DEVELOPMENT AND EVALUATION OF PROCESS PROTOCOL FOR VACUUM FRIED CARROT CHIPS (*DAUCUS CAROTA L*)

By

P. BABU

(2018-18-025)

THESIS

Submitted in partial fulfilment of the requirement for the degree
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2020

DECLARATION

I hereby declare that this thesis entitled "**Development and evaluation of process protocol for vacuum fried carrot chips** (*Daucus Carota L*)" 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.

P. Ba

Place: Tavanur

Date: 29-06-2021

P. BABU

(2018-18-025)

CERTIFICATE

Certified that this thesis entitled "**Development and evaluation of process protocol for vacuum fried carrot chips** (***Daucus Carota L***)" is a bonafide record of research work done independently by **Mr. P. Babu** 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 him.

Place : Tavanur
Date: 30-06-2021

Dr. Rajesh G K
(Major Advisor, Advisory committee)
Assistant Professor
Department of Processing and
Food Engineering
KCAET, Tavanur

CERTIFICATE

We, the undersigned members of the advisory committee of **Mr. P. Babu (2018-18-025)** a candidate for the degree of Master of Technology in Agricultural Engineering with major in Agricultural Processing and Food Engineering, agree that the thesis entitled "**Development and evaluation of process protocol for vacuum fried carrot chips (*Daucus Carota L*)**" may be submitted by **Mr. P. Babu (2018-18-025)** in partial fulfilment of the requirement for the degree.

Dr. Rajesh G K
(Chairman)
Assistant Professor,
Dept. of P&FE
KCAET, Tavanur.

Members :

Dr.Prince M V
(Member)
Professor & Head
Dept of P&FE
KCAET, Tavanur.

Dr. Sudheer K P
(Member)
Professor & Head
Dept of Agrl. Engg
COA, Vellanikara.

Dr.Jayan P R
(Member)
Professor & Head
Dept of FMPE
KCAET, Tavanur.

Dr. Manoj Kumar T.S
(External Examiner)
Principal Scientist and Head
ICAR-KVK, CPCRI
Kasargod.

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P. Babu

DEDICATED
TO

My Beloved Family, Relatives, Friends,
Researchers

&

My Guide

(Dr. Rajesh G K)

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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
AOAC : Association of official analytical chemists
aw : Water activity
b* : Blueness or Yellowness
CAF : Carrot with atmospheric frying
CB : Carrot with blanching
CBD : Carrot with blanching cum drying
CBF : Carrot with blanching cum freezing
CF : Carrot with freezing
CGG : Carrot with guar gum coating
CaCl2 : Calcium chloride
CAO : Canola oil
Cm : Centimetre
Cm^{-1} : Per centimetre
CMC : Carboxy methyl cellulose

CO_2 : Carbon dioxide
COO : Corn oil
cP : CentiPoise
CPO : Crude palm oil
CRD : Completely randomized design
DAD : Diode array detector
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
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 square

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 polyethylene

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/m2	:	Newton second per square metre
°C	:	Degree celsius
OLO	:	Olive oil
Pa.s	:	Pascal second
PET	:	Polyethylene terephthalate
PID	:	Proportional Integral Derivative
PO	:	Palm oil
POD	:	Peroxidase
POO	:	Palm olein oil
ppb	:	Parts per billion
PPO	:	Polyphenol oxidase
pps	:	Parts per second
PV	:	Peroxide value
RBO	:	Rice bran oil
rpm	:	Revolution per minute
RSM	:	Response surface methodology
s	:	Seconds
SEM	:	Scanning electron microscopy
SPI	:	Soy protein isolate
SPSS	:	Statistical package for social science
SS	:	Stainless steel
TA	:	Texture analyzer
TPC	:	Total polar compounds
VF	:	Vacuum frying
w.b	:	Wet basis
W/V	:	Weight per volume
WPI	:	Whey protein isolate

X1 : Frying temperature

X2 : Frying pressure

X3 : Frying pressure

α : Alpha

β : Beta

ΔE : Color difference

INTRODUCTION

CHAPTER I

INTRODUCTION

In the last few years, there is an increasing trend in the production of fruits and vegetables in our country. India is the second largest producer of fruits and vegetables next to china in the world. The production of horticulture crops in India during 2017-18 was 311.71 Million Tonnes (MT) from an area of 25.43 Million Hectare (Mha). The production of vegetables as well as its cultivation area in India during 2017-18 were 184.40 MT and 10.26 Mha, respectively (NHB,2018). The scenario of horticulture crops in our country has become very uplifting. The percentage share of horticulture output in agriculture comes about 33%. The total vegetable production and the area under cultivation in Kerala, during 2017-18 were 2.5 MT and 0.1 Mha, respectively (NHB,2018). Though India has progressed a lot in agricultural production, the processing level in horticulture crops is extremely low. By comparing with other countries like USA (65%) and china (23%), India's processing level of farm products is only 2.2%. The estimated post-harvest loss in fruits and vegetables are elevated and reached up to 20%. These percentages are intolerable and badly affect the economy of India (Hegazy, 2016). Though, India's contribution in vegetable production is 12% of the farm products, the per capita vegetable consumption is only 135 g/day as against the recommended dietary allowances of 230 g/day. In order to reduce the postharvest loss in horticultural farm produce, development of value-added products / ready to eat (RTE) products from locally available vegetables and fruits has to be promoted to improve consumptional usage, to maintain the quality and nutritive value, to increase the shelf life and to ensure food security (Ravindranath, 2005).

Carrot (*Daucus carota L*) is one of the most important cool season root crop vegetable cultivated in tropical region as well as temperate regions during winter and summer season, respectively (Raees-ul and Prasad, 2015). Carrots are biannuals belongs to the Apiaceae (*Umbelliferae*) family, with a crispy texture when fresh. During the last 30 years, world-wide carrot production was significantly increased (Rubatzky and Yamagunchi, 2012). According to National Horticulture Board

(NHB) 2018, the area under carrot in India was 96,510 ha with an annual production of 1648 thousand tonnes with Haryana, Punjab, Uttar pradesh, Bihar, Madhya Pradesh and Tamil Nadu being the major producing states during 2017-18. The area and production of carrot in Kerala was 800 ha and 9600 tonnes, respectively. The carrot production ranking of Kerala occupies 15th place in India (NHB,2018).

Carrots are moderately hard, long and thin, cylindrical or spherical in shape (Alam *et al.,* 2018).The most usually eaten part of a carrot is the taproot, which contains high levels of β-carotene (pre-vitamin A) and carbohydrates (sugars).The different varieties of carrot cultivated in all over India are *Ooty-1, Early Nantes, New Korda, India Gold, Pusa Kesar and Half Long Danvers* (NHB, 2010). Basically, carrot root flesh is available in different colors *viz.,* white, yellow, orange, red, purple, or very dark purple. Now a days, orange color carrots (Carlos and Dias, 2014) become very popular due to the presence of provitamin A content and high amount of α and β-carotene. Carrot is a root vegetable that has worldwide distribution. To maintain freshness and crispiness of the carrot, good washing, and hydro cooling (< 5°C) is necessary. To prevent the decaying and sprouting of carrot, storage temperature at 0 to 1°C is required. The recommended storage conditions for commercial storage of carrots are 0 °C with 98 to 100% RH (Suojara, 1999).

Carrots are highly nutritious vegetable which can be consumed in raw and processed form throughout the world. Carrot plays a vital role for the protection and development of human body. Carrot recorded the highest amount of carotene content of any human foods (Desobry *et al.,* 1998). Carrot contains vitamins *viz.,* B1(Thiamine), B2(Riboflavin), B6(Niacin) and B12 (Cobalamin) besides rich in source of β-carotene and dietary fibres which are helpful to prevent cancer and other dreadful diseases occur in human body (Ong and Chytil,1983). Carrot not only contains the vitamins but also consists of pectin, iron, complex carbohydrates and various minerals such as Ca, P, Fe and Mg (Gazalli *et al.,* 2013). 100 g fresh carrot contains 8285μg of β-carotene and 2.8g of dietary fibers, which are beneficial to human health (Forrest, 1987). Carotene, a source of provitamin A, is helpful for reducing the various diseases that are associated with oxidative stress and damage

(Handelman, 2001) and preventing the antioxidant and anticancer activities (Kotecha *et al.,* 1998).

In Kerala, carrot production is very limited, but its consumption is more. The post-harvest loss of carrot was noted as 15-20%. Carrot is a seasonal crop and perishable. Due to seasonal variations the price of carrots varies. The preparation of value-added products from carrot is an idealistic solution to reduce the post-harvest loss when it is available in plenty with less price especially during the glut season. The value-added products obtained from the carrots were pickles, chips, canned slices, juice, concentrate, preserve, cake, halwa, strips, flakes intermediate moisture foods, dehydrated, frozen canned product and various types of ready to serve beverages such as flavored carrot juice and blended beverage.

Now a days, there is an increasing demand for healthy snacks which provides healthy and nutritious food for consumption to reduce obesity. The production of crispy and crunchy snacks using different frying, freezing, drying and other processing methods enhance the acceptability and consumption of carrot (Huang & Zhang, 2012). Carrot chips, with its unique sensory attributes are a popular variety of snacks which is dry and crispy. So far, there is a limited availability of ready-to-eat carrots chips in the market.

Frying is a simple method of cooking any kind of foods such as chips, french fries, meat, fruits, and vegetables. During frying, the raw/pre-treated food items are dipping in the hot oil at high temperature *i.e.,* 160-180 °C over a short period of food (Hubbard and Farkas, 2000). During frying, the oil enters into the product in short time due to moisture loss occur in food (kita *et al.,* 2007). It results in the thermal destruction of micro-organisms and enzymes as well as it reduces water activity at the surface and thereby enhance the shelf life of the product. In the present era of junk foods, fried foods are gaining much market importance. Snack food market has registered an enormous growth among food processing sector in India. Deep fat frying/immersion frying is the most common technology followed in food sector to produce fried items. The frying process involves immersion of a food material to 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 process. Partially hydrogenated oils also have been suggested, to reduce the oxidation (Melton,1993). The quality of fried product mainly depends on factors such as frying temperature, frying time, type of oil, size and nature of sample (Ophithakorn and Yaeed, 2018). During frying process, the physical, chemical and textural characteristics of the food are modified. The main disadvantage for consumption of deep fat fried food items is the presence of more oil content (Garayo and Moreria, 2002). High oil uptake is associated with several health diseases *viz.,* cardiovascular diseases, cancer, obesity and hypertension.

At present, there is a lot of demand for healthy and tasty snack products with less oil content, for providing good health. In this context, investigation on processing technologies focus on producing high quality fried products with less oil which produce a fried product with no acrylamide content. The technology of vacuum frying is a best option for production of novel snacks which fulfill the consumers demand and meet nutritious requirements (Dueik *et al.,* 2010). The vacuum frying process was carried out in a closed system, the samples were fried under vacuum condition (<6 kPa). Due to low pressure, the boiling point of the oil and water in the food was reduced (Maity *et al.,* 2014). Vacuum technology reduces the oil content and acrylamide content of fried product (Granda, Moreira &Tichy, 2004), preserve the color, texture, flavor and preserve the nutritional compounds (Da Silva & Moreira, 2008). Besides these advantages, the vacuum fried oil can be reused efficiently for several times without alter the oil quality thus enhancing its economic feasibility.

Vacuum frying is new technology which uses a very low pressure and temperature rather than atmospheric deep fat frying to improve the quality attributes of food products. In vacuum frying the food is heated at very low pressure (less than 6 kPa). At such reduced pressures, the boiling point as well as smoke point of oil gets reduced. The absence of air during the frying process inhibits oxidation including lipid oxidation and enzymatic browning and thus could retain color and flavor. Vacuum frying offers a minimal change in oil quality and desired organoleptic properties without loss in nutritional value. It is widely used for processing various foods, mostly vegetables and fruits. Vacuum frying offers to improve the quality attributes of fried foods rather than atmospheric frying. It maintains color and flavor of the product. Moreover, oil used in vacuum frying can be reused to several times without affecting its quality thus increasing its economic feasibility.

Carrot chips are generally prepared from mature carrot. Higher frying temperature results in scorching of sample and negligible moisture removal from it. Vacuum frying technology is an alternative and best method in this case. Hence a research work entitled "Development and Evaluation of Process Protocol for Vacuum Fried Carrot Chips (*Daucus Carota L*)" was investigated with the following objectives.

1. To study the physico-chemical properties of raw carrot cultivar (*Ooty-1*) cultivar
2. To optimize the pre-treatments of vacuum fried carrot chips.
3. To optimize the process parameters of vacuum fried carrot chips and evaluation of oil quality
4. To conduct shelf-life studies of vacuum fried carrot chips.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter illustrates a comprehensive review of the research work done by various researchers regarding the traditional frying methods, vacuum frying systems, frying oil properties, vacuum fried product properties and storage studies of vacuum fried products.

2.1. CARROT

Carrots are highly nutritious vegetable and it can be consumed in raw as well as processed form throughout the world. It plays a major role in human body protection and its development. Carrot recorded the highest amount of carotene content among the horticultural produce (Desobry *et al.*, 1998). Carrots contains vitamins *viz.*, B1(thiamine), B2(riboflavin), B6(pyridoxine) and B12(cobalamin), besides rich source of beta-carotene (precursor of vitamin A). Carrot not only contains the vitamins, but also consists of pectin, dietary fibres, iron, complex carbohydrates and various minerals such as Ca, P, Fe and Mg (Gazalli *et al.*, 2013). 100 g fresh carrot contains 8285µg of β-carotene and 2.8 g of dietary fibers (Forrest, 1987), which are beneficial to human health. Carotene, a source of provitamin A, helps to reduce various diseases which are associated with oxidative stress and damage from free radicals (Handelman, 2001). Carotenoids and anthocyanins are the two main types of antioxidants present in carrot. Orange and yellow colors of carrot are due to the presence of carotenoids while red and purple colors due to anthocyanin content. Now a days, the consumption of carrot and its value-added products have increased steadily due to the recognition of antioxidant and anticancer activities (Kotecha *et al.*, 1998). The proximate and nutritional composition of carrot are shown in Table 2.1.

Sampathu *et al.* (1981) developed carrot halwa which is famous and popular sweet dish in northern India. Beerh *et al.* (1984) developed a preserve carrot candy. Carrot candy was prepared by dipping the carrot slices in sucrose or sugar syrup. Results showed that the final total soluble solids content (TSS) was 70–75^0 brix.

Salwa *et al.* (2004) developed carrot yoghurt, prepared by mixing the milk in different proportions of carrot juice (5–20%) before fermentation. Purthi *et al.* (1980) developed a carrot pickle by lactic acid fermentation and was stored up to 6 months in non-air tight containers.

Manjunath *et al.* (2003) developed a kheer mix product, prepared from dehydrated carrot powder, skim milk powder, sugar and other ingredients and its shelf life studies were conducted for shelf stability as well as sensory quality. The kheer mix product packed in paper-aluminium foil-polypropylene laminate pouches was found to be the best packaging material and the food products were stored up to 9 months with good sensory quality.

Singh *et al.* (2006) developed a carrot based condensed milk product (gazrella) using waste residues (pomace) obtained from the carrot juice extraction. The carrot pomace was dipped in 65^0 brix syrup firstly, then added 35% dry sucrose powder to the pomace followed by conventional drying at 60°C temperature for 2h. The osmotically dehydrated pomace was packed in laminated aluminium laminated package (100 gauge) under vacuum conditions. Results showed that gazrella product had good acceptability after 6 months stored under ambient conditions.

Sharma *et al.* (2012) developed a honey-based carrot candy. Results showed that the candy prepared at 1000:750 was found to have better sensory attributes. The β carotene retained upto 60% in the glass container stored at low temperature (1-3°C) and could be stored for 6 months. Suman and Kumari (2002) developed the carrot products such as halwa, biscuits and carrot curry by using dehydrated carrot products like carrot shreds, carrot powder and carrot chops respectively. Results revealed that dehydrated products can be stored for 2-3 months and carrot powder had more β-carotene retention (70%) during storage. The carrot products like carrot biscuits and halwa were accepted more compared with carrot curry.

Gazalli *et al.* (2013) conducted a study to evaluate proximate composition of carrot pomace powder. Carrot pomace is a by-product obtained from carrot juice processing. Results showed that average proximate composition of carrot pomace powder in terms of moisture, ash, protein, fat and crude fibre were 8.78, 5.05, 6.16, 2.43 and 24.66 %, respectively. Based on proximate analysis it was understood that the developed carrot powder had high nutritional value and low moisture content which could enhance its shelf life.

