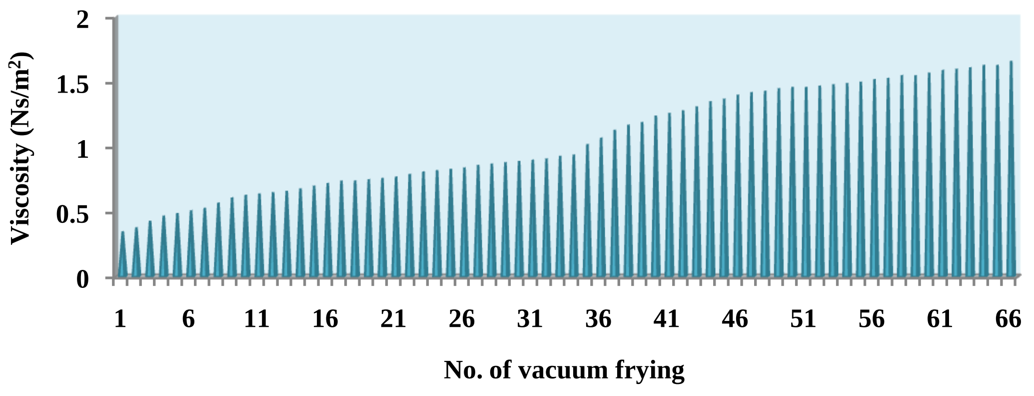

Fig. 4.42 Changes of the viscosity in blended oil during vacuum frying

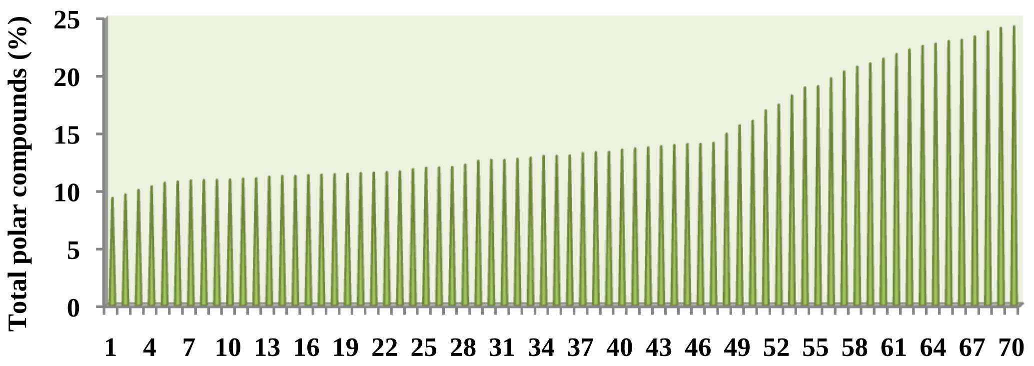

Fig. 4.43 Changes of the total polar compounds during vacuum frying

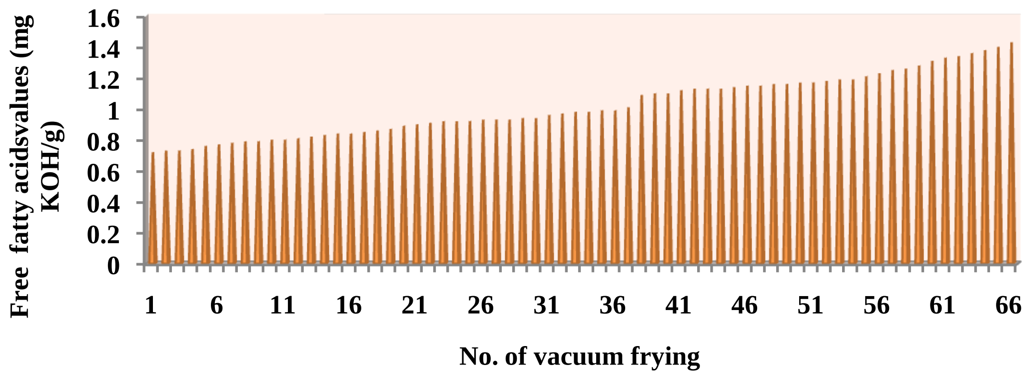

Fig. 4.44 Changes of free fatty acids in blended oil during vacuum frying

The total polar compound is important oil quality parameter and it is easily measurable property to decide the usability of oil. The threshold level of TPC in edible oil was 25-27%. The Fig. 4.43 shows the changes of total polar compounds in blended oil during vacuum frying. The TPC of blended oil was increased from 9.3% to 24.21% after 70th batch of vacuum frying, which is well below the threshold limit. This made help to recommended for reuse the oil upto 70 time of vacuum frying. The increased in the extent of polar compounds in the oil indicates the formation of compounds such as Triacylglycerols, secondary oxidation of oil (Latha and Nasirullah, 2011).

4.5.3 Free fatty acids

The free fatty acid deterioration is one of the natural phenomena in the frying process. The initial free fatty acid of the blended oil is 0.72 mg KOH/g. The FFA value was increased from 0.72 to 1.43 mg KOH/g after sixty-six time of vacuum frying. The obtained results were conformity with Kusucharid *et al.* 2009 that was observed with FFA value of palm oil blend during atmospheric and vacuum frying of carrot chips. The FFA value of atmospheric fried oil was higher than the vacuum fried oil. The Fig. 4.44 illustrated the changes in the free fatty acid during vacuum frying. Abdulkarim *et al.*, 2007 stated that increases of the free fatty acid are due to the deterioration of triglycerols and oxidation of oil during frying. The increased free fatty acid of blended oil during frying is due to the increased temperature (Mudawi *et al.*, 2014).

4.5.4 Peroxide value

The peroxide value of blended oil during vacuum frying represented in Fig. 4.45. The peroxide value of blended oil was increased from 0.26 meq O_2/kg to 4.47 meq O_2/kg after sixty- six batch of vacuum frying. The primary oxidation reactions cause an increase in the concentration of the peroxides to a maximum value beyond which its concentration decreases due to thermal decomposition thereof into carbonyl compounds and aldehydes (Crosa *et al*., 2014).

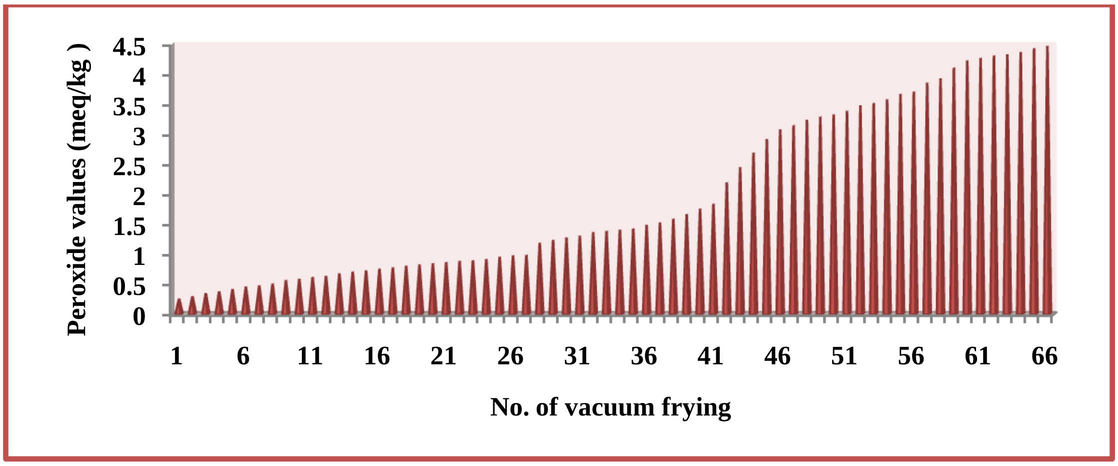

Fig. 4.45 Changes of the peroxide values in blended oil during vacuum frying

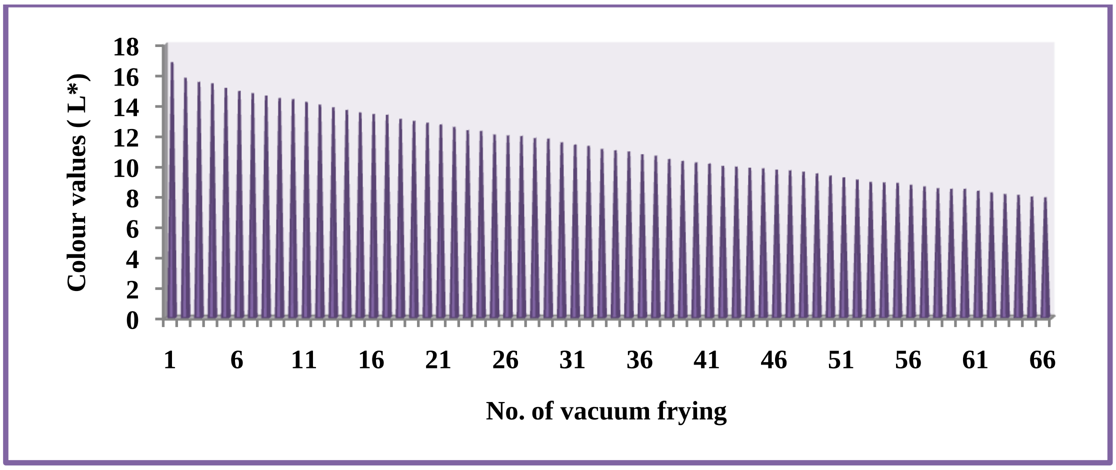

Fig. 4.46 Changes of the L* in blended oil values during vacuum frying

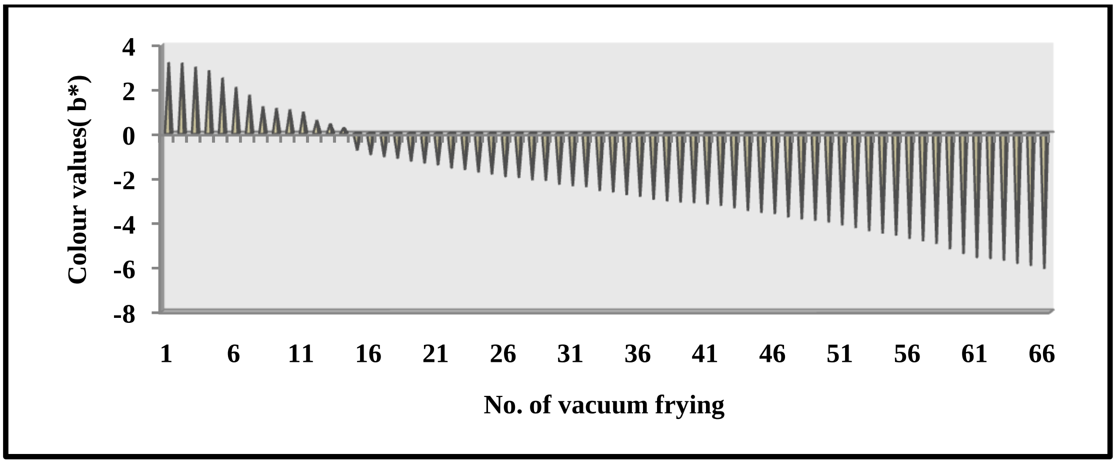

Fig. 4.47 Changes of b* in blended oil values during vacuum frying

The increase in PV of blended oil was within the recommendable level after sixty six batches of vacuum frying. Tyagi and Vasishtha (1996) stated that used of palm, lard, peanut, cotton seed, nigerseed, rape seed, mustard, rice bran, soya bean, sun flower, sesame oil and soya bean oil in vacuum frying of carrot chips showed no significant changes in peroxide after six consecutive batches of frying at 170°C for 10 min.

4.5.5 Colour values

Changes in colour values of L*, a* and b* are showed in Fig. 4.46, 4.47 and 4.48. The colour values L*, a* and b* of blended oil was changed from 16.81 to 7.92, from -0.54 to -3.82 and from 3.21 to -6.08 correspondingly, after sixty six batches of vacuum frying. The decreases in colour values indicated that darkening of oil in vacuum frying. The results were confirmed in Gutierrez *et al.* (1988) who observed relatively less colour darkening in vacuum frying compared to traditional frying. Accumulation of non-volatile decomposition products such as oxidized Triacylglycerols and FFA during oxidation can lead to colour changes which indicate the extent of oil deterioration by Mishra and Sharma (2014). Tarmizi *et al.*, 2013 stated that less darkening of oil drained in vacuum frying compared to atmospheric condition.

The Stastical analysis of the oil quality parameters were analysed using SPSS.16 general factorial method. The ANOVA table for the changes in oil quality attributes were represented in appendix- F3. The final results showed that increases in peroxide, colour, viscosity and total polar compounds were within the allowable limits. But in case of free fatty acid of blended oil was increased beyond its recommended value after sixty-six batches of vacuum frying. Hence, blended oil could be recommended upto seventy batches of vacuum frying for bitter gourd chips based on the TPC value.