Table 2.1. Proximate and nutritional composition of carrot

Proximate Analysis		**Nutritional Analysis**			
Parameter	**Composition (g / 100g)**	**Vitamins**		**Minerals**	
Water	88.59g	Vitamin A	835 µg	Potassium	320 mg
Protein	0.93 g	Vitamin K	13.2 µg	Manganese	0.143 mg
Carbohydrates	9.58 g	Vitamin C	5.9 mg	Copper	0.045 mg
Total fats	0.24 g	Niacin (B3)	0.983 mg	Phosphorus	35 mg
Dietary fibre	2.8 g	Pantothenic acid (B5)	0.273 mg	Calcium	33 mg
Calories	41 kcal/100 g	Thiamine (B1)	0.66 mg	Magnesium	12 mg
		Riboflavin (B2)	0.058 mg	Zinc	0.24 mg
		Vitamin E	0.66 mg	Iron	0.3 mg

(Source : USDA National Nutrient Database)

Olalude *et al.* (2015) conducted a study on physico-chemical analysis of carrot juice. The result revealed that the moisture content, protein content, crude fat, ash, crude fibre, carbohydrate, specific gravity, pH and ascorbic acid was 91.000 ± 0.265 %,1.067 ± 0.058 %, 0.367 ± 0.089 %, 1.333 ± 0.153 %, 1.167 ± 0.153 %, 6.100 ± 0.346 %, 1.069 ± 0.003, 6.333 ± 0.058, 16.667 ± 1.332, respectively. The mineral content of carrot juices also analyzed and the various minerals *viz.,* Ca^{++} (mg/100g), Fe^{++}(mg/100g), PO_4^{-}(mg/100g), thiamine (mg/100g), niacin(mg/100g) and riboflavin(mg/100g) were 55.000 ± 0.000, 1.667

± 0.153, 44.333 ± 1.155, 0.057 ± 0.006, 0.300 ± 0.000, 0.100 ± 0.000, respectively. The content of β-carotene and vitamin A were 2730 ± 43.589 and 2805 ± 6.532, respectively. Based on results, it was concluded that carrot juice contained high vitamin A and β carotene which was good for human health and body fitness.

Chen *et al.* (2018) developed a healthy crispy carrot snack by using sequential infrared blanching (IR) and hot air (HA) drying technologies. The results showed that IR blanching reduced the drying time to 32.3%, 41.1% and 45.0% at different temperatures of 60, 70 and 80°C, respectively. Both IR blanching and HA drying techniques were applied in producing carrot snacks with improved sensory quality.

2.2. FRYING

Frying is a simple method of cooking any kinds of food such as chips, french fries, meat, fruits and vegetables. In frying, raw/pretreated food items are dipping in hot oil at high temperature (160-180°C) over a short period of time (Hubbard and Farkas, 2000). During frying, the oil slowly enters the product in short time due to moisture loss from food (kita *et al.,* 2007).

Frying is a dehydration process in which a simultaneous heat and mass transfer process occurs (Krokida *et al.,* 2000). During frying, a series of chemical and physical changes occur in the final product. The chemical changes occur in fried product are oil absorption, protein denaturation, starch gelatinization, surface browning and rapid water absorption. Frying is an efficient cooking method because it is a result of combined heat transfer and high temperature (Sanibal and Filho, 2002).

From last few decades, frying is the most common method employed in most of the food processing operations. Basically, frying is done to prepare fried foods such as snacks, fried chicken etc. For domestic and industrial scale, frying is the most commonly used technique to produce acceptable food for consumers in terms of combination of texture, color and unique flavor in the final product (Mestdagh *et al.*, 2008). Fried food can be preserved by inactivating the enzymes, thermal destruction of micro-organisms and lowering the water activity on the surface of the product (Fellows, 2006). However, many research studies showed the excess consumption of oil foods leads to serious health risks such as cardiovascular diseases, hypertension, diabetes, cancers, and obesity.

The selection of frying oil mainly depends on several factors *viz.*, stability and resistance of the oil, cost economics and fried products to oxidation (Gadiraju *et al.*, 2015). The temperature of normal frying was about 150–200^{0}C or higher temperature which tremendously increases unsaturated bonds of the vegetable oils that reduces the frying life and shelf life of food product due to oxidation. The most common types of traditional frying methods include deep fat frying, shallow frying, stir frying and sauteing.

In deep fat frying, the food was immersed in an edible oil or fat maintained at a temperature of about 150–200^{0}C (Yamsaengsung and Moreira, 2002). This type of frying was known as immersion frying. Shallow frying or contact frying is a method in which the food is placed in a frying pan that contains a thin layer of oil and heat is transferred by conduction (Okea *et al.*,2017). Stir-frying is another method to heat the food very fast at higher temperature. In sauteing, small amount of oil was added to the pan and frying was carried out in low flame (Blumenthal and Stier, 1991).

2.3 FRYING OIL

Gopala Krishna *et al.* (2004) studied the frying performance of refined rice bran oils (chemical refined and physically refined) and compared with the sunflower oil. Bhujia was prepared by using both rice barn and sunflower oil. Results showed that rice bran oil (RBO) had a higher thermal-oxidative stability than sunflower oil during frying. The low oil content (-7.9%) in the bhujia was noted in the chemically refined barn oil compared with sunflower oil, due to low oryzanol content and high oil content (+7.0%) in the bhujia was observed in the physically refined barn oil compared with sunflower oil, due to high oryzanol content.

Adolfo *et al.* (2006) conducted the study on effect of physico-chemical and structural characteristics of olive and sunflower oils after heating at frying temperatures. The olive and sunflower oils were heated at 150°C and 225°C in the time interval of 1-15 days. By comparing the two vegetable oils, sunflower oil was found to be more sensitive to thermal treatment which undergone more changes in the properties, especially in viscosity and rheological properties.

Chatzilazarou *et al.* (2006) determined the effect of physico-chemical changes in olive oil and vegetable oils during frying. During frying process, the various oil parameters such as iodine value, tocopherol and polyunsaturated fatty acids concentration decreased, whereas total polar compounds (TPC), peroxide value, viscosity and color values were increased. Based on sensory and analytical data, lowest oil deterioration occurred in olive oil compared to other oils.

Kita *et al.* (2007) studied the effects of oils and frying temperature on fat content and texture of potato crisps. The eight kinds of vegetable oils used in this study *viz.*, sunflower oil, rape seed, soya bean, olive, peanut, palm, partially hydrogenated rapeseed oil and a mixture of hydrogenated oil with palm oil. Potato crisps were fried in oils at different temperatures (150, 170 and 190°C). The results showed that fat content and texture of potato crisps were influenced by the type of the oil used for frying.

Aladedunye and Przybylski (2009) studied the effect of changes in the regular canola oil. French fries were fried at different frying temperature in the regular canola oil for 7 h for seven consecutive days. The results showed that total polar compounds (TPC), anisidine value, color and trans fatty acid content in the canola oil were increased significantly with increase in frying temperature and frying time.

Fan *et al.* (2012) conducted a study to measure frying stability of rice bran oil (RBO) and palm olein (PO). The French fries were continuously fried in both oils for six hours per day up to six days at a temperature of 185 ± 5°C. Results showed that free fatty acids (FFA), peroxide value (PV), color and anisidine valueof the oil were increased whereas the smoke point decreased in both oils (RBO &PO). In general, RBO showed greater stability than the PO in deep frying of French fries.

Romano *et al.* (2012) conducted a study on comparison of frying performance of olive oil (OO) and palm super olein (PSO). Based on analytical evaluation, PSO showed better results compared to OO. The oil parameters such as free fatty acids

(FFA) and total polar compounds (TPC) tend to increase faster in PSO compared to OO, due to presence of a high amount of saturated fatty acids in the PSO.

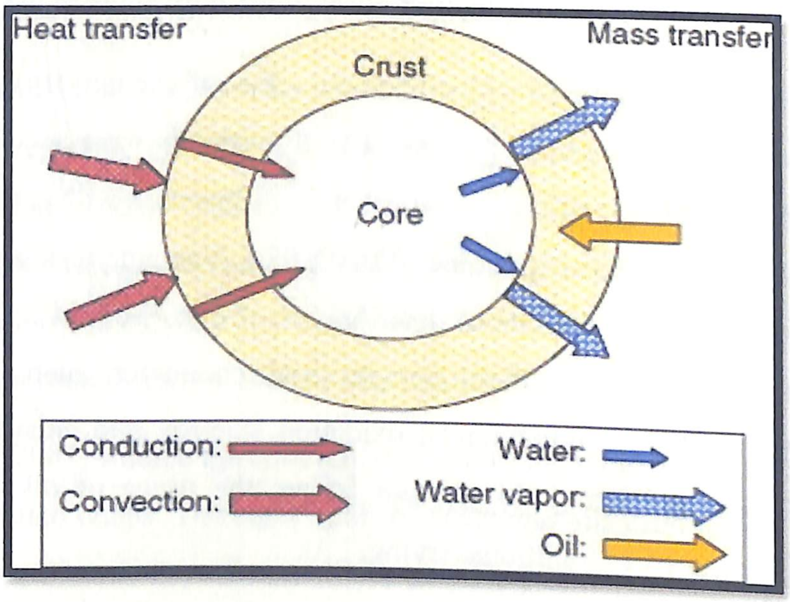
Carosa and Perkins (2014) studied the effect of vacuum frying and traditional frying on oil degradation. Two types of sunflower oils were used for the analysis: sunflower oil with high oleic acid content and sunflower oil with synthetic antioxidant *i.e.,* teritary hydro-butyal quinoine (TBHQ-SO). Vacuum frying achieves a great significant decrease in the rate of deterioration of oils. Sunflower oil with synthetic antioxidant showed a very slight changes in all parameters such as peroxides, free fatty acids, total polar compounds, oxidation stability and anisidine valuecontent during 10 days of frying. In vacuum frying, the usage of oil was significantly increased compared to traditional frying.

2.4 DEEP FAT FRYING

Deep fat frying is a unit operation and it is defined as a process of drying and cooking in hot oil (Sahin *et al.,* 1999).Deep fat frying is most commonly used for the preparation of snacks and fried foods, because consumers prefer color, taste, texture and appearance of the food (Brncic *et al.,*2004).High heat and mass transfer rates occur in the development of fried foods. During frying, oil absorption was more due to more amount of water loss from the food. When the food undergoes frying, the physico-chemical characteristics of food are affected and it depends on process time, temperature and pressure of the frying system.

Bhat *et al.* (2000) stated that the amount of water loss is more than oil uptake in the deep fat frying of chickpea-based flour suspensions (small and large *boondi*). The initial color of the raw batter was bright yellowish orange and it was changed to dull orange in the final product.

Albert and Mittal (2002) evaluated eleven types of edible coatings to reduce fat uptake in a deep-fried cereal product. Based on results methyl cellulose (MC), soya protein isolate (SPI) and whey protein index (WPI) were the best coating materials to reduce oil uptake during frying. Mixed coatings like SPI/MC and SPI/WPI were reduced the oil uptake up to 99.8%.



(Source: Brncic *et al.*, 2004)

Plate 2.1. Heat and mass transfer mechanism during deep fat frying

Brncic *et al.* (2004) reported that the potato slices blanched with calcium chloride (0.5 %) and followed by immersion in 1 % carboxy methyl solution had great reduction in oil uptake up to 54%.

Yildiz *et al.* (2007) determined the heat and mass transfer parameters during deep fat frying of potato chips. The potato slices were fried in sunflower oil at different temperatures *viz.,*150, 170, and 190°C. During frying, heat transfer coefficient was decreased with increase in oil temperature, whereas mass transfer coefficient increased linearly and mass diffusivity increased exponentially with increase in frying temperature.

Freitas *et al.* (2009) conducted a research on deep fat frying of cassava chips. The cassava slices were coated with three types of hydro-colloids (whey protein, pectin and soya isolate) and fried in electrical fryer. Results revealed that 27% fat reduction takes place in whey protein compared with hydrocolloidal coatings.

Gamboaa *et al.* (2015) studied the effect of blanching treatment during deep fat frying of taro chips. The 2-3 mm thickness samples were blanched, fried at different temperatures (180 to 200°C) and frying time (1 – 3 min). Results showed that the oil uptake was less in the combination of short frying time and high temperatures in both blanched and unblanched samples. The oil uptake was increased with increase in thickness of unblanched samples and opposite to the blanched samples.

Lien (2016) studied the kinetics of physical quality changes during deep fat frying of sweet potato chips. The chips having 3 mm thickness were fried at different temperatures ranges from 120 to 150°C. Results revealed that the physical parameters such as moisture content, oil content, color and textural values were significantly increased with increasing in temperature. The regression coefficient (0.98) was noted for all physical parameters and all parameters significantly increased with increase in temperature at 5% ($p \leq 0.05$).

Ogan *et al.* (2018) determined the characterization of tocopherols, tocotrienols and total carotenoids in deep fat fried French fries. French fries were fried at 170°C with different refined crude palm oil (CPO), refined canola oil (CO) and blended CPO/CO at 1:1 w/w. Results showed that the french fries absorbed < 20% of tocopherols, 40% of tocotrienols and 50% of total carotenoids from the oils. The french fries fried in CPO and blended oil had less oil content and more amount of vitamin E and carotenoids.

2.5 VACUUM FRYING AND VACUUM FRYING SYSTEMS

Vacuum-frying is a promising technology and efficient method to reduce the oil content, moisture content and maintaining the nutritional quality in fried foods (Diamante *et al.*, 2011). During vacuum-frying, food is heated under low pressure (6-10 kPa) in a closed system that causes a reduction in the boiling point of frying oil as well as the moisture in the food (Shyu and Hwang, 2001).

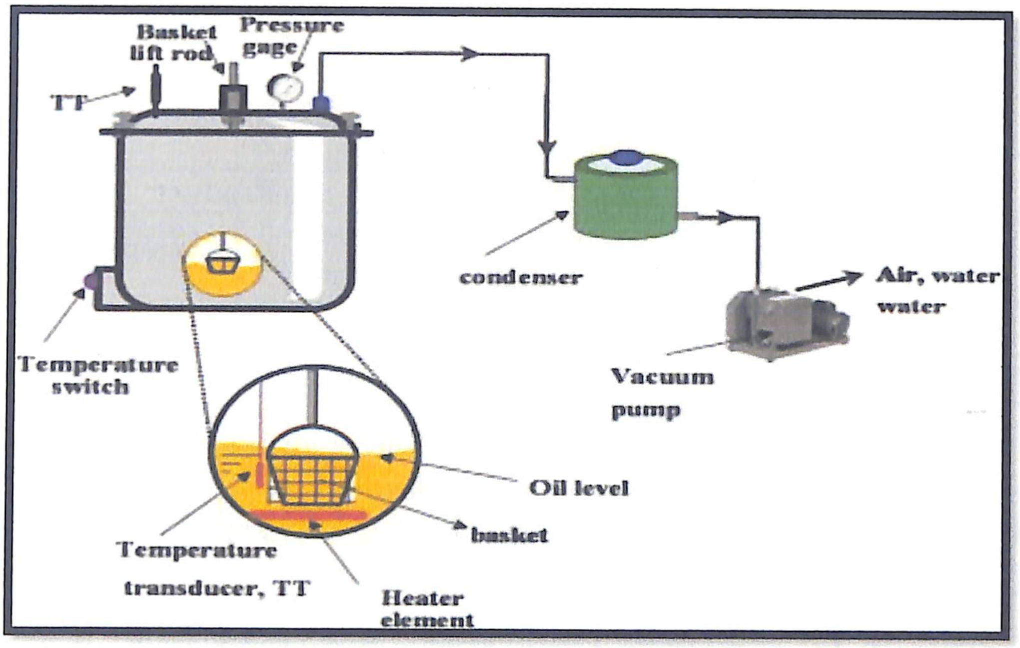
The most important factors affecting the vacuum fried products are time, temperature and pressure combinations. For getting the acceptable physicochemical attributes (such as moisture and oil contents, color, appearance, texture and flavor) as well as to improve its nutritional qualities, the process parameters of vacuum frying need to be optimized. This technology could be employed indifferent foods *viz.*, fruits, vegetables, sea foods, meat, and cereal products to produce snacks with good texture and without darkening /scorching of product (Da Silva and Moreira, 2008).