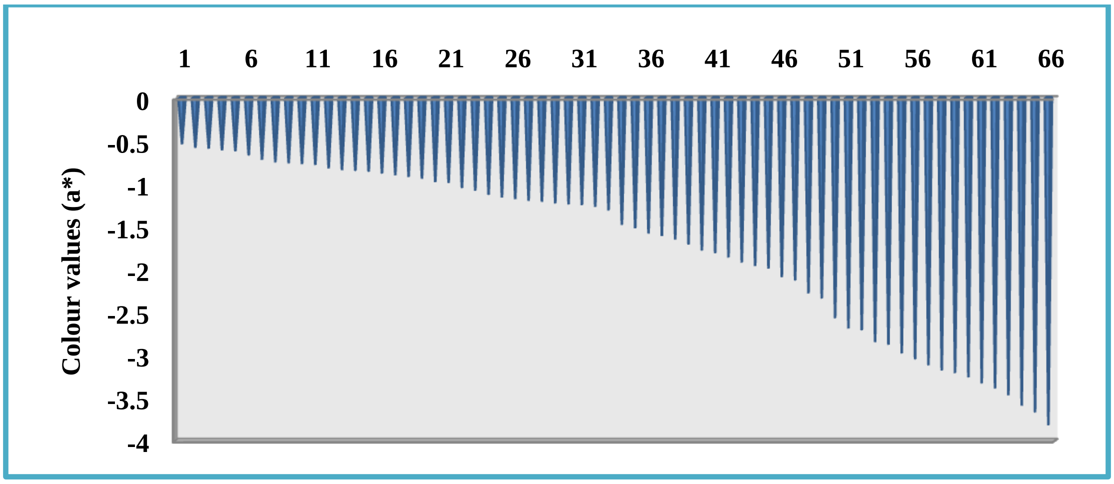

Fig. 4.48 Changes of the a* values in blended oil during vacuum frying

4.6. Cost economics

The cost economics of the vacuum fried bitter gourd chips was determined based on the cost of machinery, building and some assumptions. The production cost of the vacuum fried bitter gourd was 308.7/ - per kg. The benefit ratio for the production of vacuum fried bitter gourd chips was found to be 3.23:1.

CHAPTER-V

SUMMARY AND CONCLUSION

Bitter gourd (*Momordica charantia*) is one of the nature's most bountiful gifts, which belongs to the Cucurbitaceae family and it is considered as most bitter among all fruits and vegetables. The estimated post harvest loss of bitter gourd was 25%. A realistic solution for reducing the post harvest loss in bitter gourd is the adoption of the appropriate processing technologies. Numerous value added products like chips, pickles, curries, powder and medicinal products, are made from bitter gourd. Nowadays with growing demand of snacks around the world, products like chips, French fries and other fried food products are becoming more marketable. The consumption of fried chips is unhealthy and it leads to several diseases like obesity, cardiovascular diseases, cancer and hypertension. At present, modern consumers are very health conscious, but not ready to compromise the taste of the food they consume. In this context, investigation on processing technologies focusing on high quality fried products with less oil and less harmful by-products like acrylamide is the need of the hour. Vacuum frying is a promising technology to fulfil these objectives. It is an excellent alternative method, in which food is fried under low pressure and temperature. In vacuum frying, low pressure decreases the boiling point of water in foods and smoking point in oil. This technology was also used to preserve the colour, nutrients and in improving the textural properties of products.

The current investigation on "Development and evaluation of process protocol for vacuum fried bitter gourd chips" and was under taken in Department of Food and Agricultural Process Engineering, KCAET, Tavanur, Kerala, India.

Standardisation of different pre-treatments by using blanching cum drying (2 min water blanching at 95ºC and drying at 70ºC for 1 h 30 min), freezing (-30ºC for 8 h) and edible gum coating (dipping in 1.5% guar gum for 5 min), were compared with control (un-treated) and atmospheric fried bitter gourd chips. The blended oil (rice bran and palm oil, 80:20) was used as frying oil and de-oiling was carried out at 1000 rpm for 5 min. The control (un-treated) vacuum fried bitter gourd chips had a oil content (4.43 %), moisture content (0.264), water activity (0.250), bulk density (0.370 g/cm^3), true density (1.438 g/cm^3), thickness expansion (-55.96 %), hardness (1.422 N), L* (50.47), a* (-4.13) and b* (26.78). The sensory evaluation of control (un-treated) and frozen pre-treated sample had high sensory score than the other samples. Considering all the results of quality parameters control (un-treated) sample had best results and further optmisation of process parameters was carried out by using control sample.

Optimisation of process parameters was done for three different combination of temperature (100, 110 and 120ºC), pressure (9, 11 and 14 kPa) and time (10, 12 and 14 min) under the centrifugation speed of 1000 rpm for 5 min for all treatments. This experiment was done by using completely randomised design with 27 treatments in 3 replications for vacuum fried bitter gourd chips. The frying conditions affected the product parameters of vacuum fried bitter gourd chips. The vacuum fried bitter gourd chips at 100ºC, 9 kPa for 10 min had good results with production of oil content (4.011 %), acrylamide content (56.52 ppb), hardness (1.411 N), energy content (1042.3 kJ/100g), bulk density (0.578 g/cm^3), water activity (0.498), true density (0.688 g/cm^3), moisture content (3.852 %), L* (50.19), a* (-5.3) and b* (27.68). Storage studies were conducted for treatments that scored high in the nine-point hedonic scale and fuzzy logic comprehensive model were selected for storage studies.

Packaging studies were done for vacuum fried bitter gourd chips for selecting good packaging material. The different packaging materials namely, low density polyethylene stand up pouches, zipper pouches with aluminium foil back (one side silver other side transparent) and laminated aluminium flexible pouches were analysed during 60 days of studies. Based on the results obtained during packaging studies laminated aluminium flexible packaging with nitrogen flushing was found to be the best for vacuum fried bitter gourd chips i.e. upto 60 days of storage.

The high sensory scored treatments were packed into laminated aluminium packaging for shelf life studies upto 90 days. During storage, oil content remained unchanged throughout the 90 days of storage period. The moisture content, water activity, hardness got increased and colour values got decreased with increased storage period. A high sensory score with good acceptance was observed upto 60th day of storage (> 8.0 Hedonic scale). However the score reduced to a sensory score of 7.0 after 90th day of storage with appreciable consumer acceptance.

The blended oil (rice bran and palm oil, 80:20) was evaluated for its quality evaluation after its repeated use for several batches of vacuum frying. Each batch of vacuum frying was done at 100ºC and 9 kPa for 10 min of vacuum frying. The peroxide value, viscosity and total polar compound values increased during vacuum frying but within the allowable limits after sixty-six batches of vacuum frying, the free fatty acids in blended oil increased above the allowable limits after 50 batches of vacuum frying. The total polar compounds (TPC) increased from 9.3 to 24.21 % after seventy batches of vacuum frying, which were well below the threshold limit for usage of oil. The colour of oil slightly decreased during vacuum frying. The cost economics for the production of the vacuum fried bitter gourd chips was Rs.308.7/- per kg and cost benefit ratio was 1: 3.23.

Based on the results following conclusions were made

- Vacuum frying technology is a promising technology for production of bitter gourd chip
- The control (un-treated) VF-bitter gourd chips had better quality attributes compared to other pre-treated bitter gourd chips
- The process condition at 100ºC and 9 kPa for 10 min produced a novel healthy snacks with low oil content and acrylamide content
- The laminated aluminium flexible packaging with nitrogen flushing was found to be the best for storing vacuum fried bitter gourd chips
- The storage life of vacuum fried bitter gourd chips was more than 90 days

- The quality of oil could be maintained for upto seventy batches based on TPC during vacuum frying
- Cost of vacuum fried bitter gourd chips was Rs. 308.7/- per kg

Future line of work

a. Conduct the packaging studies with other different packaging materials for vacuum fried bitter gourd chips
b. The vacuum frying system could be evaluated for other vegetables, fruits, sea foods and meat.

CHAPTER-VI
REFERENCES

Abbas-Ali, M., Hassan-Ali, A.N., Latip, R.A., Othman, N.H., Majid, F.A.A., and Salleh, L.M. 2013. Effect of heating at frying temperature on the quality characteristics of regular and high-oleic acid sunflower oils. *Act. Sci. Pol. Technol. Aliment*. 12(2): 159-167.

Abdel-Monem, S.A.I., Ali, R.F.M., Askar, M., and Samy, M.W. 2013. Impact of pre-treatments on the acrylamide formation and organoleptic evolution of fried potato chips. *Am. J. Biochem. Biotech.* 9(2): 90-101**.**

Abdel-Razek, A.G., Ragab, G.H., and Ali, H.S. 2012 Effect of pretreatments and frying time on physical and chemical properties of cottonseed oil. *J. Appl. Sci. Res*. 8(11): 5381-5387.

Abdulkarim, S.K., Long, K., Lai, O.M., Muhammad, S.K.S., and Ghazali, H.M. 2007. Frying quality and stability of high-oleic moringa oleifera seed oil in comparison with other vegetable oils. *Food Chem*. 105(4): 1382-1389.

Abdulla, G., Gehan, A., Shourbagy, E., and Sitohy, Z.M. 2013. Effect of pre-drying, blanching and citric acid treatments on the quality of fried sweet potato chips. *Am. J. Food Technol*. 9(1): 39-48.

Abiona, O.O., Awojide, S.H., Anifowoshe, A.J., and Babalola, O.B. 2011. Comparative study on effect of frying process on the fatty acid profile of vegetable oil and palm oil. *Int. Sci. Res. J.* 3(3): 2094-1749.

Afjeh, F.A., Bassiri, A., and Nafchi, A.M. 2014. Optimization of vacuum frying parameters in combination with osmotic dehydration of kiwi slices to produce healthy product. *J. Chem. Hlth. Risks.* 4(1):13–22.

Ahromrit, A. and Nema, P.K. 2010. Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. *J. Food Sci. Technol.* 47(6): 632-637.

Aladedunye, F.A. and Przybylski, P. 2009. Degradation and nutritional quality changes of oil during frying. *J. Am. Oil. Chem. Soc.* 86: 149–156.

Albert, S. and Mittal, G.S. 2002. Comparative evaluation of edible coatings to reduce fat uptake in a deep-fried cereal product. *Food Res. Int.* 35: 445-458.

Almeida, D.T., Curvelo, F.M., Costa, M.M., Viana, T.V., and Lima, P.C. 2017. Oxidative stability of crude palm oil after deep frying akara (*Fried Bean Paste*). *Food Sci. Technol.* Departamento de Ciências dos Alimentos, Escola de Nutrição, Universidade Federal da Bahia – UFBA, Salvador, BA, Brazil.

Amany-Basuny, M.M., Shaker-Arafat, M., and Azza-Ahmed, A.A. 2012. Vacuum frying: An alternative to obtain high quality potato chips and fried oil. *Glo. Adv. Res. J. Microbiol*. 1(2): 019-026.

Ammawath, W., Che, M.Y.B., Yusof, S., and Rahman, R.A. 2002. Effects of type of packaging material on physicochemical and sensory characteristics of deep-fat-fried banana chips. *J. Sci. Food Agric.* 82:1621-1627.

Angor, M.M. 2016. Reducing fat content of fried potato pellet chips using carboxy methyl cellulose and soy protein isolate solutions as coating films. *J. Agri. Sci.* 8(3): 1916-9760.

Arlai, A., Jhasang, W., Pouphet, S., and Yuang, S. 2014. Effect of calcium chloride and freezing on vacuum fried okra quality. *Food Appl. Biosci. J.* 2(2): 161-168.

Association of Official Analytical Chemists (AOAC). 1980. *Official Methods of Analysis, 31th ed.* Washington, DC.

Association of official analytical chemists (AOAC). 1986. Official Methods of Analysis of the AOAC International. 18th edn. Gaithersburg, MD, USA.

Association of Official Analytical Chemists (AOAC). 1990. *Official Methods of Analysis, 11th ed.* Washington, DC.

Association of official analytical chemists (AOAC). 2005. Official Methods of Analysis of the AOAC International. 18th edn. Gaithersburg, MD, USA.

Barutcu, I., Sahin, S., and Sumnu, G. 2009. Acrylamide formation in different batter formulations during microwave frying. *Food Sci. Technol*. 42: 17–22.

Behera, T. K., Behera, S., Bharathi, L.K., John, K. J., Simon, P.W., and Staub, J.E. 2010. Bitter Gourd: Botany, Horticulture, Breeding. *Hort. Rev*. 37: 101-141.

Bekas, W., Kowalska, D., and Kowalski, B. 2006. Acrylamide in commercial potato chips from warsaw market. *Polish J. Food Nutr. Sci*. 56(4): 391-394.

Bhattacharjee, D., Das, S., and Dhua, R.S. 2016. Dehydration for better quality value added product of bitter gourd (*Momordica charantia* l.). *Indian. J. Pharma. Biol. Res.* 4(4): 39-45.

Blumenthal, M.M. and Stier, R.F. 1991. Optimization of deep-fat frying operations. *Trends Food Sci. Technol.* 2: 144-148.

Bognar, A. 1998. Comparative study of frying to other cooking techniques influence on the nutritive value. *Grasas. Y. Aceites*. 49(4): 250-260.

Bordin, K., Kunitake, M.T., Aracava, K.K., and Trindade, C.S. 2013. Changes in food caused by deep fat frying. *Arch. Latino Am. nutr.* 63(1): 2013.

Borse, V.H. and Mishra, A.A. 2014. Studies on effect of different frying temperatures on physico-chemical properties of bitter gourd chips. *Int. J. Res. Eng. Adv. Technol.* 2(3): 2320 – 8791.

Bouaziz, F., Koubaa, M., Neifar , M., Zouari-Ellouzi, S., Besbes, S., Chaari, S., Amel, K., Chaabouni, M., Chaabouni, S.E., and Ghorbel, R.E. 2016. Feasibility of using almond gum as coating agent to improve the quality of fried potato chips: evaluation of sensorial properties. *Food Sci. Technol.* 65: 800-807.

Brncic, S.R., Lelas, V., Rade, D., and Simundic, B. 2004. Decreasing of oil absorption in potato strips during deep fat frying. *J. Food. Eng.* 64: 237–241.

Carla, V. Y. and Moreira, R. G. 2011. Physical and thermal properties of potato chips during vacuum frying. *J. Food Eng.* 104: 272-283.

Chatzilazarou, A., Gortzi, O., Lalas, S., Zoidis, E., and Tsaknis, J. 2006. Physicochemical changes of olive oil and selected vegetable oils during frying. *J. Food. Lipids*. 13: 27–35.

Choudhary, M. and Grover, K. 2013. Effect of deep-fat frying on physicochemical properties of rice bran oil blends. *J. Nursing Hlth Sci.* 1(4): 01-10.

Crosa, M.J., Skerl, V., Cadenazzi, M., Olazábal, L., Silva, R., Suburú, G., and Torres, M. 2014. Changes produced in oils during vacuum and traditional frying of potato chips. *Food Chem.*146: 603–607.

Daniali, G., Jinap, S., Zaidul, S.I.M., and Hanifah, N.L. 2010. Determination of acrylamide in banana based snacks by gas chromatography-mass spectrometry. *Int. Food Res. J.* 17: 433-439.

Da-Silva, P.F. and Moreira, R.G. 2008. Vacuum frying of high-quality fruit and vegetable-based snacks. *Food Sci. Technol*. 41: 1758-1767.

Debnath, S., Bhat, K.K., and Rastogi, N.K. 2003. Effect of pre-drying on kinetics of moisture loss and oil uptake during deep fat frying of chickpea flour-based snack food. *Food Sci. Technol.* 36: 91-98.

Debnath, S., Rastogi, K.N., Krishna, A.G., and Lokesh, B.R. 2012. Effect of frying cycles on physical, chemical and heat transfer quality of rice bran oil during deep-fat frying of poori: An Indian traditional fried food. *Food Bioproducts Processing.* 90: 249–256.

Deepa, J. 2015. Development of value added products from bitter gourd. M.Sc. (Ag) thesis, University of Agricultural Science, Bangalore, 96 p.

Dehghannya, J., Enayat-Allah, N., and Ghanbarzadeh, B. 2015. Frying of potato strips pre-treated by ultrasound-assisted air-drying. *J. Food Processing Preservation.* 1-10.

Deshpande, H.W. and Poshadri, A. 2011. Physical and sensory characteristics of extruded snacks prepared from Foxtail millet based composite flours. *Int. Food Res. J.* 18: 751-756.

Diamante, L. M., Press-wood, H. A., Savage, G. P., and Vanhanen L. 2011. Vacuum fried gold kiwifruit: Effects of frying process and pre-treatment on the Physico-chemical and nutritional qualities. *Int. J. Food Res*. 18: 632-639.

Diamante, L. M., Savage, G.P., and Vanhanen, L. 2012. Optimisation of vacuum frying of gold kiwifruit slices: application of response surface methodology. *Int. J. Food Sci. Technol*. 47: 518–524.

Diamante, L.M., Savage, G.P., Vanhanen, L., and Ihns, R. 2011. Vacuum-frying of apricot slices: effects of frying temperature, time and maltodextrin levels on the moisture colour and texture properties. *J. Food Processing Preservation*: 1745-4549.

Diamante, L.M., Shi, S., Hellmann, A., and Busch, H. 2014. Vacuum frying foods: products, process and optimization. *Int. Food. Res. J*. 22(1): 15-22.

Din, A., Bukhari, S.A.H., Salam, A., and Ishfaq, B. 2011. Development of functional and dietetic beverage from bitter gourd. *Internet J. Food Safety*. 13: 355-360.

Dueik, V. and Bouchon, P. 2011. Vacuum frying as a route to produce novel snacks with desired according to quality attributes according to new health trends. *J. Food Sci.* 76 (2): 188-195.

Dueik, V., Robert, P., and Bouchon, P. 2010. Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps. *Food Chem.* 119: 1143-1149.

Efird, J.T., Choi, Y.M., Davies, S.W., Mehrao, S., Anderson, E.J., and Katunga, L.A. 2014. Potential for improved glycemic control with dietary momordica charantia in patients with insulin resistance and pre-diabetes. *Int. J. Environ. Res. Public Hlth.*11: 2328-2345.

Ekanayake, S., Jansz, E.R., and Nair, B.M. 1999. Proximate composition, mineral and amino acid content of mature canavalia gladiate seeds. *Food Chem*. 66: 115-119.

Esana, T.A., Sobukolaa, O.P., Sannia, L.O., Bakareb, H.A., and Munoz, L. 2015. Process optimization by response surface methodology and quality attributes of vacuum fried yellow fleshed sweet potato (*Ipomoea Batatas L.)* chips. *Food Bioproducts Proc.* 95: 27-37.

Fan, H. Y., Sharifudin, M. S., Hasmadi, M., and Chew, H. M. 2013. Frying stability of rice bran oil and palm olein. *Int. Food. Res. J*. 20(1): 403-407.

Fan, L.P., Zhang, M., and Mujumdar, A.S. 2006. Effect of various pre-treatments on the quality of vacuum-fried carrot chips. *Drying Technol*. 24: 1481–1486.

Fan, L.P., Zhang, M., and Mujumdar, A.S. 2007. Storage Stability of Carrot Chips. *Drying Technol*. 25: 1537–1543.

Fan, L.P., Zhang, M., Gong-nian, X., Jin-cai, S., and Tao, Q. 2005. The optimization of vacuum frying to dehydrate carrot chips. *Int. J. Food Sci. Technol*. 40: 911-919.

Farhoosh, R., Kenari, R.E., and Poorazrang, H. 2009. Frying stability of canola oil blended with palm olein, olive, and corn oils. *J. Am. Oil Chem. Soc.* 86: 71–76.

Farkas, B.E. and Hubbard, L.J. 2000. Analysis of convective heat to transfer during immersion frying. *Drying Technol*. 18(6): 1269-1285.

Fisher, R.A. and Feynman, R.P. 2007. Completely Randomized Designs. *J. Hist. Biol.* 40(2): 295-325.

Fontana, A.J. 1998. Water activity: why it is important for food safety. *In Proceedings of the 1st NSF International Conference on Food Safety*. pp. 177–185.

Freitas, D.G.C., Shirley, A.G.B., Patricia, P., Farayde, M.F., Fernanda, P.C.Q., and Vicente, E. 2009. Reducing of fat uptake in cassava product during deep-fat frying. *J. Food Eng*. 94: 390-394.

Gadiraju, T.V., Patel, Y., Gaziano, J. M., and Djousse, L. 2015. Fried food consumption and cardiovascular health: A review of current evidence. *Nutrients*. 7: 8424–8430.

Garayo, J. and Moreira, R. 2002. Vacuum frying of potato chips. *J. Food Eng.* 55: 181–191.

García-Segovia, P., Urbano-Ramos, A.M., Fiszman, S., and Martínez-Monz, J. 2016. Effects of processing conditions on the quality of vacuum fried cassava chips (*Manihot esculenta Crantz*). *Food Sci. Technol.* 69: 515-521.

Garmakhany, A.D., Aghajani, N., and Kashiri, M**.** 2011. Use of hydrocolloids as edible covers to produce low fat French fries. *Latin. Am. Appl. Res*. 41:211-216.

Gharachorloo, M., Ghavami, M., Mahdiani, M., and Azizinezhad, R. 2010. The effects of microwave frying on physicochemical properties of frying and sunflower oils. *J. Am. Oil Chem. Soc.* 87: 355–360.

Gopala Krishna, A.G., Khatoon, S., and Babylatha, R. 2005. Frying performance of processed rice bran oils. *J. Food Lipids.* 12: 1–11.

Goswami, G., Bora, R., and Rathore, M.S. 2015. Oxidation of cooking oils due to repeated frying and human health. *Int. J. Sci. Technol. Manag*. 4(1). 495-501.

Granda, C. and Moreira, R.G. 2005. Kinetics of acrylamide formation during traditional and vacuum frying of potato chips. *J. Food. Process. Eng*. 28: 478–493.

Granda, C., Moreira, R.G., and Tichy, S.E. 2004. Reduction of acrylamide formation in potato chips by low-temperature vacuum frying. *J. Food Sci*. 69: 405-411.

Guillén, M.D. and Uriarte, P.S. 2012. Simultaneous control of the evolution of the percentage in weight of polar compounds, iodine value, and acyl groups proportions and aldehydes concentrations in sunflower oil submitted to frying temperature in an industrial fryer. *Food Control*. 24: 50-56.

Gupta, M., Sharma, S., Ajay, K., Gautam., and Bhadauria, R. 2011. Momordica charantia linn. (Karela) natures silent healer. *Int. J. Pharma. Sci. Rev. Res.* 11(1): 32-37.

Gutierrez, R., Gonzalez, O., and Dobarganes, M. C. 1988. Analytical procedures for the evaluation of used frying fats. In: Frying of Food: Principles, Changes, New Approaches (G. Varela, A. E. Bender and I. D. Morton, Eds.). Ellis Horwood Series in Food Science and Technology, Chichester, U.K. p.141-154.

Hasimah, H.A., Zainon, I., and Norbaiti, B. 2011. Effect of pre-treatments on sensory characteristics of vacuum fried pineapple snack - a preliminary investigation. *Int. Soc. Hortic. Sci*. 555-558.

Hong-Wei, X., Pan, Z., Li-Zhen, D., El-Mashad, H.M., Xu-Hai,Y., Mujumdar, A.S., Zhen-Jiang, G., and Zhang, Q. 2017. Recent developments and trends in thermal blanching – A comprehensive review. *Inf. Processing. In. Agric*. 4: 101–127.

Illeperuma, C.K. and Jayasuriya, P. 2002. Prolonged storage of karuthacolomban mango by modified atmosphere packaging at low temperature. *J. Hortic. Sci. Biotechnol.* 77 (2). 153-157.

Ismed. 2016. Effect of frying time and temperature on characteristics of carrot (Daucus Carota, L.) chips using vacuum frying. *Int. J. Adv. Res.* 4(11): 348-353.

Jaya, S. and Das, H. 2003. Sensory evaluation of mango drinks using fuzzy logic. *J. Sensory Stud*. 18: 163-176.

Jorge, M.B., Rosa, O., and Salvador, L.M. 2012. Influence of temperature on heat transfer coefficient during moderate vacuum deep-fat frying. *J. Food Eng*. 113: 167-176.

Joseph, B. and Jini, D. 2013. Antidiabetic effects of bitter melon (*Momordica charantia*) and its medicinal potency. *Asian. Pacif. J. Trop. Dis*. 3(2): 93-102.

Karthickumar, P., Ranasalva, N., and Jeyan, A.M. 2015. The technology of blending edible oils. *Beverage Food World*. 42(12): 29-30.

Kaushik, N., Gondi, A.R., Rana, R., and Rao, P.S. 2015. Application of fuzzy logic technique for sensory evaluation of high pressure processed mango pulp and litchi juice and its comparison to thermal treatment. *Innovative Food Sci. Emerging. Technol*. 32: 70–78.

Kawas, M.L. and Moreira, R.G. 2001. Effect of degree of starch gelatinization on quality attributes of fried tortilla chips. *J. Food Sci*. 66(2): 300-306.

Khan, M.I., Asha, M.R., Bhat, K.K., and Khatoon, S. 2008. Studies on quality of coconut oil blends after frying potato chips. *J. Am. Oil. Chem. Soc*. 85: 1165–1172.

Kharel, G.P. and Khanal, D. 2002. Drying optimization and storage stability of bitter gourd *(Momordica charantia* L). *J. Sci. Technol*. 4: 83-86.