Tan and Mittal (2006) developed á batch type vacuum frying system for development of vacuum fried doughnuts. The system consists of a dual-seal vacuum pump, a heater and a condenser. A shaft was attached to the basket moves up and down, so that the doughnuts could be moved either into the oil while frying or above the oil after frying. Pressure cooker having a capacity of 11.4 L was modified to serve as a vacuum vessel. Results stated that vacuum frying could lower the frying temperature than atmospheric frying.

Nunes and Moreira (2009) developed a small-scale vacuum frying system. The vacuum vessel is made of cast aluminium. The construction details of vacuum frying system are oil capacity- 6L, basket capacity – 1Kg, resistance heater, max temp generated-140°C, maximum rotational speed for de-oiling – 650 rpm, dual seal vacuum pump with vacuum capacity of 10 torr (1.33 KPa) and a condenser. Based on sensory evaluation, the results revealed that mango chips prepared using vacuum frying was found to be superior compared with atmospheric frying.

Bello *et al.* (2010) designed a vacuum frying system (GASTROVAC company) to develop the gilthead sea bream fillets. The construction details of vacuum frying system are electric appliance pressure cooker vessel with an inner basket, a membrane vacuum pump and a heating system. The capacity of oil storage and the basket was 2L and 1 kg, respectively. Atmospheric fried fillets (37 %) had greatest shrinkage than vacuum frying fillets (23%).

Yamsaengsung *et al.* (2011) developed an experimental setup for vacuum frying system and studied the effect of vacuum frying on structural changes of banana chips. The capacity of the basket and oil chamber was around 800g and 14L, respectively. It consisted of liquid ring vacuum pump, condenser, fryer and centrifuge. Gas cylinder was used as the heat source for both frying and oil storage chambers. The results showed that the product fried at operating conditions (110^{0}C and 8 kPa) had maximum volume expansion.



(Source: Da silva and Moreira, 2008)

Plate 2.2 Schematic diagram of vacuum frying system

Zhu *et al.* (2014) conducted an experiment on vacuum frying of peas. The capacity of oil storage chamber was 15L and basket capacity was 100g peas. A segregator is attached to the condenser to collect the recyclable waste. Results showed that all the fried peas had water activity values less than 0.35, which was an indication of products with long shelf life.

Ranasalva (2017) developed a batch type vacuum frying system. The vacuum frying system consisted of two chambers *viz.,* oil storage (35L capacity) and frying chamber (3kg capacity) were made of stainless steel (SS 316). Apart from this, it also consisted of vacuum pump, water pump, cooling tower and de-oiling motor. The whole system of vacuum frying was controlled by a microprocessor and PID (Proportional Integral Derivative) controller. The effect of vacuum pressure, frying temperature and frying time on quality attributes of vacuum fried chips were studied. Results showed that banana chips fried under the operating conditions such as 100°C, 20 kPa and 10 min was superior as compared with other treatments.

2.5.1 PROCESS PARAMETERS OF VACUUM FRYING SYSTEM

Many researchers studied the different process parameters to develop different fried products which are tabulated in Table 2.2.

Table 2.2. Different process parameters for snack products

Authour	**Process Parameters**	**Product**
Shyu and Hwang (2001)	Temperature: 100 – 110^{0}C Pressure: 98.66 kPa Time: 20- 25 min	Apple chips
Da Silva and Moreira, (2008)	Temperature: 120 -130^{0}C Pressure: 1.33 kPa Time: 3-4 min Others: 50% maltodextrin	Blue potato Green pea Mango Sweet potato
Perez-Tinoco *et al.* (2008)	Temperature: 112^{0}C Pressure: 24 kPa Time: 6.9 min	Pineapple chips
Nunes and Moreira, (2009)	Temperature: 120^{0}C Pressure: 1.33 kPa Time: 60 min	Mango chips
Diamante *et al.* (2011)	Temperature: 100^{0}C Pressure: 1.33 kPa Time: 65 min Others: 70 % maltodextrin	Apricot chips
Diamante *et al.* (2011)	Temperature: 80-100^{0}C Pressure: 2.3 kPa Time: 30 min	Kiwi chips
Tarzi *et al.* (2011)	Temperature: 90^{0}C Pressure: 4.25 kPa Time: 12.5 min	Mushroom chips
Yagua *et al.* (2011)	Temperature: 120-140^{0}C Pressure: 1.33 kPa Time: 1 min	Potato chips
Mehrjardi *et al.* (2012)	Temperature: 84.5^{0}C Pressure: 40 m bar Time: 18 min	Pumpkin chips
Yang *et al.* (2012)	Temperature: 90^{0}C Pressure: 20 kPa Time: 30 min	Sweet potato chips
Arlai *et al.* (2014)	Temperature: 80^{0}C Pressure: 760 mmHg Time: 2 h	Okra chips

Chen *et al.* (2014)	Temperature: 100C–110^{0}C Pressure: 8 kPa Time: 15 min	Desalted grass craps
Maity *et al.* (2014)	Temperature: 90-100^{0}C Pressure:100 mbar Time: 25-30 min	Jackfruit bulbs
Ophithakorn and Yaeed (2016)	Temperature: 120^{0}C Pressure: 21 kPa Time: 150 s	Fish tofu
Segovia *et al.* (2016)	Temperature: 120-140^{0}C Pressure: 1.33 kPa Time: 1-10 min	Cassava chips

2.6 DEOILING OF VACUUM FRIED PRODUCTS

The de-oiling is a centrifugation process, to eliminate the surface oil resulting in low oil content in the final product. De-oiling mechanism is an essential requirement to reduce the excess oil content in the fried chips.

Moriera *et al.* (2008) studied the effect of de-oiling process for production of high-quality vacuum fried potato chips. The potato slices were fried at 120°C, 130°C and 140°C for 6 min and de-oiled at 750 rpm for 40 s. Results showed that 86% of oil was removed by using the de-oiling process for vacuum fried potato chips at 120°C.

Maity *et al.* (2014) developed vacuum fried jackfruit chips. The vacuum fried jack fruit is subjected to centrifuge at 500 rpm for 8 min to remove oil. The results showed that 70% reduction in oil content was found in vacuum fried sample compared to control sample. Pandey and Chauhan (2018) reported the oil content was decreased when the vacuum fried papaya chips subjected to centrifuge for 2 min at 750 rpm. Tarzi *et al.* (2011) and Mehrjardi *et al.* (2012) studied the effect of centrifugation speed for mushroom and pumpkin chips. Both mushroom and pumpkin chips were subjected to centrifugation for 10 min at 400 rpm and the oil content was reduced upto 85% and 88%, respectively.

Sothornvit (2011) evaluated the effect of edible gum coating and centrifugation speed on oil content of vacuum fried banana chips. Banana slices were dipped in the 1.5% (xanthan gum or guar gum) solution. The results revealed that combination of centrifugation speed (280 rpm) and edible gum coating had significantly reduced the oil content (33.71%) compared to other samples.

Ranasalva and Sudheer (2017) conducted a study on de-oiling of vacuum fried banana chips. The study was conducted with different centrifuging speed (400, 600, 800 and 1000 rpm) and different time (0, 3, 5, 7, 9 min) on vacuum fried banana chips at 100°C for 12 min. The results showed that the oil content of de-oiled vacuum fried banana chips was reduced up to 90.9% at a speed of 1000 rpm for 5 min.

2.7 PRETREATMENTS OF VACUUM FRYING

Pretreatment process was done to the raw material before frying, to improves the quality of the fried products, to maintain/preserve the nutritional compounds, color and to reduce the oil content of the fried product (Ren *et al.,*2018). The different pretreatments applied to the food products are blanching, drying, freezing, different types of edible gum coating, osmotic dehydration and combined pretreatments. For research purposes, pretreatments *viz.,* blanching cum drying, edible gum coating, freezing (Ranasalva and Sudheer, 2017b), blanching, blanching cum freezing (Fan *et al.,*2006) are generally used.

2.7.1 Blanching cum Drying

Blanching is a hot water treatment method, where the raw product was dipped/placed in the boiling water or steam used to reduce the enzymatic activity. Blanching is one of the most important pretreatment methods to prevent browning and to leach soluble sugars (Krokida *et al.,* 2001).

Shyu and Hwang (2001) studied the effect of different pretreatments to produce the high-quality vacuum fried apple chips. The slices were blanched at 90°C for 1 min and vacuum fried at 100°C for 20 mins. Results revealed that the moisture content of the vacuum fried chips was reduced, while oil content and crispiness were increased with increase in frying temperature and time.

Pedreschi and Moyano (2005) studied the effect of pre-drying treatment on quality parameters of vacuum fried potato chips. The samples were blanched at 85°C for 3.5 min, air dried at 60°C and then fried at different temperature (120, 160,180°C). The results showed that chips fried at 120°C was more-crispier and having less oil content than the chips fried at other temperatures. Blanched potato slices had less oil absorption and more crispiness than unblanched samples.

Segovia *et al.* (2016) investigated the effect of blanching pretreatment on the quality of cassava vacuum fried chips. Cassava samples were blanched in hot water at 70°C for 10 min. The results showed that blanching pretreatment implied a considerable improvement in the color of the vacuum fried chips with less oil absorption.

2.7.2 Freezing

Freezing is one of the popular and oldest method of food preservation, which allows to retain the texture, taste and nutritional values of foods. The food samples were frozen at lower temperatures and helps in prevention of growth of microorganisms, delaying in the cellular metabolic reactions and chemical reactions were lowered. Freezing affects the change in the cellular wall structure of food materials and quick removal of moisture due to formation of ice crystal formation (Fan *et al.,* 2006).

Shyu and Hwang (2001) studied the effect of pretreatments to produce high quality vacuum fried apple chips. The blanched apple slices were immersed in the 30% fructose solution for 15 min at 15^0C followed by freezing at -30^0C for overnight and fried at 100^0C for 20 min. Results showed that moisture content and breaking force of apple chips were decreased, while oil content was increased with increasing in frying temperature and time.

The apricot slices were soaked in 70% maltodextrin (MD) at 20°C (Diamante *et al.,* 2011), then frozen at -18°C in a blast freezer for 24 h and then fried at 100°C for 65 min. Results showed that product got acceptable moisture, color and improved texture properties compared to untreated sample.

Hasimah *et al.* (2011) studied the sensory qualities of vacuum fried pineapple snack. The blanched sample were dipped in the 25% glucose syrup solution for 20 h followed by freezing at -18°C for 20 h. Results revealed that the (blanching+ syrup +freezing) vacuum fried pineapple snacks have good textural property and better appearance compared to other pretreatments.

Arlai *et al.* (2014) studied the effect of calcium chloride and freezing on vacuum fried okra quality. The okra samples were blanched in calcium chloride solution @ 0.5% (w/v) at 100°C for 90 s, the blanched sample were then freeze in the air blast freezer at -30 °C for 4 h and fried at 80 °C for 2 h. Based on the results, oil content was increased and moisture content was decreased. The crispness and sensory parameters of vacuum fried okra chips was improved with increase in calcium chloride concentration and freezing level.

Ophithakorn and sutisa (2016) studied the effect of freezing on quality parameters of vacuum fried tofu fishes. Steamed tofu fish was packed in vacuum polythene bags followed by the frozen at -20°C until defrosting. The frozen sample was defrosted at 4 °C overnight in a refrigerator before use and then fried at 120°C and 21 kPa. The microstructure of the tofu fish was retained and the oil absorption was found to be less in vacuum fried fish compared to ordinary fried fish.

2.7.3 Edible Gum Coating

The main aim of gum coating is to reduce oil absorption in fried products. Reducing the fat content of fried foods by application of coatings is an alternative solution to comply with both health concerns and consumer preferences (Garmakhany *et al.*, 2008). Hydrocolloids are usually used as coating material for food products to improve color, texture, flavor and also increase the shelf life of the product (Williams *et al.*, 2000). Hydrocolloids act as emulsifiers due to stabilizing effect (Baldwin *et al.*, 1995).

Susanne and Gauri (2002) studied the effects of 11 types of hydrocolloid materials, including gelatine, gellangum, k-carrageenan-konjac-blend, locust bean gum, methyl-cellulose (MC), microcrystalline cellulose, pectin (three types), sodium caseinate, soy protein isolate (SPI), vital wheat gluten, and whey protein isolate. Their results showed that all coating agents reduced oil absorption as compared to control samples.

Garmakhany *et al.* (2008) studied the oil uptake and some quality attributes of potato chips treated with hydrocolloids. Based on the results, carboxy methyl cellulose (CMC) was the best gum for coating in-terms of fat uptake and index value. CMC of 1% was selected as the best gum for coating potato chips.

Garcia *et al.* (2002) investigated the different cellulose derivatives as a coating material to reduce the oil uptake of fried products. Results showed that the coating applied with methyl cellulose were most effective and reduce the oil content up to 35–40% depending on the product.

Akdeniz *et al.* (2005) reported the use of four different gum type (hydroxyl propyl methyl cellulose (HPMC), guar gum, xanthan gum, and gum Arabic) coated in carrot slices for deep fat frying. Coated sample was fried at 170°C for 2, 3and 4min. Results revealed, that xanthan gum reduced the oil content (53%) in fried carrot as compared to other hydrocolloids.

Sakhal *et al.* (2011) determined the effect of hydrocolloids incorporation for the preparation of samosa on reduction of oil uptake. Four types of hydrocolloids *viz.,* hydroxypropyl methyl cellulose, carboxymethyl cellulose, guar gum and xanthan gum were used for this study. The results revealed that xanthan gum at 1.5% level significantly reduced the fat content in samosa (8.56%) as compared to all other hydrocolloids.

Izadi *et al.* (2014) determined the influence of hydrocolloid coatings (carboxymethyl cellulose, guar gum, tragacanth and zedo gum) on oil content and quality parameters of shrimp after deep-fat frying. Hydrocolloid solutions (0.5, 1.0 and 1.5 % w/v) were used for coating. Results showed that the coated shrimps with 1.5 % tragacanth solution had lowest oil content than the other samples.

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, color values, peroxide value, viscosity and free fatty acids.

2.8.1 Free Fatty Acids

FFA content is the most frequently used quality test. This acidity is mainly formed through the hydrolysis of triglycerides, which is promoted by food moisture, and by oxidation or through oil reacting with moisture formed during other deterioration reactions (Al-Harbi and Al-Kabtani, 1993). The permissible limits of the free fatty acids of palm oil was <1 mg KOH/g.

Abdul karim *et al.* (2007) studied the quality parameters of used vegetable oils after frying. Different oils were used for frying of potato chips *viz.*, Moringa oleifera seed oil (MoO), canola oil (CLO), soybean oil (SBO), and palm olein (PO). The oils were used for frying chips continuously for daily 6 h @5 days. Results showed the lowest free fatty acids were found in SBO (60.0%), PO (65.0%), MoO (66.6%) and highest free fatty acids was found in CLO (71.4%), after 30 batches of frying.

Kusucharid *et al.* (2009) studied the palm oil quality parameters during vacuum frying and atmospheric frying of sweet potato chips. Initially, free fatty acid value in the palm oil was 0.46 mg KOH/g. After frying the FFA values increased more in atmospheric frying (3.82 mg KOH/g) than vacuum frying (1.42 mg KOH/g) at the end of 6th day of frying.

Romano *et al.* (2012) studied the chemical changes in comparison of olive oil (OO) and palm superolien (PSO). The results showed that the FFA values increased significantly with increasing heat treatment times for both oils. The highest level of FFA in the frying oil is due to the release of water from the food matrix immersed in the oil bath.

Nayak *et al.* (2016) reported that, FFA of mustard oil increased from 0.73 to 4.38% after 30 h of deep fat frying.

2.8.2 Total Polar Compounds (TPC)

Total polar compounds are the most important parameter to measure the extent of oxidative deterioration of frying oil quality. TPC value refers to all degraded products from the initial triglycerides present in oil. Oil tester based on dielectric method is generally used to measure total polar compounds. Total polar compounds can be easily measured using this device and hence decides the usability of the oil. The limiting value of TPC in edible oil was 25-27%.

Aladedunye and Przybylski (2009) studied the effect of changes in regular canola oil on frying temperature. In this study, the contents of TPC increased almost linearly with increased in frying time and temperature. Total polar compounds were increased from 19.8% to 38% after 49 batches of frying.

Kusucharid *et al.* (2009) studied the effect of changes in the palm oil during the frying of sweet potato chips. Results showed that at the sixth day of frying, TPC values of palm oil was increased more in atmospheric frying (6.25% - 25.25%) than vacuum frying (6.25 - 12.57%) of sweet potato chips.

Amany *et al.* (2012) conducted a study to obtain high-quality potato chips by vacuum frying process. Initially, the polar compound of sunflower oil was 0.01%. Results showed that after 24 h of frying, the polar compounds values in vacuum frying was low (25%) compared to atmospheric frying (29.1%). In both frying methods, total polar compounds significantly increased with increasing in the frying time.

Shyu *et al.* (1998) reported that the concentration of polar compounds was higher in soyabean oil (19 %), lard (14%) and lower in palm oil (13%) under vacuum frying for 48h.

2.8.3 Viscosity

Viscosity is an important property of fluids and measures the internal friction of a liquid or its ability to resist the flow. Changes in viscosity of frying oil are mainly due to formation of polymers. Viscosity is one of the important parameters to determine the quality of frying oil (Gertz, 2000).

Shyu *et al.* (1998) studied the effect of vacuum frying on the oxidative stability of the oils. The chips were fried in three different oils *viz.*, soyabean oil, lard oil and palm oil, under vacuum conditions (105^{0}C for 20 min) for six consecutive days for 8 h. Results revealed that the viscosity of soyabean oil, lard and palm oil increased from 35 to 43 mPa-s, 48 to 58 mPa-s and 38 to 50 mPa-s, respectively, after 48 h of vacuum frying. The increased in the viscosity of oils was due to formation of higher molecular compounds by polymerization of unsaturated fatty acids.

Kusucharid *et al.* (2009) studied the changes in the palm oil quality during vacuum frying and atmospheric frying of sweet potato chips. Results showed that the viscosity of the frying oil under vacuum frying conditions increased from 71.13 to 72.13 cP. There was no significant change under vacuum conditions. The frying was carried out for 8 h/day for 6 consecutive days.

Probir *et al.* (2012) stated that there was a significant increase in viscosity of soyabean oil from 56 to 84.48 mPa-s, after eight times of deep fat frying. Lioumbas *et al.* (2012) studied the viscosity changes in palm and olive during vacuum frying. There was no significant change in viscosity of olive oil, after 40 times of frying.

Hazim *et al.* (2013) studied the physico-chemical changes occurring in the palm oil during atmospheric frying and vacuum frying. Results showed that the viscosity of palm oil significantly increased from 45.48 to 54.12 mPa-s under vacuum conditions and 45.48 to 55.97 mPa-s under atmospheric conditions, after two days of frying.

2.8.4 Peroxide Value

Peroxide value is one of the most used parameters to determine the oxidation level in oils and fats and its value measures the oxidative rancidity or degrees of oxidation. It is expressed in terms of m eq/kg.

Ramaswamy and Nasirullah (2011) conducted a study on physico-chemical changes in rice bran oil during heating at frying temperatures. Rice bran oil was heated at 180°C in a domestic fryer for 8 h. In this process, 150-200 ml of the heated oil samples were drawn, for every 2 h interval. Results reported that the peroxide value gradually increased from 0.2 to 2.9 m eq/kg.

Naz *et al.* (2005) studied the quality changes in soyabean, corn and olive oil. French fries were fried at 180^0C for 30, 60, and 90 min interval. Results revealed that peroxide values showed an increasing order: soyabean> corn > olive oil.

Kusucharid *et al.* (2009) stated that peroxide value in palm oil was significantly increased from first to fourth day of frying and then level off. After that the peroxide values slightly decreased in both the atmospheric and vacuum frying. This was caused due to oxidation reaction occurs when the oil was heated.

Amany *et al.* (2012) reported that the peroxide value in sunflower oil was slightly increased with frying time and it was less than 42.12 meq/kg after 24 h of vacuum frying (120^0C and 5.7 kPa) compared with the deep fat frying(180^0C) under atmospheric pressure, the peroxide values was increased greater than 45.13 meq/kg oil. In both frying, the chips were fried for 20 min/hr for 4 h shift.

Romano *et al.* (2012) studied the oil quality parameters in olive oil (OO) and palm superolein (PSO). Results indicated that peroxide value in PSO was always lower than in OO. The higher value of peroxide value in olive oil may be due to the presence of unsaturated fatty acid.

2.8.5 Color

Color change is a visual indication of the extent of oil deterioration caused by oxidation in frying oils. The changes in color values of oil mainly depend on heating temperature and time.

Abdul karim *et al.* (2007) investigated the quality characteristics of oil by using different vegetable oils (palm olein (PO), canola oil (CLO), soybean oil (SBO) and moringa oleifera oil (MoO). Potato chips were fried at 95⁰C for 45 min under vacuum conditions (6 h for 5 days). Results revealed that at the end of the frying, color value shows no significant difference in entire oils.

Kusucharid *et al.* (2009) studied the quality characteristics of palm oil during vacuum and atmospheric frying conditions. The chips were fried at 110⁰C for 10 mins under vacuum conditions and 190⁰C for 90 s under atmospheric conditions. The experiment was carried out for 8 h/day for 6 consecutive days. Results reported that the color values of L* value decreased, while a* and b* values was increased with frying time in both conditions.

Hazim *et al.* (2013) explained the physical-chemical changes occurring in the oil during atmospheric frying. Results showed that oil was darkened during the frying, having lower L* values, higher a* and b* values.

Nayak *et al.* (2016) conducted the study on the quality characteristics of mustard oil during frying. The oil was continuously heated at the temperature of 185⁰C for 5 h/day for 6 hours. The color values (L*, a* and b*) decreased and a* became negative after 30 hours of frying. This indicated that the color of the oil changed to darker, highly reddish as compared to color of fresh oil.

2.9 CHARACTERISTICS OF VACUUM FRIED CHIPS

2.9.1 Moisture Content

Tarzi *et al.* (2011) studied the effect of processing condition based on the quality parameters of vacuum fried mushroom chips. Chips were fried at 90⁰C,4.11

kPa and 12.5 min. Results shown that moisture content was decreased with increase in frying time and temperature.

Yang *et al.* (2012) conducted a study on the quality characteristics of vacuum fried sweet potato chips. Results revealed that the vacuum-fried snacks contain moisture content ranges from 1.2-1.4% which was 50% less compared to the atmospheric fried snacks.

Diamante *et al.* (2011) suggested that moisture content significantly decreased with increasing frying time (65 min), frying temperature(100^{0}C) and maltodextrin (70%) in vacuum-fried apricot slices. Arlai *et al.* (2014) studied the effect of calcium chloride and freezing on VF-okra quality. The okra slices were blanched in calcium chloride solution (0.5, 1.0 and 1.5% w/v) and heated for 90 s at 100^{0}C.The blanched slices were vacuum fried at 80^{0}C for 2h. Results reported that the moisture content was significantly decreased in vacuum fried okra chips with increased in percentage of calcium chloride solution on okra slices.

Chen *et al.* (2014) studied the moisture content parameter for vacuum fried desalted grass craps. The optimal process conditions for frying of craps *viz.*, temperature, vacuum pressure and time were 100°C–110°C, 0.08MPa and 15 min, respectively. Results revealed that the moisture content of the fillet was decreased with increase in the frying time and temperature.

Su*et al.* (2016) studied the application of novel microwave-assisted vacuum frying technology for producing potato chips. The operation conditions were: microwave power density (12, 16 and 20 Watt/g), frying temperature (100, 110 and 120^{0}C) and vacuum pressure (0.065, 0.075 and 0.085 MPa). The moisture content reduced significantly in the microwave-assisted vacuum frying method compared to vacuum frying due to the application of microwave energy.

2.9.2 Oil Content

Yamsaengsung and Rungsee (2003) found that vacuum fried potato and guava chips had lower oil content and more natural colourations than those fried in conventional fryers.

Tarzi *et al.* (2011) studied the effect of processing condition based on the quality parameters of vacuum fried mushroom chips. Results revealed that oil content increased with increase in frying time and temperature, but vacuum pressure had less significant effect on oil content.

Yagua and Moreira (2011) studied the physical and chemical changes during vacuum frying of potato chips. The chips were fried at different temperatures *viz.*, 120, 130 and 140^{0}C for different time intervals. Results showed that the chips fried at higher temperature recorded the maximum oil content.

Maity *et al.* (2014) studied the effect of vacuum frying on changes in quality attributes of jackfruit bulb (JF) slices. The JF slices were fried at different temperatures *i.e.*, 80, 90 and 100^{0}C for different time intervals. Results reported that the oil content of JF chips increased with increase in frying temperature as well as frying time.

Chen *et al.* (2014) studied the effect of quality parameters on vacuum fried desalted grass craps. Results revealed that the vacuum-fried desalted grass carp fillets observed very less oil content at frying conditions (100-110^{0}C, 0.08MPa and 15 mins) than the atmospheric-fried fillets (170^{0}C for 4 mins). The oil content in the fillets was increased with increase in frying time and temperature.

Segovia *et al.* (2016) stated that blanching pre-treatment combined with vacuum frying (120^{0}C) was a simple technology to reduce the oil content in cassava chips.

2.9.3 Water Activity

Water activity plays a vital role to protect the food from the microbial growth, rates of deteriorative reactions, and chemical/physical properties. The limiting value of a_w for the growth of any microorganism is less than 0.6.

Perez-Tinoco *et al.* (2008) studied the effect of quality parameters on vacuum fried pineapple chips. The pineapple slices were fried under vacuum conditions

(112^{0}C, 24 kPa and 6.9 min). Results showed that the water activity of vacuum fried pineapple chips was less than 0.29 a_w.

Sothornvit (2011) determined the effect of edible gum coating on quality parameters of vacuum fried banana chips. The banana slices were dipped in the hydrocolloid solution for 10 min (15: 1 ratio) and the slices were fried at 89^{0}C for 90 min. Results showed that hydrocolloidal solution coated for vacuum fried banana chips had lesser water activity (0.25) than control chips.

Ren *et al.* (2018) studied the effect of pretreatments on quality characteristics of vacuum fried shiitake mushroom chips. Four different pre-treatments were used for the study *viz.*, blanching, blanching + osmotic dehydration+ maltodextrin (MD) solution, blanching +osmotic dehydration+ coating with sodium carboxymethyl cellulose (CMC), blanching + osmotic dehydration+ freezing. The chips were vacuum fried at 90^{0}C for 30 min. Results revealed that (blanching + osmotic +freezing) sample had lower a_w (0.25) compared to other pre-treatments.

The above-mentioned water activity values of different fried products were less than limiting value (0.6), which showed that the product had more shelf life.

2.9.4 Color

Color is an important property which greatly affects consumer acceptability and satisifaction. The colour values were expressed in terms of L-value (lightness, ranging from zero (black) to 100 (white)), a-value (+60 (red) to −60 (green)) and b-value (+60 (yellow) to −60 (blue)).

Tan and Mittal (2006) investigated the physico-chemical properties of vacuum fried doughnuts. Results revealed that vacuum fried doughnuts had the lowest ΔE (13.8) at a low temperature of 150^{0}C for 9 kPa and highest ΔE (21.3) was noted in the atmospheric fried doughnuts at a high temperature of 190^{0}C. The color change in the fried foods was caused by non-enzymatic browning during heating due to maillard reactions.

Perez-Tinoco *et al.* (2008) determined the effect of quality parameters on vacuum fried pineapple chips. The chips were vacuum fried at 112^{0}C,24kPa and 6.7 min. Results revealed that chips fried at 112^{0}C had good colour values of L*(81.2), a*(9.12) and b*(41.29) than at other frying temperatures.

Tarzi *et al.* (2011) studied the effect of operating condition based on the quality parameters of vacuum fried mushroom chips. Chips were fried at temperature, pressure and time are 90^{0}C, 4.11 kPa and 12.5 min. Results denoted that greater color (ΔE) differences led to the lower color quality on the product. When frying temperature and time increased, the color difference(ΔE) significantly decreases in vacuum fried mushroom chips.

Yang *et al.* (2012) found that higher L* and b* values, lower a* value shown in vacuum-fried snacks compared to atmospheric fried snacks in all sweet potato cultivar chips. The chips were fried at 90^{0}C, 20 kPa and 30 min. Pan *et al.* (2015) reported that vacuum fried shrimps had higher L*, lower a* and b* values compared to the atmospheric fried shrimps. The L * increased due to increase in the frying time and temperature. Maity *et al.* (2017) concluded that higher L*, lower a* and b* values were noted in the untreated and frozen samples than other pre-treated vacuum fried jack fruit chips at 90^{0}C for 30 min.

Ren *et al.* (2018) explained the effect of pre-treatment on quality attributes of vacuum fried shiitake mushroom chips. The chips were vacuum fried at 90^{0}C for 30 mins. The hydrocolloidal coated chips were reported the least oil uptake and browning, so the L* value was maximum and a* and b* value was minimum.

2.9.5 Texture

A texture analyzer was used to determine the hardness and crispiness of the fried samples. Hardness and crispiness would vary for different pretreated samples. Both parameters will affect the processing parameters (temperature, pressure and time) of the product.

Shyu and Hwang (2001) concluded that the vacuum fried apple chips fried at 110°C for 25 min had better crispness which had low breaking force compared to other fried samples.

Perez-Tinoco *et al.* (2008) studied the effect of quality parameters on vacuum fried pineapple chips. Results revealed that breaking force of less than 1.9 N was considered as best hardness value for vacuum fried pineapple chips (112^{0}C, 24 kPa and 6.9 min). There was a significant effect on hardness with frying temperature. The hardness of the chips was decreased with increasing the frying temperature.

Tarzi *et al.* (2011) investigated the effect of quality parameters on vacuum fried mushroom chips. Results indicated that vacuum pressure and time were not significantly affected, while the effect of temperature was significant on the crispness. The good texture was observed for vacuum fried mushroom chips at 90^{0}C, 4.25 kPa and 12.5 min.

Chen *et al.* (2014) studied the effect of hardness value on vacuum frying of desalted grass carp fillets. The grass carp fillets were vacuum fried at 100^{0}C, 8kPa and 15 min. According to the results, the hardness was directly proportional to the vacuum-frying time and temperature. Most of the vacuum-fried samples had better hardness values than those of the atmospheric-fried samples.

Wexler *et al.* (2016) studied the effect of quality parameters on vacuum fried papaya chips. Results showed that the hardness values of 4 N and 7.79 N of vacuum fried papaya chips was observed for the vacuum frying (117 °C) and atmospheric frying (150°C) of chips, respectively. The low hardness values were obtained in the vacuum fried chips as compared to the atmospheric fried chips. The high hardness value indicated the less crispy product.

2.9.6 Thickness Expansion

Nunes and Moreira (2009) studied the effect of osmotic dehydration (OD) on quality parameters of vacuum fried mango chips. The maximum degree of shrinkage (16.93%) occurred at 138°C for 70 min with OD (65% w/v). The minimum degree of shrinkage (12.02%) was observed at 120 °C for 45 min with

OD (65% w/v). Results revealed that the degree of shrinkage in the vacuum fried mango chips was significantly affected by frying temperature and time.

Yamsaengsung *et al.* (2011) studied the effect of structural changes on vacuum fried banana chips. Results showed that the maximum degree of expansion of 1.32 % was obtained for vacuum fried banana chips at 110°C, 8 kPa and 20 min.

Ravli *et al.* (2011) studied the thickness expansion of vacuum fried sweet potato chips at different frying temperature (120,130 and 140^{0}C). The thickness of expansion of the sweet potato chips was suddenly reduced to negative values for the early times of frying and then slowly increased the thickness expansion to reach the constant value. Thickness expansion of vacuum fried chips ranged between -45.26±2.46 % to 50.97±1.39 %.

2.9.7 Acrylamide Content

Acrylamide is also known as carcinogen substance and also one of the hazardous compounds formed when carbohydrate-rich food products were subjected to baking, frying, roasting and grilling operations.

Granda and Moreira (2005) reported that reduction of acrylamide content was 94% in vacuum fried potato chips. The potato chips were fried under vacuum conditions (118°C and 8 min), Moreover, vacuum fried chips had very low (25 ppb) acrylamide content compared with atmospheric fried chips (198 ppb).

Bekas *et al.* (2006) identified the safe limits of acrylamide content for deep fat fried potato chips and ranged between 380 µg/kg to 861 µg/kg. More than this ranges the consumption of fried potato chips was not good for health.

Daniali *et al.* (2010) showed that banana fitters had the highest acrylamide content of 7468.8 µg/kg compared to raw banana chips and sweet banana chips.

Ana *et al.* (2013) optimized the frying process parameter to obtain minimum acrylamide content from the fried product using dynamic optimization method. The results of the study confirmed that there was a 16.5% reduction in acrylamide content.