Kim, D.N., Lima, J., Bae, I.Y., Lee, H.G., and Lee, S. 2011. Effect of hydrocolloid coatings on the heat transfer and oil uptake during frying of potato strips. *J. Food Eng.* 102: 317-320.

Krishnankutty, S., Varkey, G.A., Bhat, A.V., Dhanaraj, S., and Shanthi, N. 1981. Packaging and storage studies of deep fat fried Nendran banana chips. J *Food Sci. Technol.* 18: 104-108.

Kusucharid, C., Jangchud, A., and Thamakorn, P. 2009. Changes in characteristics of palm oil during vacuum and atmospheric frying conditions of sweet potato. *Kasetsart. J.* 43: 298-304.

Kwon, C. W., Kyung-Min, P., Park, J.W., Lee, J.H., Choi, S.J., and Chang, P.S. 2016. Rapid and sensitive determination of lipid oxidation using the reagent kit based on spectrophotometry. *J. Chem.* 1: 1-7.

Lastriyanto, A., Soeparman, S., Soenoko, R., and Sumardi, H.S. 2013. Analysis frying constant of pineapples vacuum frying. *World Appl. Sci. J*. 23 (11): 1465-1470.

Latha, R.B. and Nasirullah, D.R. 2011. Physico-chemical changes in rice bran oil during heating at frying temperature. *J. Food Sci. Technol*. 1-6.

Lazim, M.A. and Suriani, M. 2009. Sensory evaluation of the selected coffee products using fuzzy approach. *Int. J. Math. Computational Sci*. 3(2): 133-136.

Lioumbas, J.S., Christos, A., and Karapantsios, T.D. 2012. Effect of potato deep-fat frying conditions on temperature dependence of olive oil and palm oil viscosity. *J. Food Eng.* 113: 217-225.

Maadyrad, A., Tarzi, B.G., Bassiri, A., and Bamenimoghada, M. 2011. Process optimization in vacuum frying of kiwi slices using response surface methodology. *J. Food Biosci. Technol.*1: 33-40.

Maity, T., Bawa, A.S., and Raju, P.S. 2014. Effect of vacuum frying on changes in quality attributes of jackfruit (*Artocarpus heterophyllus*) bulb slices. *Int. J. Food Sci*: 8.

Maity, T., Bawa, A.S., and Raju, P.S. 2017. Effect of pre-conditioning on physico-chemical, micro structural and sensory quality of vacuum fried jackfruit chips. *An Int. J.* 01: 28.

Maneerote, J., Noomhorm, A., and Takha, P.S. 2009. Optimization of processing conditions to reduce oil uptake and enhance Physico-chemical properties of deep fried rice crackers. *Food sci. Technol.* 42: 805–812.

Mariscal, M. and Bouchon, P. 2008. Comparison between atmospheric and vacuum frying of apple slices. *Food Chem.* 107: 1561–1569.

Mishra, R. and Sharma, H.K. 2014. Effect of frying conditions on the physico-chemical properties of rice bran oil and its blended oil. *J. Food Sci. Technol*. 51(6): 1076–1084.

Mohammad, R., Moghaddam, A., Rafe, A., and Taghizadeh, M. 2013. Kinetics of color and physical attributes of cookie during deep-fat frying by image processing techniques. *J. Food. Processing Preservation*: 1745-4549.

Mohammed, M. and Wickham, L.D. 1993. Extension of bitter gourd storage life through the use of reduced temperature and polyethylene wraps. *J. Food Quality* .16(37): 1-382.

Molla, M.M., Nasrin, T. A. A., and Islam, M.N. 2009. Study on the suitability of banana varieties in relation to preparation of chips. *J. Agric. Rural Dev.* 7(1&2): 81-86.

Molla, M.M., Nasrin, T., Islam, M.N., and Bhuyan, M.A.J. 2008. Preparation and packaging of jackfruit chips. *Int. J. Sustain. Crop Prod.* 3(6): 41-47.

Moreira, R.G. 2009. Deep-fat frying. Department of Biological and Agricultural Engineering, Texas A&M University. Chapter-7. College Station, TX, USA: 1755-8336.

Moreira, R.G., Da-Silva, P.F., and Gomes, D. 2009. The effect of a de-oiling mechanism on the production of high quality vacuum fried potato chips. *J. Food Eng*. 92: 297–304.

Morrison, W.H., Robertson, J.A., Burdick, D., and Russell, R.B.1973. Deep-fat frying on sunflower oils. *J. Am. Oil. Chem. Soc.* 50: 440-442.

Moyanoa, P.C. and Pedreschib, F. 2006. Kinetics of oil uptake during frying of potato slices: Effect of pre-treatments. *Swiss Soc. Food Sci. Technol.* 39: 285–291.

Mudawi, H.A., Mohammed, S.M.E., and Abdel, M.E.S. 2014. Effect of frying process on physicochemical characteristics of corn and sunflower oils. *Food Public Health*. 4(4): 181-184.

Mukhopadhyay, S., Mujumdar, G.C., Goswami, T.K., and Mishra, H.N. 2013. Fuzzy logic approach for sensory evaluation of *chhana podo. Food Sci. Technol.* 53: 204-210.

Naimeh, K., Mohsen, E., and Zahra, E.D. 2016. Effect of active edible coatings made by basil seed gum and thymol on oil uptake and oxidation in shrimp during deep-fat frying. *Carbohyd. Polym*. 137: 249-254.

Nayak, P. K., Dash, U., and Rayaguru, K. 2016. Quality assessment of mustard oil in deep fat frying. *Asian J. Dairy Food Res*. 35(2): 168-171.

NHB [National *Horticulture* Board]. 2017. Annual Report. 2016-2017. Ministry of Agriculture & Farmers Welfare, Gurugram, 43p.

Norizzah, A. R., Junaida, A. R., and Maryam, A. L. 2016. Effects of repeated frying and hydrocolloids on the oil absorption and acceptability of banana *(Musa acuminate)* fritters. *Int. Food Res. J.* 23(2): 694-699.

Nunes, Y. and Moreira, R.G. 2009. Effect of osmotic dehydration and vacuum-frying parameters to produce high-quality mango chips. *J. Food Sci*. 74(7): 355-362.

Ophithakorn, T. and Yaeed, S. 2016. Influence of temperature on microstructure and oil content in vacuum frying of fish tofu. *Int. J. Adv. Agric. Environ. Eng.* 3(1): 2349 -1523.

Orthoefer, F.T. 1987. Oil use in the food-service industry. *J. Am. Oil Chem. Soc*. 64(6): 795-799.

Pahade, P. K. and Sakhale, B. K. 2012. Effect of blanching and coating with hydrocolloids on reduction of oil uptake in French fries. *Int. Food Res. J.* 19(2): 697-699.

Pan, G., Ji, H., Liu, S., and He, X. 2015.Vacuum frying of breaded shrimps. *Food Sci. Technol.* 62: 734-739.

Pandey A. 2009. Batch vacuum frying system analysis for potato chips. *J. Food Process Eng.* 1-11.

Paul, S.R. 2011. Food frying (Volume-III). *Department of Biological and Agricultural Engineering, University of California, Davis, California, USA*: pp.1.

Pedreschi, F. and Moyano, P. 2005. Effect of pre-drying on texture and oil uptake of potato chips. *Swiss. Soc. Food Sci. Technol*. 38: 599-604.

Pedreschi, F., Kaack, K., and Granby, K. 2016. Acrylamide generation in pre-treated potato chips. *Agro. Food. Ind*. 19: 04-06.

Perez-Tinoco, M.R., Perez, A., Salgado-Cervantes, M., Reynes, M., and Vaillant, F. 2008. Effect of vacuum frying on main physicochemical and nutritional quality parameters of pineapple chips. *J. Sci. Food Agric*. 88: 945–953.

Piana, M.L., Oddo, L.P., Bentabol, A., Bruneau, E., Stefan Bogdanov, S., and Declerck, C.G. 2004. Sensory analysis applied to honey: state of the art. *Apidologie.* 35: 26–37.

Powers, S. J., Mottram, D.S., Curtis, A., and Halford, N.G. 2017. Acrylamide content in potato chips. *Food Additives Contaminants*. 1-16.

Presswood, H. 2012. Lipid stability of dehydrated (vacuum fried) beef strips stored in two packaging types. Publication/Sveriges lantbruksunversitet, Institutionen för livsmdelsvetenskap, No. 360. 48 pages. Uppsala, Sweden.

Probir, K.G., Chatterjee, D., and Bhattacharjee, P. 2012. Alternative methods of frying and antioxidant stability in soybean oil. *Adv. J. Food Sci. Technol.* 4(1): 26-33.

Raghav, P. K., Agarwal, N., and Saini, M. 2016. Edible coating of fruits and vegetables. *Int. J. Scient. Res. Modern Educ*. (1)1: 188-204.

Ranasalva N. 2017. Development and evaluation of a vacuum frying system for banana chips *(musa spp.)*. Phd. (Ag. Eng.) thesis, Kerala Agricultural University, Thrissur, 36p.

Ranasalva, N. and Sudheer, K.P. 2015. Effects of vacuum and atmospheric frying on quality of ripen nedran banana. XXIVth ICFoST. 18-19, Dec. 2015, Held at College of Food Technology, Parbhani, and Maharashtra. pp.78.

Ranasalva, N. and Sudheer, K.P. 2017a. Effect of post centrifugation (De-oiling) on quality of vacuum fried banana (Nendran) chips. *The Bioscan*. 12(2): 749-753.

Ranasalva, N. and Sudheer, K.P. 2017b. Effect of pre-treatments on quality parameters of vacuum fried ripened banana (Nendran) chips. *J. Trop. Agric.* 55 (2): 161-166.

Rani, A.K., Yella-Reddy, S., and Chetana, R. 2010. Quality changes in Trans and Trans free fats and products during frying, *Eur. Food Res. Technol.* 230: 803–811.

Rani, B., Jat, B.L., Pandey, M., Malhotra, J., Mohan, L., Bugasara, P.S., and Maheshwari, R.K. 2014. Dietetic corollary of *momordica charantia* for vivaciousness and sanguinity. *Int. J. Pharmaceutical Res. Biosci.* 3(2): 141-154.

Rashmi, V.T., Kamlesh, J.W., Jayashri, B.T., and Milind, J.U. 2011. Bitter melon: a bitter body with a sweet soul. *Int. J. Res. Ayurveda Pharmacy*. 2(2): 443-447.

Ravindranath, B. 2005. Value addition - an integrated approach. *Food plus Souvenir*: 46.

Ravli, Y. 2012. Improved vacuum frying process for high quality sweet potato chips. M.Sc. (Agri. Engng.) thesis, A&M University, Kingsville, 61p.

Ravli, Y., Da-Silva, P., and Moreira, R.G. 2013. Two-stage frying process for high quality sweet-potato chips. *J. Food. Eng.* 118: 31- 40.

Rehab, F.A. and Anany, E. A. 2012. Physicochemical studies on sunflower oil blended with cold pressed tiger nut oil, during deep frying process. *J. Food Process. Technol.* 3(8): 1-8.

Ren, A., Pan, S., Li, W., Chen, G., and Duan, X. 2018. Effect of various pre-treatments on quality attributes of vacuum-fried shiitake mushroom chips. *J. Food Quality*: 2018(4510126): 7.

Romano, R., Giordano, A., Vitiello, S., Grottaglie, L.L., and Musso, S.S. 2012. Comparison of the frying performance of olive oil and palm superolein. *J. Food Sci*. 77(5): 512-531.

Routray, W. and Mishra, H.N. 2012. Sensory evaluation of different drinks formulated from dahi (Indian yogurt) powder using fuzzy logic. *J. Food Processing Preservation*. 36:1–10.

Rubalya-Valantina, S., Arockia-Sahayaraj, P., and Angelin-Prema, A. 2010. Antioxidant stability in palm and rice bran oil using simple parameters. *Rasayan J. Chem*. 3(1): 44-50.

Ruttanadech, N. and Chungcharoen, T. 2015. Effects of temperature and time on the physical properties of banana by vacuum frying technique. *Int. Conf. Adv. Agric. Biol. Environ. Sci. (AABES-2015) July 22-23, 2015 London* (*UK).*

Sahin, S., Sumnu, G., and Altunakar, B. 2005. Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. *J. Sci. Food Agric.* 85: 2375-2379.

Satishkumar., Karthik S.K., Palanimuthu, V., and Munishamanna, K.B. 2016. Study the suitability of packaging material for storage of jackfruit chips. *Int. J. Agric. Sci*. 8(30): 1635-1638.

Segovia, P.G., Ramos, A.M., Fizman, S., and Monzo, J.M. 2016. Effects of process condition on the quality of vacuum fried cassava chips. *J. Food. Sci. Technol*. 69: 515-521.