Abdel-Monem *et al.* (2013) studied the effect of pre-treatment on acrylamide formation in fried chips. The results found that blanched fried chips produce less acrylamide content than control (un-treated) products.

Pedreschi *et al.* (2016) reported the potato slices soaked in NaCl solution had less acrylamide content and the pre-dried sample had high acrylamide content. Powers *et al.* (2017) stated the acrylamide content increased with increased temperature of 120-170°C in potato chips.

2.9.8 Bulk density and True density

Bulk density can be defined as the weight of a sample per unit of bulk volume. Bulk density does not include only the volume of liquids and solid, but also it includes the volume of the air within the sample. True density is the weight of a material per unit of true volume. True volume includes the volume of liquids in the material (Kawas, 2000).

Taiwo and Baik (2007) found that the bulk density of the deep fat fried sweet potato chips decreased from 1.18-0.73 g/cm^3 due to increasing in frying time. Moreira *et al.* (2009) reported that bulk density value was less in centrifuged vacuum fried potato chips (488 kg/m^3) than non-centrifuged chips (803 kg/m^3).

Yagua and Moreira *et al.* (2011) reported that bulk density value decreased from 1110 to 453 kg/m^3 and true density value increased from 1088 to 1404 kg/m^3 in vacuum fried potato chips. Both densities were changed due to the change in porosity.

Ravli *et al.* (2013) conducted research on vacuum frying of sweet potato chips in two stages. The results showed that bulk and true density were decreased during single stage frying and increased under the second stage vacuum frying.

2.9.9 Sensory Evaluation

A nine-point Hedonic scale was used by Yamsaengsung *et al.* (2011), Arlai *et al.* (2014), Maity *et al.* (2017), Ranasalva and Sudheer (2017a), Pooja (2018) to perform the sensory evaluation of vacuum fried potato, okra, jackfruit, banana and bitter gourd chips, respectively.

2.9.10 Fuzzy Logic on Sensory Evaluation

Fuzzy comprehensive model for ranking of foods and developing new food products were developed in 1991.Fuzzy logic is an important tool by which indistinct and vague data can be analyzed and important conclusions regarding acceptance, rejection, ranking, strong and weak attributes of food can be drawn.

Jaya and Das (2003) conducted an experiment on sensory analysis of mango drinks using fuzzy logic. For sensory evaluation, three brands of mango drinks were used namely Frooti (S1), Real(S2) and Slice(S3). The sensory evaluation was conducted by 11 judges. The order of quality ranking values of mango drinks was: S3>S1>S2(in-terms of taste).

Lazim and Suriani (2009) studied a sensory evaluation of coffee products by using fuzzy approach. Three types of coffee product (Nesc, Indoc, Incom) were selected for sensory evaluation. The results were shown based on the quality ranking subset value of coffee products *viz.*, Indoc product (0.950)>Nesc product (0.820) >Incom coffee product (0.700) (in-terms of taste and overall acceptability).

Routray and Mishra (2012) conducted a fuzzy logical sensory evaluation for dahi drink. Three types of samples were used for sensory evaluation i.e., dahi powder and water (S1), dahi powder+ guar gum+ locust bean gum + water (S2), dahi powder +guar gum +locust bean gum+ vanilla essence +water(S3). The result found that S3 and S2 were good in taste and flavor compared to the S1. The order of ranking of three drinks was: S3>S2>S1.

Singh *et al.* (2012) studied the fuzzy analysis of sensory study for bread prepared from millet-based composite flours. Three different samples namely BWB (barnyard millet +wheat bread), BFPWB (barnyard millet + finger-millet + proso-millet + wheat bread) and WB (wheat bread) evaluated by the trained judges. Based on the maximum similarity values, the order of ranking of three samples was: BFPWB>WB>BWB (in terms of taste and overall acceptability).

Fatma *et al.* (2016) conducted a fuzzy analysis of sensory data for ranking of beetroot candy. Eight samples with different formulations (65 % sugar, 3%pectin and 0.5% citric acid) of beetroot candy were prepared and coded as S1, S2, S3, S4, S5, S6, S7 and S8. The subjective evaluation was analyzed by 15 judges for eight beetroot candy samples. Results showed that order of ranking based on the sensory attributes: S8>S7>S6>S2>S5>S1>S3>S4(in-terms of overall acceptability).

Ranasalva and Sudheer (2017a) used a fuzzy logic sensory analysis for pre-treated vacuum fried banana chips. Results showed that untreated vacuum fried banana chips sample ranked first in color and taste than other pre-treated vacuum fried banana chips.

Sasikumar *et al.* (2019) studied the sensory evaluation were analyzed for the khoonphal juice samples by using fuzzy logic. Four different treatments were used for sensory evaluation. The different treatments were followed: T1 for ultrasonication (US), T2 for microwave processing (MW), T3 for conventional thermal pasteurized juice (CT) and T4 for ultrasound-assisted microwave treated juice (UM). Based on quality ranking T4 was the best treatment compared to other treatments in terms of taste. The order of ranking of treatments was: T4>T2>T1>T3.

2.9.11 Packaging and Storage Studies

Ammawath *et al.* (2002) conducted packaging studies on deep fried banana chips. Based on quality and sensory attributes, low density polyethylene (LDPE) had the best quality and sensory attributes compared to laminated oriented polypropylene (OPP), polypropylene (PP) and laminated aluminium foil (LAF). The chips were stored under LDPE pouches had a shelf-life upto 8 weeks.

Illeperuma and Jayasuria (2002) stated that osmotic dehydrated bananas chips extended their shelf life upto eight months in laminated aluminium pouches flushed with nitrogen gas.

Molla *et al.* (2008) conducted a research on three different packaging materials for deep fried jackfruit chips. The different packaging materials *viz.*, high density polyethylene, metalex foil pouch and polypropylene pouch. Two months of storage studies were conducted on chips. Based on the quality attributes, the chips packed in metalex foil pouch was good compared to other packaging materials.

Presswood (2012) studied the packaging and storage studies for marinated vacuum fried beef chips. Two different types of packaging materials were used *viz.*, aluminium foil laminate and polyethylene terephthalate (PET). Results revealed that aluminium foil packaging material was selected as best in terms of low water vapor transmission rates and the strips were stored upto 32 weeks at 15-25 °C temperature.

Khanvilkar *et al.* (2016) reported that banana chips fried in sunflower oil and packed in the low-density polyethylene film had a shelf life of 45 days with good crispiness.

Bedoya *et al.* (2018) conducted the storage studies on the vacuum fried potato chips. Results showed that the samples packed in LDPE with N_2 gas were stored upto 150 days at the temperature of 15°C.

2.10 OPTIMIZATION OF PROCESS PARAMETERS

Optimization of process parameters were done by Response surface methodology.

Bas and Boyai (2007) explained the concept of response surface methodology (RSM) and it consists of a group of mathematical and statistical techniques that can be make use for defining the relationship between the independent variables and dependent variables(responses). It can define the effect of independent variables, individual or in combination, on the processes.

RSM is a commanding statistical procedure which is commonly used in many engineering applications to construct accurate models in an optimization design (Aghbashlo *et al.*, 2012). RSM is mainly used for developing and amplifying the optimisation of process parameters. It is most broadly applied in numerous stages like experimental design selection, generating response surfaces, contour plots, prediction and verification of model equations, determination of multi response parameters and their effective levels, and determination of optimum conditions. With low cost and minimum time, RSM can be applied for optimization process for obtaining high efficiency for the development of improved.

2.10.1 Statistical Analysis

For optimization of vacuum fried chips, different statistical software were used by the many researchers.

The response surface methodology, Box-Behnken design was used by Diamante *et al.* (2011), Esana *et al.* (2015) and Bouaziz *et al.* (2016) for optimization of process parameters of vacuum fried apricot slices, sweet potato chips and potato chips and the data were analysed by using design expert 8.0 (SPSS).

The response surface methodology (RSM), central composite rotatable design (CCRD) was used by Ranasalva and Sudheer K P (2017), Tarzi *et al.* (2011), Shyu and Hwang (2001), Mehrjardi *et al.* (2012) and Pandey *et al.* (2018) for optimization of process parameters of banana, mushroom, apple, pumpkin and papaya and the data were analysed by using statistical analysis system software package.

Sothornvit R (2011) and Pooja (2018) selected the completely randomized experimental design for optimization of vacuum fried banana and bitter gourd chips. Zhu *et al.* (2014), Nunes and Moreira (2009) and Yagua *et al.* (2010) the data were analysed using SPSS 11.5 and analysis of variance (ANOVA) was conducted for vacuum frying of peas, mango and potato. Diamante *et al.* (2011) used statistical analysis of a two-way analysis of variance (ANOVA) using Minitab 15 for vacuum fried gold kiwi fruit slices. However, the statistical design for the standardization was based on the levels and treatments factors.

MATERIALS & METHODS

Chapter III

MATERIALS AND METHODS

This chapter provides the detailed information regarding materials used and the methodologies adopted for the thesis work entitled "Development and Evaluation of Process Protocol for Vacuum Fried Carrot Chips (*Daucus Carota L.*)". This research work was carried out at the Dept of Processing and Food Engineering, Kelappaji College of Agricultural Engineering and Technology, Tavanur, Kerala.

3.1 RAW MATERIALS

The orange color matured carrot was procured from the local market at Tavanur, Kerala which is shown in Plate 3.1. The average size of carrots selected was medium long (20-30 cm) and diameter of 5-6 cm. The procured carrots were packed in polythene bags (shyu *et al.,* 2005) and stored at 7°C temperature and 85-95 % relative humidity (Duiek *et al.,* 2010). The carrot cultivar (*ooty-1*) which was most commonly available in south India was used in this research study.

3.1.1 Preparation of Sample for Vacuum Frying

Carrots were cleaned manually, peeled using a hand peeler and cut into fingers (even strips) using a vegetable cutter. The average thickness and diameter of fingers were less than 3-4 mm and 6-7 mm, respectively. The thickness and diameter of carrot fingers were measured using a vernier caliper (M/s. RSK Digital Caliper, China). The raw carrot and carrot strips are shown in plate 3.1.

3.2 DEVELOPMENT OF VACUUM FRYING SYSTEM

The research was conducted using a vacuum frying system available in the Department of Processing and Food Engineering, KCAET, Tavanur. Vacuum fryer was a batch type, having a capacity of 3 kg. The system consisted of two chambers namely frying chamber and oil storage chamber. The two chambers were made up of stainless steel (SS 316). The frying chamber and oil storage chamber was provided with heaters - two heaters in frying chamber and one in oil storage chamber, respectively. The water ring vacuum pump, cooling tower, compressor, nitrogen cylinder and condenser were also attached to the vacuum frying system. The entire 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).

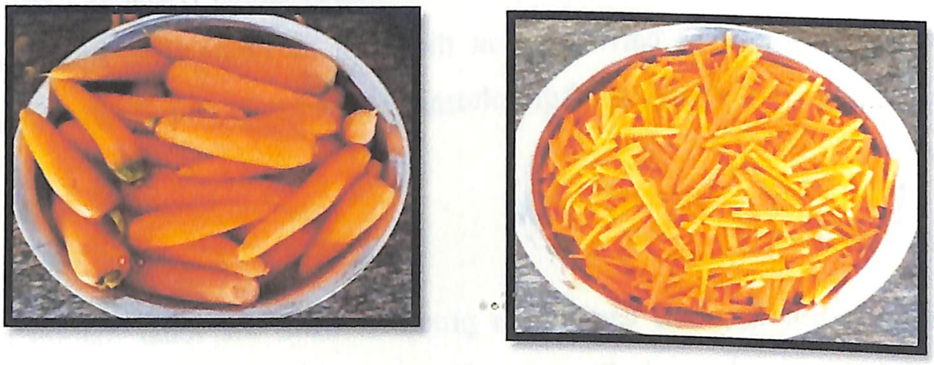


Plate 3.1. Raw carrots (*ooty -1*) cultivar and carrot strips

3.2.1 De-oiling System

De-oiling is a centrifugation process, to eliminate the surface oil resulting in very low oil content in the final product. De-oiling mechanism is an essential requirement to reduce the excess oil content in the fried chips.

De-oiling system was driven by a 0.5 hp motor (M/s. Prime motors, India) and its output shaft has 6 poles rotating at 1000 rpm. The top of frying chamber was fitted with motor and it was connected to frying basket holder with the help of shaft. The frying basket was placed in the frying basket holder with the help of fastening of screw mechanism during frying and de-oiling operations. The stainless steel (SS 316) frying basket had a curved bottom (30°) for easy draining of oil after frying (Ranasalva, 2017).

3.2.2 Pressure System

The pressure system was set up with pressure transmitter (M/s. SETRA, India) and its measuring range was 0 to 250 kPa. Both pressures (storage and frying chambers) was measured using the compound dial gauge (-1 to 4 kg/cm^2). The pressure was developed by 3hp water ring vacuum pump (M/s. Sabara, India),

having a capacity of 30 m^3/h. Two separate pneumatically operated spherical disc butterfly valves (M/s. AIRA, India) were attached with each chamber to create vacuum inside the chambers. For transferring of oil in the two chambers, the pressure difference was created through vent valves by using nitrogen gas. The main advantage of using the nitrogen gas was to maintain the oil quality, as creation of pressure gradient using air enhances the chance of oxidative rancidity. The frying oil was moved 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 consists of a cooling tower having capacity of 10 L and attached with water pump 1hp (M/s. Protech, India). During frying, vapors were removed from the product and collected through a closed basin fitted with a ball valve (Ranasalva, 2017) in a condenser using shell and tube heat exchanger.

3.2.4 Control System

The control system of vacuum frying equipment was conveyed through programmable logic controllers (Make: Omron, Europe) with HMI (Human Machine Interface). The total power required to operate the vacuum frying system was 12.5 kW (Ranaselva,2017).

3.3 VACUUM FRYING PROCESS

The vacuum frying process involved in different steps *viz.,* sample loading, frying/heating oil, depressurization, frying and de-oiling, pressurization and cooling (Garayo and Moreira, 2002; Ranasalva and Sudheer, 2017a) (Table. 3.1). The steps involved in vacuum frying process are briefly discussed below.

3.3.1 Sample Loading

Initially the samples were weighed and filled in the frying baskets. The two frying baskets were filled with equal amount (approx. 1050-1100 g each) of samples in order to maintain the balance during de-oiling. The samples filled with the frying baskets were placed in the basket holder present inside the frying chamber and closed the chamber tightly.

3.3.2 Frying Oil

The refined palm oil (RPO) purchased from the general stores (M/s. Fathima Stores, Tavanur, Kerala). The RPO was used as frying media for vacuum frying. Refined palm oil was loaded in the oil storage chamber by opening its top lid or through the frying chamber using manual operation. The oil present in the storage chamber was pre-heated to a temperature range of 100-110^{0}C for a period of 10-25 min before frying.

3.3.3 Depressurization

Depressurization phase is a stage to generate low pressure inside the frying and storage chambers before frying. Initially the pressure was high in both frying (100 kPa) and storage (100 kPa) chambers. A low pressure of 6-15 kPa (Tarzi *et al.*,2011) was generated by opening the vacuum valves of fryer and storage valves. At the same time, the frying chamber and oil chamber was heated to the desired temperatures (Ranasalva, 2017).

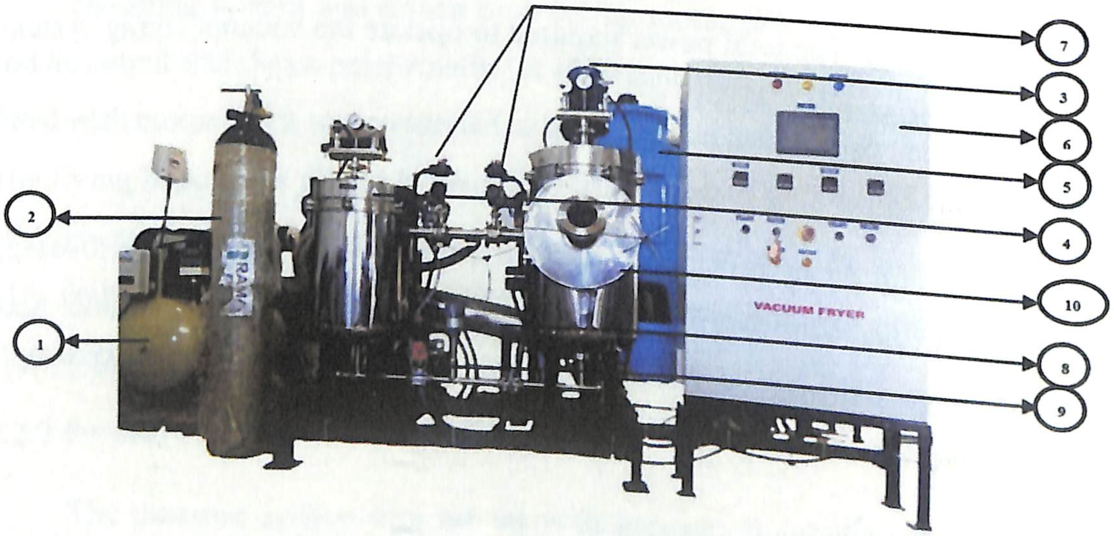


Plate 3.2. Developed Vacuum Frying System (KCAET, Tavanur, Kerala)

Parts :

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

3.3.4 Frying and De-oiling

After attaining the set temperature and vacuum pressure in frying chamber, frying process was initiated and the subsequent pressure changes occurred within the storage and frying chambers. The vent valve of storage chamber was opened to increase the pressure by employing nitrogen gas and also the oil inlet valves were also opened simultaneously. Due to the opening of valves, pressure gradient created between storage chamber (high pressure) and frying chamber (low pressure) then oil got transferred to the frying chamber through oil inlet valve (connected between storage tank and frying chamber). After reaching the oil in the frying chamber up to the desired level, both vent valve of storage and oil inlet valve were closed. The basket filled with carrot strips were immersed in the oil for a set frying time. During frying process, the frying basket was rotated at 30 rpm with the help of de-oiling motor, attached to it. After the completion of frying, again the pressure difference was generated to transfer the oil from frying chamber to storage chamber. The vent valve of the frying chamber and oil inlet valve were opened favouring the creation of pressure gradient between frying chamber (high pressure) and storage chamber (low pressure)) which facilitates the movement of oil from frying chamber to storage chamber. The vent valve of frying chamber and oil inlet valve were closed. The pressure was reduced again inside the frying chamber by opening the vent valve of fryer, prior to de-oiling. During de-oiling phase, both vent valve fryer and oil inlet valve was open. For centrifugation, the rpm of the de-oiling motor was set to a maximum of 1000 rpm for desired period (Ranasalva, 2017). The removal of surface oil from fried carrot chips was affected through a de-oiling process.

3.3.5 Pressurization and Cooling

The vacuum in the frying chamber was released using the vent valve. The product was unloaded and allowed to cool till it reached room temperature (Ranasalva, 2017). The vacuum fried carrot chips were packed in LDPE, laminated aluminium flexible pouches and polypropylene packaging with nitrogen (N_2) flush and stored at room temperature for further analysis.

The quality evaluation of vacuum fried carrot chips and refined palm oil (Brand:PRIYA GOLD, Kerala, India) were conducted through various experiments as follows. Experiment I – To study the physico-chemical properties of raw carrot cultivar (*ooty-1*), Experiment II - Optimization of pre-treatments and process conditions for vacuum frying of carrot chips, Experiment III – Standardization of process and product parameters for vacuum frying of carrot chips, Experiment IV – Packaging and shelf life studies of vacuum fried carrot chips and Experiment V – Evaluation of fried oil quality parameters.

Table 3.1. Stages of vacuum frying

Stages		**Characteristics**
Phase 1	Depressurization	Creating/reducing pressure in storage and frying chambers and increasing temperature to desired level
Phase 2	Frying and deoiling	Frying is obtained after attaining the standardized temperature, pressure and time. De-oiling is carried out by centrifugation of fried samples to remove its surface oil
Phase 3	Pressurization	Product temperature is brought to room temperature.
Phase 4	Cooling	Cool down the product temperature to room temperature before packaging and storage.

3.4 DESIGN OF EXPERIMENTS

3.4.1 To study the physico-chemical properties of raw carrot cultivar (*ooty-1*)

3.4.1.1 Physical/Engineering properties

- Sphericity
- Geometric mean diameter
- Arithmetic mean diameter
- Aspect ratio
- Surface area
- Moisture content
- Mass

3.4.1.2 Chemical/Nutritional properties

- Crude protein
- Crude fibre
- Carbohydrate
- Fat content
- Ash content
- Total energy content

3.4.2 Optimization of pretreatments of vacuum fried carrot chips

3.4.2.1 Independent variables

- Temperature – 100^{0}C
- Pressure – 13 kPa
- Time – 25 min

3.4.2.2 Dependent variables

- Moisture content
- Water activity
- Oil content

- Bulk density
- True density
- Hardness
- Thickness expansion
- Total yields
- Color
- Sensory evaluation
- Fuzzy logic sensory analysis

3.4.3 Standardization of Process Parameters of Vacuum Fried Carrot Chips

3.4.3.1 Independent variables

(1) Temperature (^{0}C)
  a) T1 – 100
  b) T2 – 110
  c) T3 – 120
(2) Pressure (kPa)
  a) P1- 11
  b) P2- 13
  c) P3- 15
(3) Time (min)
  a) t1 – 16
  b) t2 - 18
  c) t3 – 20

3.4.3.2 Dependent variables

- Moisture content
- Water activity
- Oil content
- Bulk density
- True density
- Hardness

- Thickness expansion
- Color
- Protein content
- Crude fibre content
- Carbohydrate content
- Energy content

3.4.4 Packaging and Storage Studies

3.4.4.1 Independent variables

- **Packaging materials:** Low density polyethylene (LDPE), laminated aluminium standard pouches, polypropylene
- **Packaging technology:** Three packaging materials with and without N_2 gas flushing

3.4.4.2 Dependent variables

- Moisture content
- Water activity
- Oil content
- Hardness
- Color

3.4.5 Evaluation of Oil Quality Parameters

3.4.5.1 Dependent variables

- Free fatty acids
- Peroxides
- Total polar compounds
- Viscosity
- Color

EXPERIMENT I

3.5 TO STUDY THE PHYSICO-CHEMICAL PROPERTIES OF RAW CARROT CULTIVAR (*OOTY-1*)

Prior to the development of process protocol for vacuum frying of carrot chips, the physico-chemical properties were determined. The engineering properties of the raw carrot *viz.,* mass, size, shape, sphericity, arithmetic mean diameter, geometric mean diameter, aspect ratio, surface area, moisture content, bulk density and true density were determined as per the standard procedures. The chemical/nutritional properties such as protein content, fiber content, ash content, oil content, carbohydrates and total energy content were also studied.

3.5.1 Physical Properties of Raw Carrot

The most important physical properties of raw carrot *viz.,* mass, size, shape, sphericity, arithmetic mean diameter, geometric mean diameter, aspect ratio, surface area, moisture content, bulk density, true density etc., were determined as per standard methods explained in the below section.

3.5.1.1 Determination of size of the raw carrot

Size refers to the characteristic of an object which determines the space requirement and it is expressed in terms of length, width, and thickness. For determining the size, 20-30 numbers raw carrot were selected randomly. Dimensions (length (L), width (W), and thickness (T)) of carrots were measured using a vernier caliper (M/s. RSK Digital Caliper, China) with a least count of 0.01 cm.

The geometric mean diameter (Dg) of the raw carrot was determined by using the standard method mentioned by Sharifi *et al.,* (2007).

$$\text{Geometric mean diameter } (D_g) = 3\sqrt{L.W.T} \qquad \ldots.. 3.1$$

The arithmetic mean diameter (D_a) of the raw carrot was computed using the standard method mentioned by Jahanbakhshi *et al.,* (2018).

$$\text{Arithmetic mean diameter } (D_a) = \frac{L+W+T}{3} \qquad \ldots .3.2$$

Where,

L- length of the carrot, mm

W – width of the carrot, mm

T – thickness of the carrot, mm

3.5.1.2 Determination of shape of the raw carrot

Shape plays an important role in the design of grading equipment for fruits and vegetables. The shape of fruits and vegetables is usually expressed in terms of sphericity(Ø), surface area(S)and aspect ratio (R_a). The sphericity was found out using the following equation (Singh and sahay, 2015).

$$\text{Sphericity } (\emptyset) = \frac{\sqrt[3]{L.W.T}}{L} \qquad \ldots 3.3$$

The surface area (S) and the aspect ratio (R_a) were determined using the formulae given below (Jahanbakhshi *et al.,* 2018).

$$\text{Surface area (S)} = \Pi D^2{}_g \qquad \ldots 3.4$$

$$\text{Aspect ratio } (R_a) = \frac{W}{L} \qquad \ldots 3.5$$

Where, Dg – Geometric mean diameter

3.5.1.3 Determination of mass of raw carrot

For the determination of mass of raw carrot, 10 number of raw samples were selected and measured by using an electronic balance (M/s. Ashlyn Chemunnoor Instruments PVT. LTD) to an accuracy of 0.01 g and the mean value of carrot was noted.

3.5.1.4 Determination of moisture content of raw carrot

Moisture content of raw carrots was determined as per AOAC (2005) method. Sample of 5 g carrot was taken into petri dishes and weighed. After weighing, the samples were placed in the hot air oven at 105± 2^0C and dried to constant weight, which took about 8-10 hr. The moisture content of the raw carrot was expressed as percentage wet basis (% w.b). The experiment was done by triplicates and the average value was noted. The percent of moisture content was determined by the following equation:

$$\text{Moisture content (\% wb)} = \frac{Wi - Wf}{Wi} \times 100 \qquad \ldots..3.6$$

Where

W_i – initial weight of raw carrot, g

W_f– dry weight of raw carrot, g

3.5.1.4 Determination of volume of raw carrot

The volume of the carrot was determined by platform scale method described by Mohsenin (1986). The raw carrot was totally dipped in water using the sinker rod without touching the bottom or sides of the beaker. Volume was calculated as the ratio of the weight of water displaced by the carrot to weight density of water.

$$\text{Volume of raw carrot (cm}^3\text{)} = \frac{\textbf{weight of the water displaced (g)}}{\textbf{weight density of water (g/cm3)}} \qquad \ldots\ldots.3.7$$

3.5.1.5 Determination of true and bulk density of raw carrot

The true density of the raw carrot was determined by the water displacement method (Dutta *et al.,* 1988). Raw carrot (10 No's) were randomly selected and weighed individually. The samples were immersed in a measuring cylinder containing the water and ensured that the raw carrot was completely submerged during immersion in water. The volume of water displaced by each sample was noted and the true density was calculated using the following equation:

$$\text{True density of raw carrot (g/cm}^3) = \frac{\text{Mass of the carrot (g)}}{\text{volume of the carrot(g/cm3)}} \quad \ldots\ldots.3.8$$

The bulk density is the ratio of weight of the produce to its bulk volume. The bulk density of the raw carrot was measured by using the empty beaker. The beaker was filled with raw carrot and the weight was measured. The bulk density was calculated using the equation 3.9. The experiment was replicated five times and the mean value was noted.

$$\text{Bulk density of raw carrot (g/cm}^3) = \frac{\text{weight of the carrot(g)}}{\text{volume of the beaker (cm3)}} \quad \ldots\ldots\ldots..3.9$$

3.5.2 Chemical Properties of Raw Carrot

The chemical/nutritional properties of raw carrot *viz.*, protein content, fibre content, ash content, carbohydrate content and total energy content were determined by using the standard procedures explained in the following section.

3.5.2.1 Determination of protein content

The crude protein content in the raw carrot was determined using Kjeldahl method (AOAC,2005). The experiment was conducted using a protein analyzer (M/s. Pelican Equipments, model: KEL PLUS). The sample of 0.5 g was taken into the digestion tube. The digestion mixture was prepared by mixing 2.7 g of potassium sulphate(K_2SO_4) and 0.3 g of copper sulphate ($CuSO_4$). Add 0.5 g to the digestion mixture and add 10 ml of concentrated sulphuric acid(H_2SO_4) to the sample. The sample was digested in the digestion unit (400^{0}C for 1-2 h) till it became colourless. After completion of digestion, the tubes were cooled and transferred into distillation unit. 40% NaOH solution was allowed into the tube. Liberated ammonium was absorbed in boric acid (4 %) solution containing mixed indicator (10 ml bromocresol green and 7 ml of methyl red). The colour of boric acid(pink) solution was turned to green colour in the distillation unit and the obtained solution was titrated against 0.1 N hydrochloric acid(HCL) until pink colour will obtained.

$$\text{Protein (\%)} = \frac{(\text{ml of HCL} - \text{ml of blank}) \times \text{molarity} \times 14.007 \times 100}{\text{mg test portion}} \times 6.25$$

…….3.10

3.5.2.2 Determination of fat content

The fat content of the raw carrot was determined by using AOAC standard procedure (AOAC,2005) with Soxhlet extraction method (M/s.Pelican Equipments, SOCS 06, India). The Soxhlet apparatus was shown in Plate 3.3.The sample of 2g was weighed and taken into thimble. Take the weight of empty beaker. The petroleum ether was poured into the beaker and all the beakers were loaded into the system. The petroleum ether was boiled for about 30 min at 80^0C. After completion of the process time, the temperature was doubled at 160^0C for 15-20 min to collect the petroleum ether. All the beakers from the system was removed and placed in the hot air oven for 100^0C for 1 h. Take out the sample from the hot air oven and cooled in the desiccator and again weight was noted. The final weight of the beaker was recorded and fat content was determined by using the following equation:

$$\text{Fat content (\%)} = \frac{W2 - W1}{W} \times 100$$

….3.10

Where,

W- Weight of sample taken, g

W_1- Initial weight of beakers, g

W_2- Final weight of beaker, g

3.5.2.3 Determination of ash content

The ash content of the raw carrot was determined using AOAC standard procedure (AOAC,2005). 5g of the sample was accurately weighed into the crucible. The crucible was placed on a clay pipe triangle and heated first over a low flame till the material was completely charred, followed by the muffle furnace for about 3-5 h at 550^0C. The crucibles could be cooled in the desiccator and weighed. The total ash content in the sample was determined by using the following equation:

$$\text{Total ash (\%)} = \frac{\text{weight of ash (g)}}{\text{weight of sample (g)}} \times 100$$

…..3.11

3.5.2.4 Determination of fibre content

Crude fibre consists of cellulose, variable proportion of hemicellulose and high variable proportions of lignin with some minerals. It was estimated by following the method suggested by AOAC (2005). About 2g of dried sample (W) was ground and boiled with 200 ml of H_2SO_4 for 30 min. Then the sample was filtered through muslin cloth and washed with hot water for 2-3 min so that the washings were not acidic. The residue obtained was boiled with 200 ml NaOH and filtered through muslin cloth and again washed with 25 ml of 1.25% H_2SO_4, 350 ml of water and 25 ml of alcohol. Then the residue was transferred to ashing dish (W1) and dried for 2h at 130^0C.Weight of the dish and the residue (W2) was taken after the cooling in the desiccator. Again the dish was ignited for 30 min at 600^0C and weighed after cooling (W3).

$$\text{Crude fibre content (\%)} = \frac{(W2-W1)-(W3-W1)}{W} \qquad ...3.12$$

3.5.2.5 *Determination of carbohydrate content*

The carbohydrate content of raw carrot was determined by the standard methods according to AOAC procedure (AOAC, 2005). By knowing the values of moisture content, fat content, protein, fat, and ash content, the carbohydrate content was determined by the following equation:

$$\text{Carbohydrate content (\%)} = 100- (\text{moisture(g)}+ \text{fat(g)}+ \text{protein(g)}+ \text{fibre (g)}+ \text{ash(g)}) \qquad ....3.13$$

3.5.2.6 *Determination of energy content*

The total energy content in the raw carrot was determined by standard equation as per AOAC method (AOAC,2005).

$$\text{Energy content (KJ/100g)} = [\ \text{protein(g)} \times 4 + \text{carbohydrate(g)} \times 4 + \text{fat (g)} \times 9] \qquad ......3.14$$

EXPERIMENT II

3.6 OPTIMIZATION OF PRE-TREATMENTS FOR VACUUM FRYING OF CARROT CHIPS

Based on the preliminary studies of vacuum frying of carrot and review of literature, a combination of temperature (100°C) (Pandey *et al.*,(2011); Chen *et al.*, (2004)), pressure (13 kPa) (Yang *et al.*,(2012);Perez-Tinoco *et al.*, (2008)) and time (25 min) (Maity *et al.*,(2014)); Tarzi *et al.*, (2011)) were selected for the pre-treatment study. The pre-treatments were selected to reduce the oil uptake by the product during frying and to improve the quality characteristics of the fried product. Pre-treatments like blanching, blanching cum drying, blanching cum freezing, edible gum coating and freezing were selected for this study and the pretreated samples were compared with untreated (control) and atmospheric frying samples. The process flow chart for vacuum frying of carrot chips with different pretreatments is shown in Fig. 3.1.