Sengar, G., Kaushal, P.,Sharma, H.K., and Kaur, M. 2014. Degumming of rice bran oil. *Rev. Chem. Eng*. 30(2): 183–198.

Setyawan, A. D., Sugiyarto, Solichatun., and Susilowati, A. 2013. Physical, physical chemistries, chemical and sensorial characteristics of the several fruits and vegetables chips produced by low-temperature of vacuum frying machine. *Nusantara Biosci*. 5(2): 86-103.

Shahraki, M. H. and Mashkour, M. 2012. Vacuum frying. The 1st Middle-East Drying Conference. February 19-20, Mahshahr, Iran.

Shaker, M. A. 2015. Comparison between traditional deep-fat frying and air-frying for production of healthy fried potato strips. *Int. Food. Res. J.* 22(4): 1557-1563.

Shamla, L. and Nisha, P. 2014. Acrylamide in deep-fried snacks of India. *Food Additives Contaminants.* 7(3): 220-225.

Sharma, R. and Mann, B. 2010. Changes occurring in oils and fats during frying. *Dairy Chem. Div.* National Dairy Research Institute. Karnal. pp.1-9.

Shinde, K.J. and Pardeshi, I.L. 2014. Fuzzy logic model for sensory evaluation of commercially available jam samples. *J. Ready Eat Food* .1(2): 78-84.

Shyi-Liang, S. and Hwang, L.S. 2001. Effects of processing condition on vacuum fried apple chips. *Food Res. Int.* 34: 133-142.

Shyu L.S., Lung-Bin H., and Lucy S. H. 1998. Effect of vacuum frying on the oxidative stability of Oils. *J. Am. Oil Chem. Soc*. 75: pp.1393–1398.

Shyu, S.H., Hau, L.B., and Lucy, S.H. 2005. Effects of processing conditions on the quality of vacuum-fried carrot chips. *J. Food Agric.* 85: 1903-1908.

Shyu, S.L. and Hwang, L.S. 2011. Process optimization of vacuum fried carrot chips using central composite rotatable design. *J. Food Drug. Analysis.* 19(3): 324-330.

Simon, K.P., Aruna, M., Mandha, J., and Rao, D.S. 2017. Nutritional evaluation and oil blending studies of different oils. *Int. J. Food Sci. Nutr.* 2(1): 101-105.

Singh, S., Rathor, Y.K., Porwal, P., and Pandey, R.K. 2017. Anti-radical and microbial analysis of MAP stored Bitter gourd chips Short-running title: MAP storage study of Bitter gourd chips. *Int. J. Curr. Microbiol. Appl. Sci.* 6(2): 1840-1846.

Singh, U. and Sagar, V.R. 2013. Effect of drying methods on nutritional composition of dehydrated bitter gourd (*Momordica charantia* l.) rings. *Agric. Sustain. Dev*. 1(1): 83-86.

Singthong, J. and Thongkaew, C. 2009. Using hydrocolloids to decrease oil absorption in banana chips. *Food Sci. Technol.* 42: 1199-1203.

Sonia, N.S. 2014. Development of Nedran Banana Chips With enhanced shelf and Quality. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 80p.

Sothornvit, R. 2011. Edible coating and post-frying centrifuge step effect on quality of vacuum-fried banana chips. *J. Food Eng.* 107: 319–325.

Stubbs, R.J., Ritz, P., Coward, W.A., and Prentice, A.M. 1995. Covert manipulation of ratio of dietary fat to carbohydrate and energy density: Effect of food intake and energy balance in free living men. *Am. J. Clinic. Nutr.* 62: 330-337.

Su, Y., Zhang, M., Zhang, W., Adhikari, B., and Yang, Z. 2016. Application of novel microwave-assisted vacuum frying to reduce the oil uptake and improve the quality of potato chips. *Food. Sci. Technol.* 73: 490-497.

Suryatman, S. and Ahza, A. B. 2016. Process optimization of vacuum fried rice-straw mushroom (*Volvariella volvacea*) stem chip making. *J. Food Sci. Eng*. 6: 109-120.

Tagalpallewar, G., Shrigod, N., and Sardar, N. 2008. Vacuum frying technology-new technique for healthy fried foods [abstract]. In: Abstracts, *National Seminar on Indian Dairy Industry - Opportunities and Challenges;* 5-6 March, 2008, Anand. Food Processing Technology and Bioenergy, AAU, Anand, p.194.

Tareke, E., Rydberg, P., Karlsson, P., Eriksson, S., and Tornqvist, M. 2002. Analysis of acrylamide, a carcinogen formed in heated food stuffs. *J. Agric. Food Chem*. 50: 4998–5006.

Tarmizi, A.H.A., Niranjan, K., and Gordon, M. 2013. Physico-chemical changes occurring in oil when atmospheric frying is combined with post-frying vacuum application. *Food Chem.* 136: 902-908.

Tarzi, G., Maadyrad, A., Bassiri, A., and Bamenimoghadam, M. 2011. Process Optimization in Vacuum Frying of Kiwi Slices Using Response Surface Methodology. J. Food Biosci. Technol. 1: 33-40.

Teruel, M.R., Garcia-Segovia, P., Martınez-Monzo, J., Belen Linares, M., and Garrido, M.D. 2014. Use of vacuum-frying in chicken nuggets processing. *Innovative Food Sci. Emerging Technol.* 65.

Thakur, M. and Sharma, R.K. 2016. Bitter gourd: Health properties and value addition at farm scale. *Marumegh***.** 1(2): 2016.

Tiwari, M.R., Tiwari, K.K., and Toliwal, S.D. 2014. Studies on thermal stability of palm-sesame oil blends during deep fat frying. *J. Sci. Ind. Res.* 73: 153-156.

Torres, J.D., Alvis, A., Acevedo, D., Montero, P.M., and Tirado, F.D. 2017. Optimization of vacuum frying conditions of eggplant (*Solanum melongena* l.) slices by response surface methodology. *Int. J. Sci.* 42(10).

Troncoso, E., Pedreschi F., and Zuniga R. N. 2009. Comparative study of physical and sensory properties of pre-treated potato slices during vacuum and atmospheric frying. *Food Sci. Technol.* 42: 187-195.

Tyagi, V.K. and Vasishtha, A.K. 1996. Changes in the characteristics and composition of oils during deep fat frying. *J. Am.Oil Chem. Soc.* 73(4): 499-505.

Valantina, S.R., Sahayaraj, P. A., and Prema, A.A. 2010. Antioxidant stability in palm and rice bran oil using simple parameters. *Rasayan J. Chem.* 3(1): 44-50.

Wexler, L., Perez, A.M., Cubero-Castillo, E., and Vaillant, F. 2016. Use of response surface methodology to compare vacuum and atmospheric deep-fat frying of papaya chips impregnated with blackberry juice. *J. Food*: 01-09.

Wu, M., Hu, X., Ge, B., Zhao, G., and Wang, Z. 2010. Process optimisation of the bitter gourd (Momordica charantia) concentrated juice preparation for a freeze-dried powder. *Int. J. Food Sci. Technol.*45: 2553–2559.

Xiang, C.P., Wu, C.Y., and Wang, L.P. 2000. Analysis and utilization of nutrient composition in bitter gourd *(Momordica charantia). J. Huazhong. Agr. Univ.* 19: 388-390.

Yagua, C. V. and Moreira, R.G. 2011. Physical and thermal properties of potato chips during vacuum frying. *J. Food Eng.* 104: 272–283.

Yamsaengsung, R., Ariyapuchai, T., and Prasertsit, K. 2011. Effects of vacuum frying on structural changes of bananas. *J. Food. Eng*. 106: 298–305.

Yıldız, A., Palazoglu, T.K., and Erdogdu, F. 2007. Determination of heat and mass transfer parameters during frying of potato slices. *J. Food Eng*.79: 11–17.

Zhu, Y., Zhang, M., and Wang, Y. 2015. Vacuum frying of peas: effect of coating and pre-drying. *J. Food Sci. Technol*. 52(5): 105–3110.

Appendix-A

Sensory score card for vacuum fried bitter gourd chips

Sample code	Colour and appearance	Texture	Flavour	Taste	Overall acceptability
T1					
T2					
T3					
T4					
T5					

Hedonic scale

9 – Like Extremely

8 – Like Very Much

7 – Like Moderately

6 – Like Slightly

5 – Neither Like or Dislike

4 – Dislike Slightly

3 – Dislike Moderately

2 – Dislike Very Much

1 – Dislike Extremely

Name and signature of sensory panel:

Date:

APPENDIX –B

Fuzzy logic-Model calculation table

Table.B.1 Scale Factor, Fuzzy membership function (FMF) and Normalized membership function (NFMF) for quality attributes of vacuum fried bitter gourd chips

Sensory attributes	Scale factor	T1	T1 FMF	T1 NFMF	T2	T2 FMF	T2 NFMF	T3	T3 FMF	T3 NFMF
Colour and Appearance	EX									
	GD									
	MD									
	FR									
	FR									
	Total									
Texture	EX									
	GD									
	MD									
	FR									
	FR									
	Total									
Flavour	EX									
	GD									
	MD									
	FR									
	FR									
	Total									
Taste	EX									
	GD									
	MD									
	FR									
	FR									
	Total									

Overall acceptability	EX									
	GD									
	MD									
	FR									
	FR									
	Total									

EX- Excellent, GD- Good, MD- Medium, FR- Fair, NS- Not satisfactory

Table B.2 Judgement membership function (JMF) for vacuum fried bitter gourd chips

Sensory parameters	**T1**	**T2**	**T3**
Colour and appearance			
Texture			
Flavour			
Taste			
Overall acceptability			

Table B.3 Quality ranking for the vacuum fried bitter gourd chips

Sensory parameters	**Scores for attributes**	**T1:QR**	**T2:QR**	**T3:QR**
Colour and appearance	0.300			
Texture	0.300			
Flavour	0.100			
Taste	0.100			
Overall acceptability	0.200			
Ranking				

APPENDIX-C

Economic analysis of developed vacuum fried bitter gourd chips

Estimation cost of vacuum fried bitter gourd chips

Cost of machineries and building cost:

Vacuum frying machine cost	**=** Rs. 14, 00, 000
Slicer cost	= Rs. 25, 000
Cooling chamber cost	= Rs. 5, 00, 000
Packaging machine cost	= Rs. 40, 000
Building cost (2000 sq.ft) @ 1500/sq.ft	= Rs. 30, 00, 000
Miscellaneous item	= Rs. 1, 00, 000
Total cost	**= 50, 65, 000**

Assumptions

Life span (L)	= 10 years
Annual working hours (H)	= 275 days (per day 8 hours) = 2200 hours
Salvage value (S)	= 10% of initial cost
Interest on initial cost (i)	= 15% annually
Repair & maintainece	= 10% of initial cost
Insurance & taxes	= 2% of initial cost
Electricity charges	= Rs. 7/unit
Labour wages/person	= Rs. 400/day (2 Persons)
Skilled assistants (2 Ns @ 500/day)	**= Rs**. 1000/day
One manager @ 700/day	**= Rs**. 700/day

1. **Total fixed cost**

   i. **Depreciation** $= \frac{C - S}{L \times H} = \frac{5065000 - 506500}{10 \times 2200} = 207.20/h$

   ii. **Interest** $= \frac{C + S}{2} \times \frac{i}{H} = \frac{5065000 + 506500}{2} \times \frac{15}{100 \times 2200}$

   = Rs. 189.93 /h

   iii. **Insurance & taxes** = 2% of initial cost

   $= \frac{2}{100 \times 2200} \times 5065000 = 46.045/h$

   Total fixed cost = i + ii + iii **= 443.175/h**

2. **Total variable cost**

i. Repair & maintainiece = 5% of initial cost

$= \frac{5}{100 \times 2200} \times 2532500$

= 57.55/h

ii. Electricity cost

a. Energy consumed by the vacuum fryer = **30 kWh**

Cost of energy consumption/h = $\text{Power} \times \text{duration} \times \text{cost of 1 unit}$

$= 30 \times 8 \times 7$

= 1680/day

b. Energy consumed by slicer, cooling = 2 kw/h
tray and packaging machine

Cost of energy consumption/h = $\text{Power} \times \text{duration} \times \text{cost of 1unit}$

$= 2 \times 8 \times 7$

= Rs. 112/day

iii. **Labour cost (5 persons)** **=** Rs. 2500/day

iv. Packaging cost = Rs. 2500/day

v. Cost of raw material for preparation of vacuum fried bitter gourd chips

Sl. No.	Raw materials	Quantity (kg)	Unit rate (per kg)	Total amount (Rs.)
1	Bitter gourd	1200	30	36000
2	Frying oil	150	100	15000

Therefore variable cost (Bitter gourd chips) = i+ ii+ iii+ iv+ v
= 58208.81/ day

Therefore total cost of production of 200 kg of vacuum fried bitter gourd chips
= Fixed cost + Variable cost
= 3545.4+ 58208.81
= Rs. 61754.21/200kg of vacuum fried bitter gourd chips
= Rs. 308.77/ kg of vacuum fried bitter gourd chips

The market selling price 1kg of vacuum fried bitter gourd chips is Rs. 1000 kg

$$\text{Cost benefit ratio} = \frac{1000}{308.77} = 3.23$$

The benefit ratio for the production of vacuum fried bitter gourd chips was found to be 3.23:1.

APPENDIX-D1

Table D1.1 Details of pre-treated vacuum fried bitter gourd chips

Vacuum fried matured bitter gourd	Pre-treatments
BFR	Freezing
BBD	Blanching cum drying
BGC	Edible gum coating
BWP	Un-treated
BAF	Atmospheric fried matured bitter gourd

Table D1.2 Changes in quality parameters of pre-treated vacuum frying bitter gourd chips

Sl.No	Parameters	BFR	BBD	BGC	BWP	BAF
1.	Water activity	0.251	0.192	0.276	0.250	0.238
2.	Moisture content (%)	0.269	0.210	2.304	0.264	2.014
3.	Oil content (%)	8.51	3.26	4.18	4.43	20.32
4.	Bulk density (g/cm^3)	0.368	0.395	1.083	0.370	0.993
5.	True density (g/cm^3)	1.191	1.412	1.401	1.438	1.643
6.	Hardness (N)	1.273	2.146	1.691	1.422	1.886
7.	Thickness expansion (%)	-72.33	-55.29	-59.17	-55.96	-67.51
Colour values						
8.	L*	51.13	42.58	46.28	50.47	31.19
9.	a*	-4.30	-2.61	-3.24	-4.13	6.83
10.	b*	26.47	25.08	25.18	26.78	22.12
11.	ΔE	11.02	19.86	16.14	11.66	33.78
Sensory evaluation						
12.	Colour and appearance	9.0	7.2	8.5	9.0	6.0
13.	Texture	9.0	8.5	8.5	8.5	8.5
14.	Taste	8.5	7.1	8.0	8.5	8.8
15.	Flavour	8.5	7.3	7.8	8.5	8.7
16.	Overall acceptability	8.7	7.0	8.2	8.8	6.2

Table D1.3 Fuzzy logic for pre-treated vacuum fried bitter gourd chips

Treatments	Ranking of sensory parameters
Control	C&A>OA =Taste=Texture=Flavour
BS1	C&A=Texture > OA =Taste =Flavour
BS2	Texture>Flavour>C&A>Taste>OA
BS3	C&A= Texture> OA>Taste>Flavour
Atmospheric	Taste> Flavour>Texture>OA>C&A

OA-overall acceptability, C&A- Colour and appearance

APPENDIX-D2

Table D2.1 Multi response optimisation constraints of VF-bitter gourd chips

Sl.No	Parameters	Goal	Lower limit	Upper limit
Pre-treatments – VF-BG		**Is in range**	**BS2**	**BS1**
1	Moisture content	Minimise	0.2154	0.3038
2	Oil content	Minimise	3.6024	11.2815
3	Water activity	Minimise	0.2499	0.2528
4	Thickness expansion	Maximise	-53.3048	-65.2952
5	Texture	Minimise	1.2899	2.295
6	Bulk density	Minimise	0.2335	1.0835
7	True density	Minimise	0.4255	1.8504
8	L*	Maximise	34.5875	58.2405
9	a*	Minimise	-0.8705	-5.4812
10	b*	Maximise	20.7485	26.6551
11	ΔE	In range	10.1905	23.0248

APPENDIX-D3

ANOVA Table for quality parameters of the vacuum fried bitter gourd chips

Table D3.1 Water activity

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	4	0.011	0.003	119.678	<0.0001	0.02848	0.601
Factor –A	4	0.011	0.003	119.678	<0.0001		
Error	21	0.0735	0.004				
Total	20	-		Significant			

Table D3.2 Moisture content (%)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	4	13.775	3.444	7.877E3	<0.0001	0.99207	1.587
Factor A- Product	4	13.775	3.444	7.877E3	<0.0001		
Error	21	0.25615					
Total	20	13.779		Significant			

Table D3.3 Oil content (%)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	3	596.027	149.007	2.087E3	<0.0001	6.52873	2.402
Factor -A	3	596.027	149.007	2.087E3	<0.0001		
Error	21	1.68571	8.3473				
Total	20	596.741		Significant			

Table D3.4 Bulk density (g/cm^3)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	4	1.521	0.381	826.052	<0.0001	0.33568	0.122
Factor -A	4	1.521	0.381	826.052	<0.0001		
Error	21	0.29304	0.08535				
Total	20	1.523		Significant			

Table D3.5 True density (g/cm^3)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	4	0.348	0.087	89.655	<0.0001	0.15986	0.930
Factor -A	4	0.348	0.087	89.655	<0.0001		
Error	21	0.07620	0.046				
Total	20	0.358		Significant			

Table D3.6 Hardness (N)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>F	Std. Dev.	C.V (%)
Model	4	1.340	0.335	4.382E5	<0.0001	0.32719	0.019
Factor -A	4	1.340	0.335	4.382E5	<0.0001		
Error	21	0.08012	0.04127				
Total	20	1.348		Significant			

Table D3.7 Thickness expansion (%)

Source of variation	df	Sum of squares	Mean square	F value	P value prob>0.001	Std. Dev.	C.V (%)
Model	4	681.084	170.271	2.578E3	<0.0001	6.9873	1.894

Factor -A	4	681.084	170.271	2.578E3	<0.0001
Error	21	4.288	1.80178		
Total	20	681.745		Significant	

Table D3.8		L* values					
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	4	793.237	198.30	2.810E3	<0.0001	7.53062	0.384
Factor -A	4	793.237	198.30	1.977E6	<0.0001		
Error	21	6.11776	1.9440				
Total	20	793.942		Significant			

Table D3.9		a* values					
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	4	272.939	68.235	1.810E3	<0.0001	4.35090	2.076
Factor -A	4	272.939	68.235	1.810E3	<0.0001		
Error	21	3.31061	1.14082				
Total	20	273.316		Significant			

Table D3.10		b* values					
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	4	35.260	8.815	108.891	<0.0001	1.60512	0.700
Factor -A	4	35.360	257.232	108.891	<0.0001		
Error	20	1.35581	0.4144				
Total	14	36.070		Significant			

Table D3.11		ΔE values					
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	4	1028.323	257.232	1.837E6	<0.0001	8.57292	3.728
Factor -A	4	1028.323	257.232	1.837E6	<0.0001		
Error	21	2.21352					
Total	20	1028.457		Significant			

APPENDIX-E

Table E1.1 Treatments details for optimisation of process parameters

Sl.No	Treatments VF-BG	Temperature (°C)	Pressure (kPa)	Time (min)
1	BT1	100	9	10
2	BT2	100	9	12
3	BT3	100	9	14
4	BT4	100	11	10
5	BT5	100	11	12
6	BT6	100	11	14
7	BT7	100	13	10
8	BT8	100	13	12
9	BT9	100	13	14
10	BT10	110	9	10
11	BT11	110	9	12
12	BT12	110	9	14
13	BT13	110	11	10
14	BT14	110	11	12
15	BT15	110	11	14
16	BT16	110	13	10
17	BT17	110	13	12
18	BT18	110	13	14
19	BT19	120	9	10
20	BT20	120	9	12
21	BT21	120	9	14
22	BT22	120	11	10
23	BT23	120	11	12
24	BT24	120	11	14
25	BT25	120	13	10
26	BT26	120	13	12
27	BT27	120	13	14

Table E1.2 Quality attributes of the Vacuum fried bitter gourd chips

Treatments	Moisture content (%)	Water activity (a_w)	Oil content (%)	Bulk density (g/cm^3)	True density (g/cm^3)	Thickness expansion (%)	Hardness (N)	Energy content (kJ/100g)
BT1	3.852	0.498	4.011	0.578	0.688	-52.12	1.411	1042.3
BT2	2.927	0.376	4.983	0.475	0.862	-53.65	2.154	1118.05
BT3	1.755	0.264	5.874	0.365	0.923	-54.12	2.722	1221.01
BT4	3.516	0.424	4.458	0.534	0.721	-52.95	1.729	1078.76
BT5	2.468	0.332	5.204	0.453	0.898	-53.89	2.359	1118.28
BT6	1.394	0.225	6.107	0.331	0.938	-54.67	2.940	1305.0
BT7	3.175	0.401	4.797	0.515	0.756	-53.15	1.950	1109.72
BT8	2.097	0.315	5.585	0.426	0.912	-53.99	2.571	1187.25
BT9	1.189	0.191	6.735	0.284	0.947	-54.95	3.001	1320.5
BT10	3.447	0.434	4.681	0.543	0.765	-55.37	1.724	1125.56
BT11	2.778	0.383	5.842	0.452	0.875	-56.85	2.332	1142.03
BT12	1.419	0.247	6.743	0.348	0.948	-58.19	2.957	1231.41
BT13	3.245	0.405	5.004	0.518	0.797	-55.74	1.974	1136.06
BT14	2.231	0.320	6.124	0.441	0.908	-57.28	2.576	1196.32
BT15	1.167	0.216	6.851	0.317	0.972	-58.42	3.120	1318.4
BT16	3.056	0.383	5.365	0.492	0.831	-56.29	2.080	1139.32
BT17	1.965	0.304	5.586	0.403	0.925	-57.94	2.861	1204.33
BT18	1.278	0.165	7.097	0.269	0.991	-58.75	3.542	1408.2
BT19	3.210	0.417	5.045	0.525	0.825	-57.32	2.012	1141.46
BT20	2.419	0.261	6.769	0.424	0.916	-58.84	2.709	1225.74
BT21	1.265	0.142	8.952	0.325	1.087	-60.43	3.365	1319.04
BT22	2.419	0.40	5.642	0.475	0.864	-57.75	2.212	1159.26

Treatments	Moisture content (%)	Water activity (a_w)	Oil content (%)	Bulk density (g/cm^3)	True density (g/cm^3)	Thickness expansion (%)	Hardness (N)	Energy content (kJ/100g)
BT23	2.093	0.218	7.329	0.406	0.937	-59.37	2.972	1226.09
BT24	0.972	0.135	9.517	0.304	1.249	-60.84	3.587	1330.46
BT25	2.752	0.320	6.124	0.443	0.893	-58.28	2.573	1214.99
BT26	1.684	0.184	7.924	0.382	0.958	-59.76	3.108	1255.98
BT27	0.437	0.121	10.65	0.239	1.325	-61.48	3.915	1441.12

Table E1.3 Changes in colour values and sensory properties of vacuum fried bitter gourd chips

Treatments	L*	a*	b*	ΔE	Colour and appearance	Taste	Texture	Flavour	Overall acceptability
BT1	50.19	-5.3	27.68	16.14680464	8.7	9.0	8.7	8.4	8.7
BT2	43.34	-4.18	25.59	18.84177539	7.0	7.5	8.3	8.0	7.5
BT3	40.87	-3.21	24.36	32.53434186	8.0	6.5	7.5	8.5	8.1
BT4	49.28	-5.00	26.25	12.82571246	9.0	8.5	8.5	9.0	9.0
BT5	42.01	-4.07	25.18	20.22231935	8.0	8.3	7.4	8.0	7.5
BT6	38.25	-3.02	23.85	24.02360922	8.0	7.5	7.5	7.5	7.5
BT7	45.61	-4.62	26.08	16.4985363	7.5	8.0	8.0	8.0	8.0
BT8	41.58	-3.87	24.75	20.73221165	8.5	9.0	8.5	8.5	8.5
BT9	37.27	-2.55	23.57	25.30295437	8.2	8.0	8.0	7.5	8.0
BT10	47.28	-4.97	25.38	14.94642767	8.5	8.2	7.0	7.5	8.0
BT11	42.90	-3.85	24.31	19.52552688	7.0	8.2	8.0	7.5	7.5
BT12	39.11	-2.85	22.65	23.67652635	7.5	7.6	7.2	7.7	7.5
BT13	46.48	-4.42	25.04	15.83479713	9.0	9.0	9.0	9.0	9.0
BT14	41.20	-3.43	23.95	21.29764776	7.5	7.5	8.0	8.5	8.0
BT15	38.05	-2.39	22.08	24.89395509	8.5	8.5	8.0	8.2	8.5
BT16	44.28	-4.03	24.75	18.07465076	8.0	7.5	7.4	7.7	7.4
BT17	40.19	-3.10	23.01	22.51995115	8.0	8.0	7.5	8.0	8.2
BT18	36.55	-2.19	21.78	26.43435265	8.4	8.5	8.7	8.4	8.5
BT19	44.25	-4.21	23.54	18.36195523	7.5	7.9	8.2	8.3	8.0
BT20	41.02	-3.34	22.27	21.88341153	8.6	8.5	8.0	7.4	8.1
BT21	38.47	-1.95	20.94	24.86859465	7.2	7.5	7.9	8.0	7.5
BT22	43.08	-4.18	23.12	19.59926529	9.0	8.6	8.8	8.5	8.6
BT23	40.57	-2.87	21.98	22.44951224	8.2	7.4	7.5	7.5	7.5