3.6.1 Different Pretreatments Selected for Preparation of Vacuum Fried Carrot Chips

3.6.1.1 Blanching

The raw carrot fingers (strips) of 3-4 mm thickness and length (6-7 cm) were blanched in hot water at 85°C for 3.5 min, then cooling under running tap water for 3min (Fan *et al.*, 2006).

3.6.1.2 Blanching cum drying

The raw carrot fingers (strips) of 3-4 mm thickness and length (6-7 cm) were water blanched for 85°C for 3.5 min (Pedreschi *et al.*, 2005) and dried at 70°C using a convective dryer for 1 h 30 min (Abdulla *et al.*, 2007).

3.6.1.3 Blanching cum freezing

The raw carrot fingers (strips) of 3-4 mm thickness and length (6-7 cm) were water blanched for 85°C for 3.5 min (Pedreschi *et al.,* 2005) and then frozen at –20 °C for 4 to 5 h (Fan *et al.,* 2006).

3.6.1.4 Freezing

The raw carrot fingers (strips) of 3-4 mm thickness and length (6-7 cm) were kept in a normal freezer at -18 °C for overnight (Dandamrongrak *et al.,* 2003).

3.6.1.5 Edible gum coating

The gum coating applied on sliced carrot was performed by dipping and the thickness of the coating was controlled by the duration of dipping. The guar gum solution was prepared by dissolving (1.5%) guar gum in distilled water at 90°C for 30 min (Sothornvit, 2011). The proportion of a coating solution to carrot slices was maintained at 5:4 by soaking the slices for 5-10 min within the gum solution.

3.6.1.6 Atmospheric Frying

In atmospheric frying, the carrot slices were immersed in hot oil at frying temperature of 165°C, atmospheric pressure of 101 kPa and frying time of 25 min. The fried samples were put in a stainless-steel sieve for 5 min to drain the excess oil.

3.6.2 DEVELOPMENT OF CARROT CHIPS BY VACUUM FRYING PROCESS

Development of carrot chips was carried out by using the vacuum frying technology. The standard procedure for preparation of carrot chips by using vacuum frying technology was already explained and discussed in the section 3.3. The process flow chart for development of vacuum fried carrot chips with different pretreatments was presented in Fig.3.1.

3.6.3 QUALITY PARAMETERS OF PRETREATED VACUUM FRIED (VF) CARROT CHIPS

The different quality parameters *viz.*, moisture content, oil content, bulk density, true density, thickness expansion, hardness, total yields and color values were determined as per the standard methods as explained in the following section.

3.6.3.1 Determination of moisture content

Moisture content of the pretreated vacuum fried carrot chips was determined as per the standard procedure explained in the section 3.5.1.4.

3.6.3.2 Determination of oil content

The oil content of the pretreated vacuum fried carrot chips was done as per the standard methods explained in the section 3.5.2.2.

3.6.3.3 Determination of water activity

The water activity of the pretreated vacuum fried carrot chips was determined by using water activity meter (M/s. Aqua lab, Decagon Devices Inc., Pullman (Wa), USA) (Perez-Tinoco *et al.*, 2008).

The water activity meter was shown in Plate 3.4. The sample was made into small pieces. Turn the sample drawer knob to the open or load position and pull the drawer open. Place the prepared sample in the drawer. Check the top lip of the cup to make sure it is free from sample residue carefully slide the drawer closed. Turn the sample drawer knob to read the position to seal the sample cup with the chamber. The obtained result was displayed in the screen. The experiment was repeated for three times and mean value was noted.

3.6.3.4 Determination of bulk density

The liquid displacement method with ethanol was used for determining the bulk volume of vacuum fried carrot chips. Five to six carrot chips were weighed and the volume in the beaker was noted with and without sample. The bulk density of the vacuum fried carrot chips was calculated by dividing the weight of chips to its bulk volume. The experiment was replicated three times and the mean value was noted (Ravli *et al.,* 2013). The bulk density of VF-carrot chips was calculated by using the equation (3.15):

Bulk density ρ_b, (g/cm^3) = $\frac{Ws}{Vb}$ 3.15

Where

W_s – Weight of the de-oiled sample, g

V_b –volume of the beaker, cm^3= $\frac{\pi}{4} \times D^2 \times H$

D – Diameter of the beaker, cm

H – Height of the beaker, cm

3.6.3.5 Determination of true density

True volume of vacuum fried carrot chips was calculated as per the method recommended by Deshpande and Poshadri (2011). Fill the 5g of ground sample of chips in a burette containing toluene. Then raised in toluene level was measured and an average of two readings of true density was calculated. The triplicates were carried out and it was calculated by using the equation:

True density ρ_t, (g/cm^3) = $\frac{Ws}{Vt}$ 3.16

where

Ws – Weight of the sample, g

Vt – True volume of the sample, cm^3

True volume = vol. of the flask – vol. of the toluene

3.6.3.6 Determination of thickness expansion

Thickness expansion was determined by measuring the thickness of randomly selected vacuum fried carrot chips using a vernier caliper (M/s. RSK Digital Caliper, China). Degree of thickness expansion was determined using the following equation as described by Kawas and Moreria (2001).

Thickness Expansion (%) = $\frac{Io-I(t)}{Io} \times 100$ 3.17

Where,

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

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

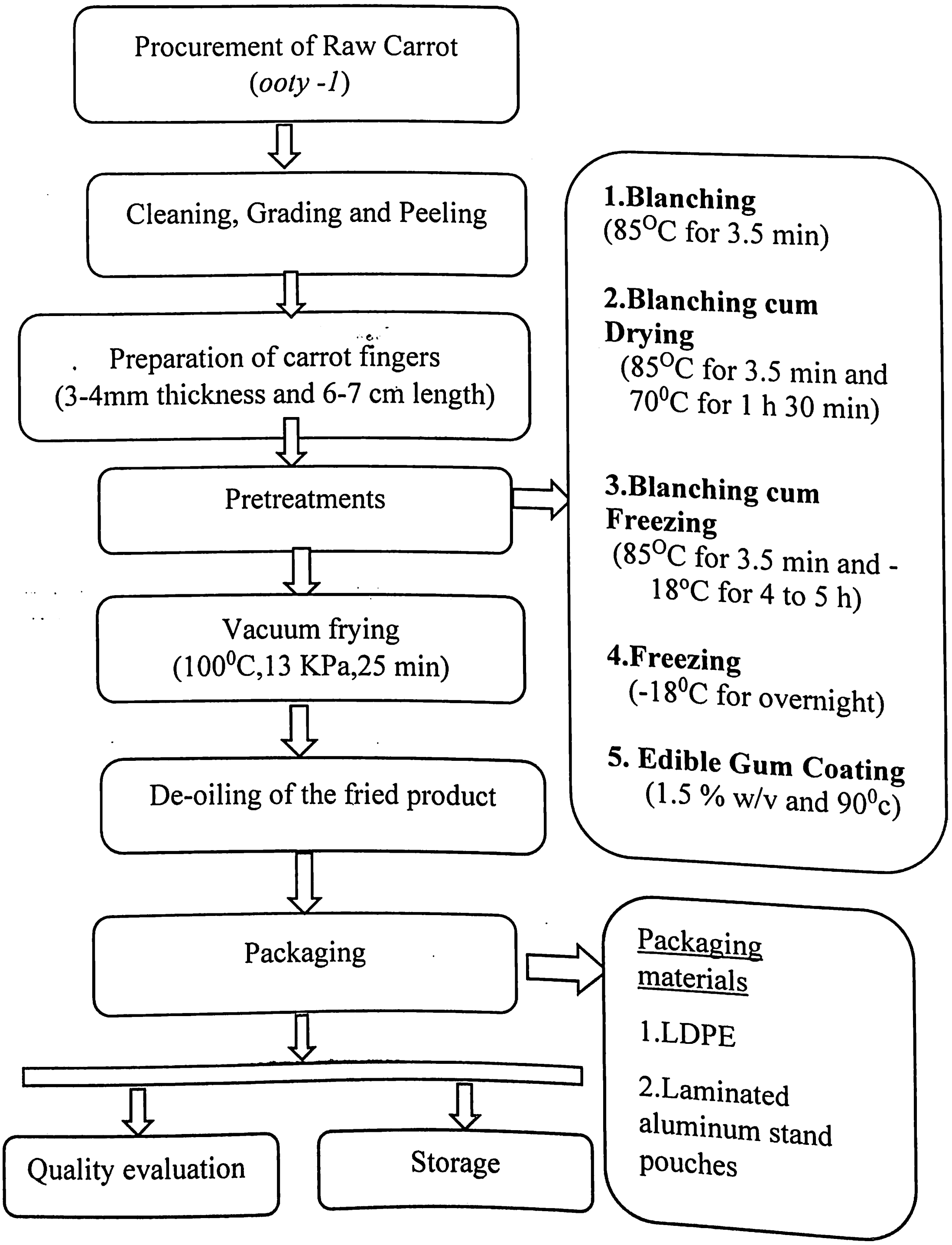


Fig.3.1 Process flow chart for development of vacuum fried carrot chips with different pretreatments

3.6.3.7 Determination of total yields:

The total yields of the vacuum fried carrot chips was determined by using the weights before frying and after frying of the sample (Fan *et al.*,2006)

Total yields (%) =initial weight of input (before frying) – final weight of output (after frying) 3.18

3.6.3.8 Determination of color

The color of the vacuum fried carrot chips was determined by using a Hunter lab Colorimeter – Color flex EZ diffuse model. It works on the principle of light focusing on the sample and measures reflected energy from the sample across the entire visible spectrum. Colorimeter having standard observer curves such as red, green and blue colors. This colorimeter expressed the colors on L*, a*, and b*. The L* value represents lightness its ranging from, 0 (blackness) to 100 (whiteness), a* represents +ve (redness) and –ve (greenness) and b* represents +ve 60 (yellowness) and –ve 60 (blueness) (Diamante *et al.,* 2010).The colour of the vacuum fried carrot chips measured by using CIELAB scale at 10° observer at D65 illuminant with 50 mm diameter measuring space. Before measuring the colour of the sample, instrument should standardise by placing black and white standard tiles. The sample was placed in the glass jar and it should be filled upto the mark. The filled glass jar was placed on CIELAB scale. The deviation from colour of the samples with the standard was observed and noted.

The total color difference (ΔE) between raw (L_0^*, a_0^*, b_0^*) and fried carrot chips (L*, a*, b*) was determined using the equation which is adopted by Yam *et al.,* (2004). Hunters lab colorimeter was displayed in Plate 3.8.

Color difference (ΔE) = $\{(L_0^* - L^*) + (a_0^* - a^*) + (b_0^* - b^*)\}^{0.5}$ 3.19

3.6.3.9 Determination of Texture

The texture analyzer was used to measure the breaking/penetration force of the food products and it was measured in terms of Newton(N) or grams(g). Texture analyzer (TA. XT Texture analyzer, M/s. Stable micro system Ltd.) was used to measure the texture of carrot chips. Hardness of the fried products were determined by using the texture analyzer. The texture analyser was shown in Plate 3.5. The hardness test was conducted for individual carrot chips in the texture analyzer and the results were obtained from a graph. During testing process, the cylindrical/ steel ball probe (Fan *et al.*,2006) 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 hardness test for vacuum fried carrot chips test was conducted in triplicates in texture analyzer. The TA settings used for the test is given below:

Texture analyzer (TA) settings:

Test Mode : Compression
Option : Return to start
Pre-test speed : 1.00 mm/sec
Test speed : 0.50 mm/sec
Post-test speed : 10.00 mm/sec
Distance : 20.00 mm
Trigger type : Auto (force)
Trigger force : 5.0 g
Probe : cylindrical (HDP/BS)

3.6.3.10 Sensory analysis for vacuum fried carrot chips

The sensory analysis is the most important step for accepting/rejecting of the products from the consumers. The sensory analysis of the product was evaluated using food quality attributes such as texture, color, flavor, taste and overall acceptability (Maity *et al.,* 2014). For sensory evaluation, nine-point hedonic scale was used and score card given to bring out good characteristics of pretreated vacuum fried carrot chips. The sensory evaluation for vacuum fried carrot chips were evaluated for texture (Hardness), color and appearance, flavor, taste and overall acceptability by a panel of 25 judges. The score card model was shown in appendix A.

3.6.3.11 Fuzzy logic sensory analysis

Fuzzy sets theory was initiated by Zadeh (1965), which allows unknown phenomena to be treated mathematically. For ranking of foods and developing new food products, fuzzy comprehensive model was developed by Zhang and Litchfield (1991). Numerous experts were involved in the evaluation of subjective. In most cases the expert's opinion rather comes in linguistic form, which contains a lot of subjectivity, vagueness, and ambiguity. The score collected from 25 judges were taken and their grammatical judgment was converted to numerical ranking using fuzzy model. The parameters assigned to respective values based on the preference given by sensory panel.

The score assigned for the vacuum fried carrot chips were texture- 0.3, color and appearance- 0.2, taste- 0.2, flavor- 0.1 and overall acceptability – 0.2.

Table 3.2. Fuzzy sets of fuzzy logic sensory model

S.No	Sets	Importance of sets
I	**Factor set (Ff)**	Quality characteristics of vacuum fried carrot chips (texture, flavor, colour and appearance, taste and overall acceptability)
II	**Evaluation set (Ef)**	Scale factors for quality attribute (Excellent (EX), Good (GD), Medium (MD), Fair (FR) and Not Satisfactory (NS))
II	**Transformation set (Tf)**	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)**–FMF was obtained by adding the individual term given to each of the quality parameter of the product and divided by the total number of judges participated and tested the chips.
- **Normalized Fuzzy membership function (NFMF)**–NFMF was obtained by multiplying individual FMF and scale factor allotted to respective membership function.
- **Normalized Fuzzy membership function matrix** – It is the NFMF matrix formulated by adding NFMF with its respective scale factors.
- **Judgment membership function matrix (JMFM)** –JFMF was a 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 last stage of fuzzy logic. The final ranking of samples evaluated along with attributes preference of judges.

The fuzzy logic model calculation along with sets and matrix table are given in detail in Appendix B.

3.6.4 Statistical Design for Pre-treatment of Vacuum Fried Carrot Chips

The vacuum frying of carrot chips was fried with refined palm oil. The quality parameters of the pre-treated vacuum fried samples were determined. The results of pre-treatments were statistically analyzed using IBM-SPSS (International business machines- statistical package for social sciences) statistics 26.0. Optimization of pre-treatments was done and the best pretreatment was selected for further studies.

Plate 3.3. Soxhlet apparatus

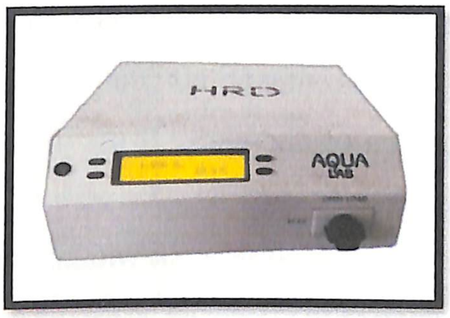


Plate 3.4. Water activity meter

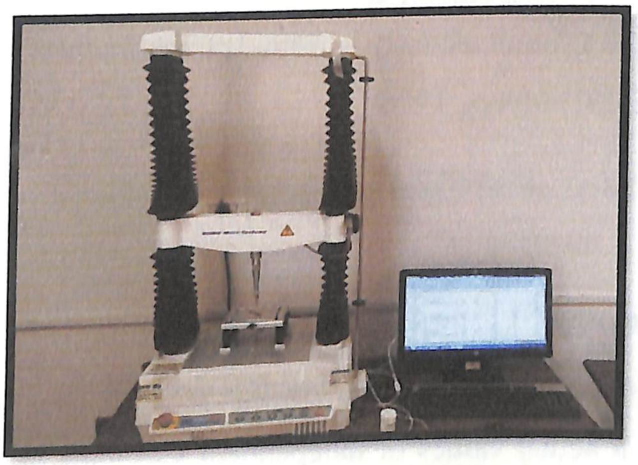


Plate 3.5. Texture analyzer

EXPERIMENT III

3.7 STANDARDIZATION OF PROCESS PARAMETERS FOR VACUUM FRYING OF CARROT CHIPS

The standardization of process parameters of vacuum fried product was done by three different combinations of frying temperature, pressure and frying time. The detailed description of the design has been explained under the section (3.7.1).