Treatments	L*	a*	b*	ΔE	Colour and appearance	Taste	Texture	Flavour	Overall acceptability
BT24	36.06	-1.64	20.31	27.37517306	7.2	7.0	7.2	7.4	7.5
BT25	42.61	-1.95	22.84	20.14313282	8.5	8.5	8.7	8.5	8.5
BT26	39.22	-2.25	21.52	23.94678475	9.0	8.7	8.0	8.1	8.5
BT27	33.72	-0.97	19.46	29.93607356	7.5	7.6	7.4	7.2	7.7

APPENDIX-E2

ANOVA for optimised process parameters

Table E2.1				**Moisture content (%)**			
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	18	66.21	3.68	804.50	<0.0001	0.0676	3.00
A -Temperature	2	3.24	1.62	354.16	<0.0001		
B- Pressure	2	4.95	2.48	541.72	<0.0001		
C- Time	2	57.33	28.67	6269.33	<0.0001		
AB	4	0.0995	0.0249	5.44	<0.0001		
AC	4	0.3134	0.0783	17.13	<0.0001		
BC	4	0.2757	0.0689	15.08	<0.0001		
Residual	62	0.2835	0.0046				
Lack of fit	8	0.2832	0.0046		0.0043	**	
Error	54	0.003	0.0354	7586.50			
Total	80	66.49	4.667E-06		Significant		

** = Not significant

Table E2.2				**Water activity**			
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14	0.8585	0.0613	444.46	<0.0001	0.0117	3.92
A -Temperature	2	0.1179	0.0589	427.20	<0.0001		
B- Pressure	2	0.0593	0.0296	214.87	<0.0001		
C- Time	2	0.6610	0.3305	2395.25	<0.0001		
AB	4	0.0025	0.0006	4.59	<0.0001		
AC	4	0.0179	0.0045	32.36	<0.0001		
Residual	62	0.0091	0.0001				
Lack of fit	12	0.0087	0.0007	86.03	0.0377	**	
Error	54	0.0005	8.383E-06				
Total	80	0.8676		Significant			

** = Not significant

Table E2.3			**Bulk density** (g/cm^3)				
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	18	0.6677	0.0371	2222.74	<0.0001	0.0041	0.9784
A -Temperature	2	0.0327	0.0163	979.04	<0.0001		
B- Pressure	2	0.0576	0.0288	1726.51	<0.0001		
C- Time	2	0.5716	0.2858	17125.46	<0.0001		
AB	4	0.0013	0.0003	19.14	<0.0001		
AC	4	0.0006	0.0001	8.61	<0.0001		
BC	4	0.0039	0.0010	59.10	<0.0001		
Residual	62	0.0010	0.0000				
Lack of fit	8	0.0010	0.0001	125.87	0.2841	**	
Error	54	0.0001	9.753E-07				
Total	80	0.6688	Significant				

** = Not significant

Table E2.4			**True density** (g/cm^3)				
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	18	1.46	0.0812	161.01	<0.0001	0.0225	2.45
A -Temperature	2	0.3564	0.1782	353.36	<0.0001		
B- Pressure	2	0.0705	0.0353	69.94	<0.0001		
C- Time	2	0.8389	0.4194	831.67	<0.0001		
AB	4	0.0133	0.0033	6.61	<0.0001		
AC	4	0.1748	0.0437	86.65	<0.0001		
BC	4	0.0076	0.0019	3.79	<0.0001		
Residual	62	0.0313	0.0005				
Lack of fit	8	0.0312	0.0039	2952.04	0.0089	**	
Error	54	0.0001	1.321E-06				
Total	80	1.49	Significant				

** = Not significant

Table E2.5				Thickness expansion (%)			
Source	Df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14	535.54	38.25	3486.16	<0.0001	0.1047	0.1845
A -Temperature	2	433.93	216.96	19789.16	<0.0001		
B- Pressure	2	9.57	4.84	441.11	<0.0001		
C- Time	2	87.51	43.76	3991.08	<0.0001		
AB	4	4.07	1.02	92.72	<0.0001		
AC	4	0.3662	0.0916	8.35	<0.0001		
Residual	66	0.7232	0.0110				
Lack of fit	12	0.7181	0.0598	583.96	0.1319	**	
Error	54	0.0055	0.0001				
Total	80	536.27		Significant			

** = Not significant

Table E2.6				Oil content (%)			
Source	Df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	18	190.35	10.58	1327.56	<0.0001	0.0893	1.42
A -Temperature	2	70.94	35.47	4452.80	<0.0001		
B- Pressure	2	10.44	5.22	655.60	<0.0001		
C- Time	2	91.36	45.68	5734.49	<0.0001		
AB	4	1.34	0.3355	42.12	<0.0001		
AC	4	16.06	4.02	504.09	<0.0001		
BC	4	0.2033	0.0508	6.38	<0.0001		
Residual	62	0.4939	0.0080		<0.0001		
Lack of fit	8	0.4936	0.0617	13152.74	0.0018	**	
Error	54	0.0003	4.691E-06				
Total	80	190.85		Significant			

** = Not significant

Table. E2.7				Hardness (N)			
Source	df	Sum of	Mean	F value	p-value	Std.	C.V

		squares	square		prob>F	Dev.	(%)
Model	10	30.36	3.04	950.26	<0.0001	0.0565	2.17
A -Temperature	2	5.29	2.64	827.77	<0.0001		
B- Pressure	2	2.97	1.49	465.17	<0.0001		
C- Time	2	22.01	11.01	3445.23	<0.0001		
AC	4	0.0840	0.0210	6.57	<0.0001		
Residual	70	0.2236	0.0032				
Lack of fit	16	0.2230	0.0139	1140.27	0.0544	**	
Error	54	0.0007	0.0000				
Total	80	30.58		Significant			

** = Not significant

Table E2.8				**L***			
Source	Df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14	1248.46	89.18	196.68	<0.0001	0.6733	1.62
A -Temperature	2	128.25	64.12	141.43	<0.0001		
B- Pressure	2	117.23	58.62	129.28	<0.0001		
C- Time	2	975.58	487.79	1075.86	<0.0001		
AB	4	15.45	3.86	8.52	<0.0001		
BC	4	11.95	2.99	6.59	0.0002		
Residual	66	29.92	0.4534				
Lack of fit	12	13.35	1.11	3.62	0.0065	**	
Error	54	16.57	0.3069				
Total	80	1278.38		Significant			

** = Not significant

Table E2.9				**a***			
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14	93.06	6.65	516.50	<0.0001	0.1134	3.31
A -Temperature	2	18.38	9.19	714.08	<0.0001		
B- Pressure	2	6.75	3.38	262.25	<0.0001		

C- Time	2	66.62	33.31	2588.20	<0.0001	
AB	4	1.02	0.2551	19.82	<0.0001	
AC	4	0.2916	0.0729	5.66	0.0006	
Residual	66	0.8494	0.0129			
Lack of fit	12	0.8440	0.0703	703.34	0.0193	**
Error	54	0.0054	0.0001			
Total	80	93.91		Significant		

** = Not significant

Table E2.10 **b***

Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	6	287.16	47.86	1119.67	<0.0001	0.2067	0.8774
A –Temperature	2	163.82	81.91	1916.27	<0.0001		
B- Pressure	2	13.39	6.70	156.66	<0.0001		
C- Time	2	109.95	54.97	1286.07	<0.0001		
Residual	74	3.16	0.0427				
Lack of fit	20	3.16	0.1579	1769.79	0.0054	**	
Error	54	0.0058	0.0001				
Total	80	290.32	Significant				

** = Not significant

Table. E2.11 **ΔE**

Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	10	1255.76	125.58	111.46	<0.0001	1.06	4.99
A –Temperature	2	162.60	81.30	72.16	<0.0001		
B- Pressure	2	124.34	62.17	55.18	<0.0001		
C- Time	2	950.02	475.01	421.61	<0.0001		
BC	4	18.80	4.70	4.71	<0.0001		
Residual	70	78.87	1.13				
Lack of fit	16	59.89	3.74	10.65	0.0042	**	
Error	54	18.97	0.3514				

Total	80	1334.63		Significant			

**= Not significant

Table E2.12			**Energy content (kJ/100g)**				
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14	7.561E+05	54006.94	205.26	<0.0001	16.22	1.34
A -Temperature	2	1.102E+05	55100.50	209.41	<0.0001		
B- Pressure	2	85916.16	42958.08	163.26	<0.0001		
C- Time	2	5.361E+05	2.580E+05	1018.69	<0.0001		
AB	2	4547.92	1136.98	4.32	<0.0001		
BC	4	19358.07	4839.52	18.39	<0.0001		
Residual	66	17365.91	263.12				
Lack of fit	12	17363.84	14446.99	37715.90	0.0014	**	
Error	54	2.07	0.0384				
Total	80	7.735E+05		Significant			

**= Not significant

Table. E2.13			**Acrylamide content (ppb)**				
Source	df	Sum of squares	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	18	3.730E+05	20718.97	267.04	<0.0001	8.81	7.73
A -Temperature	2	84608.90	42304.45	545.22	<0.0001		
B- Pressure	2	1.817E+05	90845.30	1170.81	<0.0001		
C- Time	2	19438.50	9719.25	125.26	<0.0001		
AB	4	72712.00	18178.00	234.28	<0.0001		
AC	4	7826.07	1956.52	25.22	<0.0001		
BC	4	6683.30	1670.83	21.53	<0.0001		
Lack of fit	8	4208.25	526.03	47.15	0.0544	**	
Error	54	602.45	11.16				
Total	50	3.778E+05		Signigicant			

** = Not significant

APPENDIX-F1

ANOVA table for packaging studies

Table F1.1			Moisture content (%)				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	4.979	0.622	1.834E4	<0.0001	0.43763	1.201
Factor A-Product	8	4.979	0.622	1.834E4	<0.0001		
Error	20	0.44506	0.08422				
Total	26	4.980		Significant			

Table F1.2			Water activity				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	0.182	0.023	1.417	<0.0001	0.13461	0.725
Factor A- Product	8	0.182	0.023	1.417	<0.0001		
Error	20	0.13717	0.02591				
Total	26	0.471		Significant			

Table F1.3			Hardness (N)				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	4.849	0.606	505.153	<0.0001	0.43284	0.217
Factor A- Product	8	4.849	0.606	505.153	<0.0001		
Error	20	0.43965	0.08330				
Total	26	4.871		Significant			

Table F1.4			Thickness expansion (%)				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**

Model	8	2.554	0.319	2.781E3	<0.0001	0.31355	1.816
Factor A- Product	8	2.554	0.319	2.781E3	<0.0001		
Error	20	0.31891	0.06034				
Total	26	2.556		Significant			

Table F1.5			**L***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	525.490	65.686	5.721E5	<0.0001	4.49569	2.580
Factor A- Product	8	525.490	65.686	5.721E5	<0.0001		
Error	20	4.58200	0.86520				
Total	26	525.492		Significant			

Table F1.6			**a***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	51.773	6.472	5.637E4	<0.0001	1.41116	0.743
Factor A- Product	8	51.773	6.472	5.637E4	<0.0001		
Error	20	1.43881	0.27158				
Total	26	51.776		Significant			

Table F1.7			**b***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	43.914	5.489	1.418E3	<0.0001	1.30064	0.175
Factor A- Product	8	43.914	5.489	1.418E3	<0.0001		
Error	20	1.32462	0.25031				
Total	26	43.983		Significant			

Table F1.8			ΔE				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value Prob>F**	**Std. Dev.**	**C.V (%)**
Model	8	1506.615	188.327	5.655	<0.0001	9.00004	0.942
Factor A- Product	8	1506.615	188.327	5.655	<0.0001		
Error	20	9.00004	1.73206				
Total	26	2106.017			Significant		

APPENDIX-F2

ANOVA table for storage studies of vacuum fried bitter gourd chips

Table F2.1			Moisture content				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	28.07	2.55	791.34	<0.0001	0.0568	1.92
Factor A- Product	8	25.25	3.16	978.61	<0.0001		
Factor B- Time	3	2.82	0.9416	291.95	<0.0001		
Error	24	0.87784	0.08553				
Total	35	28.15			Significant		

Table F2.2			Water activity				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	0.3460	0.0315	472.43	<0.0001	0.0082	2.25
Factor A- Product	8	0.3302	0.0413	619.94	<0.0001		
Factor B- Time	3	0.0158	0.0053	79.06	<0.0001		
Error	24	0.0182	0.010158				
Total	35	0.3476			Significant		

Table F3.3			Oil content				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	21.08	4.17	4.66	<0.0001	0.9724	16.71
Factor A- Product	8	21.08	4.22	4.66	<0.0001		
Factor B- Time	3	0.000	0.000	0.000			
Error	24	1.15869	0.11339				
Total	35	49.45			Significant		

Table F2.4			Bulk density				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	0.2160	0.0196	364.46	<0.0001	0.0073	1.53
Factor A- Product	8	0.1910	0.0239	443.28	<0.0001		
Factor B- Time	3	0.0249	0.0083	154.29	<0.0001		
Error	24	0.07741	0.00753				
Total	35	0.2172			Significant		

Table F2.5			True density				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	3.286	0.056	1.994E4	<0.0001	0.1036	11.64
Factor A- Product	8	1.126	0.032	1.764E4	<0.0001		
Factor B- Time	3	4.854	0.086	2.685E4	<0.0001		
Error	24	0.09027	0.00987				
Total	35	2.872			Significant		

Table F2.6			**Thickness expansion**				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	4933.522	140.958	1.226	<0.0001	2.68	4.75
Factor A- Product	8	3203.901	121.19	1.226	<0.0001		
Factor B- Time	3	1087.542	73.28	0.759	<0.0001		
Error	24	11.16195	1.06928				
Total	35	4766.289			Significant		

Table F2.7			**Hardness**				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	12.50	1.25	6.40	<0.0001	0.4419	15.78
Factor A- Product	8	5.44	1.05	5.57	<0.0001		
Factor B- Time	3	7.06	1.41	7.23	<0.0001		
Error	24	4.88	0.1953				
Total	35	17.38			Significant		

Table F2.8			**L***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	P value prob>F	**Std. Dev.**	**C.V (%)**
Model	11	1525.67	138.70	94.26	<0.0001	1.21	3.26
Factor A- Product	8	598.40	74.80	50.83	<0.0001		
Factor B-Time	3	927.27	309.09	210.06	<0.0001		
Error	24	3.44250	0.63661				
Total	35	1560.99			Significant		

Table F2.9			a*				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	37.98	3.45	84.82	<0.0001	0.2018	6.06
Factor A- Product	8	29.43	3.68	90.38	<0.0001		
Factor B-Time	3	8.55	2.85	69.98	<0.0001		
Error	24	0.86889	0.10344				
Total	35	38.95			Significant		

Table F2.10			b*				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	11	453.37	41.22	56.12	<0.0001	0.8570	4.09
Factor A- Product	8	241.31	30.16	41.07	<0.0001		
Factor B- Time	3	212.06	70.69	96.24	<0.0001		
Error	24	2.12973	0.35008				
Total	35	471.00			Significant		

F2.11 Changes in the colour values and Sensory attributes of vacuum fried bitter gourd chips

	Colour and appearance	**Texture**	**Flavour**	**Taste**	**Overall acceptability**
			BT1		
0th	9.0	8.5	9.0	8.5	8.7
30th	8.5	8.2	8.4	8.4	8.3
60th	8.5	8.0	8.4	8.4	8.2
90th	7.5	7.0	7.5	7.3	7.5
Control	6.0	6.5	6.2	6.1	6.2
			BT4		
0th	9.0	9.0	8.5	8.5	8.6
30th	8.5	8.5	8.3	8.5	8.5
60th	8.0	8.0	8.0	8.0	8.0
90th	7.8	7.4	7.3	7.2	7.1

Control	6.3	6.2	6.4	6.3	6.5
		BT8			
0th	8.5	8.5	8.5	8.5	8.5
30th	8.5	8.3	8.2	8.1	8.3
60th	8.0	7.8	8.0	8.0	8.2
90th	7.5	7.3	7.2	7.1	7.0
Control	6.5	6.2	6.1	6.3	6.4
		BT13			
0th	8.6	8.4	8.8	8.6	8.8
30th	8.5	8.6	8.7	8.8	8.3
60th	8.2	8.3	8.4	8.4	8.2
90th	7.9	7.7	7.6	7.5	7.5
Control	6.4	6.3	6.2	6.1	6.0
		BT15			
0th	8.0	9.0	7.0	8.0	8.2
30th	8.0	8.5	7.5	7.2	8.0
60th	8.0	8.3	7.0	8.0	7.5
90th	7.5	7.3	7.2	7.1	7.1
Control	6.2	6.1	6.4	6.2	6.1

		BT20			
0th	7.5	8.0	9.0	9.0	8.5
30th	7.5	8.0	8.5	8.5	8.3
60th	7.5	7.5	8.0	8.0	7.8
90th	7.4	7.3	7.2	7.2	7.3
Control	6.5	6.4	6.4	6.4	6.3
		BT22			
0th	8.5	8.6	8.7	8.8	8.6
30th	8.5	8.5	8.6	8.7	8.5
60th	8.4	8.3	8.4	8.3	8.4
90th	8.2	8.0	8.0	8.0	8.0
Control	6.4	6.2	6.3	6.4	6.3
		BT25			
0th	9.0	9.0	8.5	8.5	8.5
30th	8.5	8.5	8.2	8.3	8.3
60th	8.2	8.2	8.1	8.0	8.0
90th	7.9	8.0	8.1	8.2	8.0
Control	6.2	6.3	6.2	6.1	6.0

		BT26			
0^{th}	8.5	8.8	8.5	8.0	8.4
30^{th}	8.4	8.3	8.4	8.3	8.3
60^{th}	8.0	8.2	8.1	8.2	8.1
90^{th}	7.2	7.3	7.2	7.3	7.2
Control	6.9	6.5	6.4	6.2	6.2

F2.12 Fuzzy logic model for stored sample

Storage period in days	Ranking of sensory attributes
BT1	
0^{th} day	C&A=Taste>Texture=O&A>Flavour
30^{th} day	C&A=Flavour>OA>Taste>Texture
60^{th} day	OA>Texture=Flavour=C&A>Taste
90^{th} day	OA>Flavour>Texture >Taste>C&A
Control	OA>Texture>Taste>Flavour>C&A
BT4	
0^{th} day	C&A=Taste>Texture=O&A>Flavour
30^{th} day	C&A>Flavour=Taste>OA>Texture
60^{th} day	OA>Texture=Flavour=C&A>Taste
90^{th} day	OA>Taste>Flavour>Texture>C&A
Control	Taste>OA>Texture>C&A>Flavour
BT8	
0^{th} day	Texture=Taste>C&A=O&A>Flavour
30^{th} day	Taste>C&A=Texture=Flavour=OA
60^{th} day	C&A>Texture>OA>Taste>Flavour
90^{th} day	OA>Flavour>Texture >Taste>C&A
Control	OA>Texture>Taste>Flavour>C&A
BT13	
0^{th} day	O&A>Texture>C&A>Flavour>Taste
30^{th} day	Texture=Flavour>Taste>OA>C&A
60^{th} day	OA=Flavour>Taste>Texture>C&A
90^{th} day	OA=Taste=Texture>C&A=Flavour
Control	OA=CA>Taste>Texture>Flavour
BT15	
0^{th} day	C&A=Taste>=O&A>Flavour>Texture
30^{th} day	C&A=Texture=Flavour>Taste>O&A
60^{th} day	C&A=OA=Texture>Taste>Flavour
90^{th} day	OA>Texture>Taste>Flavour>C&A
Control	Taste>Texture>Taste>C&A>Flavour

BT20	
0^{th} day	Taste>texture>C&A>Flavour=O&A
30^{th} day	C&A=OA=Taste=Flavour>Texture
60^{th} day	C&A>OA=Taste>Flavour>Texture
90^{th} day	OA>Taste>Flavour>Texture>C&A
Control	C&A>OA>Flavour>Taste>Texture
BT22	
0^{th} day	C&A=O&A>Flavour>Taste>Texture
30^{th} day	C&A=OA=Texture>Flavour>Taste
60^{th} day	OA>Texture>Flavour>Taste=C&A
90^{th} day	OA>Flavour>Taste>Texture>C&A
Control	OA>Flavour>Taste>Texture>C&A
BT25	
0^{th} day	Texture=Flavour>O&A>Taste>C&A
30^{th} day	Texture=OA=C&A=flavour=taste
60^{th} day	Texture>OA>Taste>Flavour>C&A
90^{th} day	OA>Taste>Texture>Flavour>C&A
Control	Texture>Taste>Flavour>OA>C&A
BT26	
0^{th} day	C&A=Texture>Flavour>Taste=O&A
30^{th} day	Texture>Taste=Flavour=OA=C&A
60^{th} day	Taste>Flavour>OA>Texture>C&A
90^{th} day	Flavour>Taste>OA>Texture>C&A
Control	Taste=Texture=OA=C&A=Flavour

Appendix-F3

ANOVA table for oil quality parameters

Table F3.1			**Total polar compounds**				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	2744.595	42.225	49.916	<0.0001	3.80772	4.18
Factor A- Product	65	2744.595	42.225	49.916	<0.0001		
Error	30	1.73253	0.27060				
Total	95	2856.256			Significant		

Table F3.2			Free fatty acids				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	9.527	0.147	2.270E3	<0.0001	0.22001	1.01
Factor A- product	65	9.527	0.147	2.270E3	<0.0001		
Error	30	0.03261	0.01564				
Total	95	9.536			Significant		

Table F3.3			Peroxide values				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	6811.587	104.794	0.917	<0.0001	10.54	15.83
Factor A- Product	65	6811.587	104.794	0.917	<0.0001		
Error	30	10.56740	0.74915				
Total	95	21890.977			Significant		

Table F3.4				Viscosity			
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	1338.177	20.587	0.984	<0.0001	4.56141	2.41
Factor A- Product	65	1338.177	20.587	0.984	<0.0001		
Error	30	4.57298	0.32417				
Total	95	4098.870			Significant		

Table F3.5			L*				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	1052.945	16.199	16.031	<0.0001	2.45397	27.93
Factor A- Product	65	1052.945	16.199	16.031	<0.0001		

Error	30	1.00062	0.17440				
Total	95	1186.331			Significant		

Table F3.6			**a***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	183.209	2.819	502.001	<0.0001	0.96631	5.47
Factor A- Product	65	183.209	2.8190	502.001	<0.0001		
Error	30	0.25539	0.06867				
Total	95	183.950			Significant		

Table F3.7			**b***				
Source of variation	**df**	**Sum of squares**	**Mean square**	**F value**	**P value prob>F**	**Std. Dev.**	**C.V (%)**
Model	65	1316.591	20.255	1.947E5	<0.0001	2.58520	4.77
Factor A- Product	65	1316.591	20.255	1.947E5	<0.0001	2.58520	
Error	30	0.55738	0.18372				
Total	95	1316.604			Significant		

DEVELOPMENT AND EVALUATION OF PROCESS PROTOCOL FOR VACUUM FRIED BITTER GOURD CHIPS (*Momordica charantia*)

By

POOJA M.R

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ABSTRACT OF THE THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR – 679 573

KERALA, INDIA

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ABSTRACT

Bitter gourd (*Momordica charantia*) is commonly known as bitter melon or Karela in India. The estimated post harvest loss of bitter gourd was 25%. A realistic solution to reduce the post harvest loss in bitter gourd is the adoption of the appropriate processing technologies. The vacuum frying is an excellent promising technology, in which food is fried under low pressure and temperature. Vacuum frying reduces the oil absorption, less formation of acrylamide content, and retains the colour and nutrients present in fried products. The vacuum frying system consists of two main chambers namely, frying chamber and oil storage chamber. A de-oiling system is attached to frying chamber to remove the oil content in the final vacuum fried product. This vacuum frying system used for the study was batch type and had a capacity of 3 kg/ batch with oil tank storage of 30 l. After every batch of vacuum frying, chips and oil were collected for analysing the quality. The blended oil (rice bran and palm oil at 80:20) was used as frying oil and de-oiling was done at a speed of 1000 rpm for 5 min. Different pre-treatments were done for vacuum fried bitter gourd chips. Control (Un-treated) sample had the best qualities with less oil content (4.43 %), moisture content (0.264 %), hardness (1.422 N), water activity (0.250) and green colour retention (a*(-4.13)). Quality parameters like moisture content, water activity, oil content, bulk density, true density, hardness, energy content, acrylamide content, thickness expansion, colour values and sensory evaluation of vacuum fried bitter gourd chips were analysed at different frying conditions. The treatment condition at 100ºC, and 9 kPa vacuum for a duration of 10 min produced good quality parameters with less oil content (4.011%), acrylamide content (56.52 ppb), hardness value (1.411 N), high retention of green colour (a*(-5.3)) and good organoleptic properties (Hedonic score of 8.7). The laminated aluminium flexible pouches with nitrogen flushing retained the quality of bitter gourd chips during the storage period. The TPC value of blended oil increased from an initial value of 9.4 to 24.21%, due to continuous usage of oil (70 times) under the vacuum frying process, and was within the safe limit. The FFA value of blended oil was within the acceptable limit upto 50 cycles of vacuum frying process.