3.7.1 Experimental Design

3.7.1.1 Introduction to experimental design (Response surface methodology)

For the optimization of vacuum fried carrot chips, the centered central composite random design (CCRD) was selected (singh *et al.*, 2008). Central composite random design is the most popular of the many classes of RSM designs

(Khuri and Cornell 1987). A central composite design contains a fractional factorial design with center points that is augmented with a group of "star points" that allows estimation of curvature. If the distance from the center of the design space to a factorial point is ±1 unit for each factor, the distance from the center of the design space to a star point is $\pm\alpha$ with$|\alpha| > 1$.In CCRD, the star points are at the center of each face of the factorial space, so $\alpha = \pm 1$.This design requires three levels for each factor, thus making the total number of experiments equal to 20 instead of 27 with full factorial design. The main advantage of the design was that it enables the study of one or more variables simultaneously in a single experimental design of practical size (Montgomery, 2001; Myers, 1976).

Total no. of experiments (N) = 2^n +2n +nc

Where,

n = no. of factorials = 3; nc = no. of center points

3.7.1.2 Coded and actual values of experimental design

The coded and actual values of independent variables in central composite randomized design for optimization of process variables for the vacuum fried carrot chips are tabulated in Table. 3.3.

Table 3.3 Coded & actual values of independent variables in CCRD for optimization of process variables for the vacuum fried carrot chips

Independent variables	**Coded variables**	**Levels in the coded form**				
		-α	**-1**	**0**	**+1**	**+α**
Temperature	X1	93.18	100	110	120	126.82
Pressure	X2	9.636	11	13	15	16.364
Time	X3	14.636	16	18	20	21.364

(Machrouhi *et al.*,2019)

3.7.1.3 Experimental design in coded form for central composite randomized design

The number of experiments with its replications and combinations that are obtained by central composite randomized design are presented in Table 3.4.

Table 3.4. Experimental design in coded form for central composite randomized design

Coded variables			Combinations	Replications	No. of Experiments
X1	**X2**	**X3**			
±1	±1	±1	8	1	8
±α	0	0	2	1	2
0	±α	0	2	1	2
0	0	±α	2	1	2
0	0	0	1	6	6

Where,

Codes	**Parameters**
Code "0" – centre runs	X1: Temperature
Code "±1" - factorial runs	X2 : Pressure
Code " ±α " - axial points	X3 : Time

3.7.1.4 Experimental design for optimization of process parameter of vacuum fried carrot chips

Vacuum frying of carrot chips experiment was conducted with combinations of process parameters presented in Table. 3.5.

Table 3.5. Central composite randomized experimental design for optimization of process parameter for the vacuum fried carrot chips

	Coded values			Actual values		
Run	Temperature	Pressure	Time	Temperature	Pressure	Time
1	0	0	1.681	110	13	21.3636
2	-1	1	1	100	15	20
3	-1	-1	-1	100	11	16
4	1.681	0	0	126.818	13	18
5	1	1	1	120	15	20

6	1	-1	-1	120	11	16
7	0	0	0	110	13	18
8	0	0	0	110	13	18
9	0	0	-1.68	110	13	14.6364
10	0	1.681	0	110	16.363	18
11	-1.681	0	0	93.1821	13	18
12	1	-1	1	120	11	20
13	-1	-1	1	100	11	20
14	0	-1.681	01	110	9.6364	18
15	0	0	0	110	13	18
16	0	0	0	110	13	18
17	1	1	-1	120	15	16
18	-1	1	-1	100	15	16
19	0	0	0	110	13	18
20	0	0	0	110	13	18

3.7.2 Preparation of Vacuum Fried Carrot Chips

The process flow chart for vacuum frying of carrot chips with different combination treatments is shown in Fig.3.2.

3.7.3 Quality Analysis of Standardized Vacuum Fried Carrot Chips

The quality parameters such as moisture content, oil content, water activity, bulk density, true density, thickness expansion, color, hardness and energy content were determined as per the standard procedures explained below.

3.7.3.1 Determination of moisture content

The moisture content of the vacuum fried carrot chips with different combinations was determined and discussed in the section 3.5.1.4. The initial and final weights of vacuum fried chips were noted and the same was used to calculate the moisture content of chips.

3.7.3.2 Determination of water activity

The water activity of the vacuum fried carrot chips with different treatments was determined by using water activity meter (Model: Aqua lab, Decagon Devices Inc., Pullman, USA) (Perez-Tinoco *et al.,* 2008). The procedure was explained in the section 3.6.2.3

3.7.3.3 Determination of oil content

The oil content of the vacuum fried carrot chips with different combinations was conducted as per the procedure described in the section 3.5.2.2.

3.7.3.4 Determination of bulk density

The bulk density of the vacuum fried carrot chips with different combinations was determined as per the procedure described in section 3.6.2.4

3.7.3.5 Determination of true density

The true density of the vacuum fried carrot chips with different treatments was conducted as per the procedure described in the section 3.6.2.5

3.7.3.6 Determination of thickness expansion

Thickness expansion was determined by measuring the thickness of randomly selected vacuum fried carrot chips by using the vernier caliper (M/s. RSK Digital Caliper, China). The thickness expansion of the vacuum fried carrot chips with different combinations was determined as per the procedure discussed in the section 3.6.2.6

3.7.3.7 Determination of color

The color of the vacuum fried carrot chips was determined using a Hunter lab Colorimeter – Color flex EZ diffuse model. The color values of the vacuum fried carrot chips with various treatments were determined as per the procedure described in the section 3.6.2.8.

3.7.3.8 Determination of Texture

Texture analyzer (TA.XT Texture analyzer, Stable micro system Ltd.) was used to measure the breaking/penetration force of the food products and it was measured in terms of Newton(N) or grams(g).The hardness of vacuum fried carrot chips with different treatments was discussed as per standard procedures described in section 3.6.2.9.

3.7.3.9 Sensory analysis

Sensory analysis was performed to the twenty treatments of vacuum fried carrot chips. The sensory evaluation for vacuum fried carrot chips were evaluated for texture (Hardness), color and appearance, flavor, taste and overall acceptability by a panel of 25 judges. The sensory score card model is represented in Appendix A.

3.7.3.10. Fuzzy logic comprehensive model

The fuzzy logical sensory analysis was conducted to the vacuum fried carrot chips as per standard methods discussed in the section 3.6.2.11. The fuzzy logic model calculation along with sets and matrix table are presented in Appendix B.

3.7.4 STATISTICAL ANALYSIS

A central composite rotatable design (CCRD) using three factors at five levels (coded levels $-\alpha$, -1, 0,1 and $-\alpha$) was used for optimisation of a responses (quality attributes of VF carrot chips) for different experimental combinations were related to the coded variables (X_1, X_2 and X_3) by a second degree polynomial equation predicted for optimisation of dependent variables (Y) is

$$Y=\beta0+\beta1\ X1+\beta2\ X2+\beta3\ X3+\ +\beta11\ X1^2+\beta22\ X2^2+\beta33\ X3^2+\beta12X1.X2+ +\beta13X1.X3+\beta23X2.X3+\varepsilon \qquad \ldots\ldots\ldots\ldots 3.20$$

where, Y = Predicted response

$\beta0$ (constant),

$\beta1, \beta2, \beta3$ (coefficients for linear effects)

$\beta12, \beta13, \beta23$ (coefficients for interaction effects)

$\beta11, \beta22, \beta33$ (coefficients for quadratic effects) and

ε (random error).

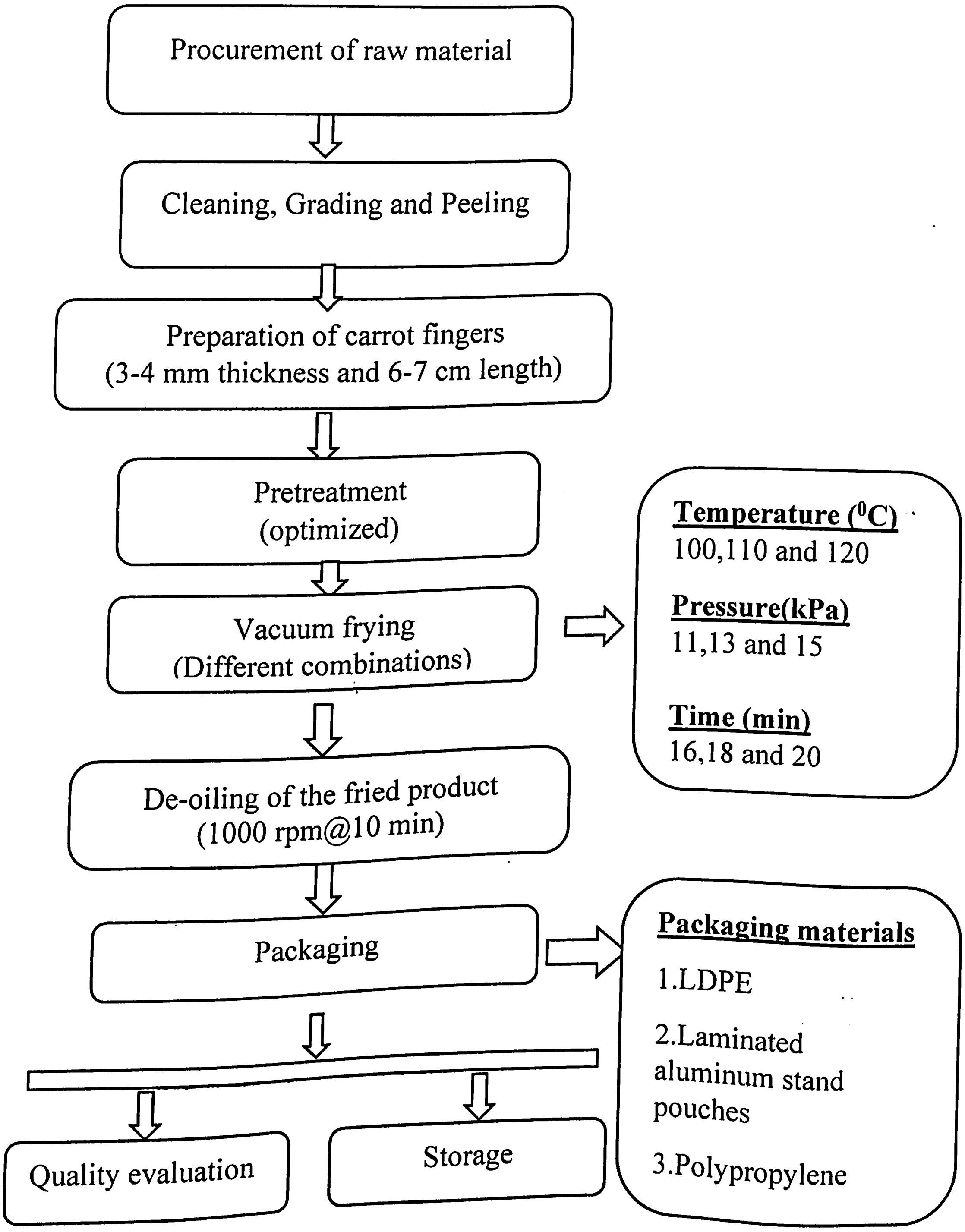


Fig.3.2. Process flow chart for development of vacuum fried carrot chips with different combination treatments

The quality of the fit of the polynomial model was expressed by the correlation coefficient (R^2). The significance and adequacy of the used model was further explained using F-value (Fisher variation ratio), probability value (Prob > F), and adequate precision (AP).

3.7.4.1 Analysis of Data

A complete second order quadratic model was utilized to correlate the independent process variables. The second order polynomial coefficient for each term of equation was determined through multiple regression analysis using design expert. Experimental data were fitted to the selected models and regression coefficients obtained. Statistical significance of terms in the regression equation was examined by analysis of variance (ANOVA) for each response. ANOVA is important in determining the adequacy and significance of quadratic model. The p values were used as a tool to check the significance of each coefficient, which in turn, were necessary to understand the pattern of mutual interactions between test variables. Smaller the magnitude of p, the more significant is its corresponding coefficient. Values of p less than 0.05, indicated that model terms were significant. The adequacy of regression model was checked by R^2(Montgomery, 2001).

The smaller the value of R^2, lesser will be the relevance of dependent variables in the model that explains the behaviour variation. Optimisation of process parameters was done by partially differentiating the model with respect to each parameter, equating to zero and simultaneously solving the resulting function. The regression coefficients were then used to make statistical calculation to generate three-dimensional plots for the regression model.

EXPERIMENT – IV

3.8 PACKAGING AND STORAGE STUDIES OF OPTIMIZED VACUUM FRIED CARROT CHIPS

3.8.1 Experimental Design

3.8.1.1 Independent variables

- P1- LDPE stand up pouches with (95 %) N_2 gas filling (Fan *et al.*, 2006)
- P2- Laminated aluminum foil flexible pouches with (95 %) N_2 gas filling
- P3 - Polypropylene pouches without (95 %) N_2 gas filling.
- P4- LDPE stand up pouches without N_2 gas filling
- P5- Laminated aluminum foil flexible pouches without N_2 gas filling and
- P6 - Polypropylene pouches without N_2 gas filling

3.8.1.2 Dependent variables

- Moisture content
- Oil content
- Water activity
- Hardness
- Color

The optimized vacuum fried carrot chips were packed under different packages. 200 micron thickness packaging materials were selected for the storage studies. The packaging was done using nitrogen flush packaging machine (Model: QS 400 V, M/s. Sevana packaging solutions, Kerala, India) with 95% of N_2 gas flushing (Fan *et al.*, 2007). The packed samples were stored at ambient temperature (25±5°C) and relative humidity (70±10%) during the study period. During storage studies, the changes in the physical and biochemical qualities of vacuum fried carrot chips were analyzed for every 30 days of regular interval. Storages studies were conducted for 4 months. Triplicates were carried out for the experiment and mean value was taken for the analysis.

3.8.2 QUALITY ANALYSIS OF OPTIMALLY PRODUCE VF-CARROT CHIPS FOR STORAGE STUDIES

The quality parameters of stored products *viz.*, moisture content, oil content, water activity, color, hardness, were determined using the standard procedures explained in the sections 3.5.1.4, 3.5.2.2, 3.6.2.3, 3.6.2.8 and 3.6.2.9, respectively.

3.8.2.1 Statistical Analysis for Quality Changes of Vacuum Fried Carrot Chips During the Storage Period

Two treatments (six different packaging technology) were statistically analysed by using statistical package for social science (SPSS) software. An optimisation of the storage studies was done in terms of quality attributes of the stored products. The analysis of variance (ANOVA) and mean table for different packaging materials were tabulated and the level of significance was reported.

EXPERIMENT -V

3.9 EVALUATION OF QUALITY PARAMETERS OF FRYING OIL

The refined palm oil (RPO) was evaluated for testing the oil quality after its frequent use for multiple batches of vacuum frying. After completion of vacuum frying, every batch of the fried oil was tested for its quality assessment. By using the repeated frying oil, there were changes in the oil quality *viz.*, viscosity, total polar compounds, free fatty acids, peroxides, and color values were evaluated. The oil was heated under processing conditions of the optimised sample. For quality evaluation, the oil was cooled for 10 mins after every batch of vacuum frying. Changes in the oil quality parameters of frying oil are discussed in the following section.

3.9.1 Effect of Processing Parameters on Oil Quality During Vacuum Frying of Carrot Chips

3.9.1.1 Oxidation stability (Peroxide and Free Fatty Acids)

The peroxide value (PV) was expressed in active oxygen per kilogram (meq O_2/kg) and the fatty acids expressed in oleic acid percentage. These two parameters play a vital role for determination of oxidation stability of the edible oil. The rapid analysis equipment (CDR FoodLab, Italy) was used to determine these parameters and it was shown in Plate 3.6.

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

In case of peroxide test, 10 µl of R2 solution was collected with micro pipette and added along with sample and R1 in the cuvette. Shake the cuvette gently for few seconds and place it in the incubator for three minutes. 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 showed on the display board and recorded.

In case of FFA, the reagent R1 were filled in the cuvette and placed in one of the incubation cells and let it heat for 4 min. Shake the cuvette gently for 5 times and place in the cell marked with blue light and then pressed the read button to obtain blank readings. Then the oil sample was drawn with the pipette tube. Then 2.5 µl of sample was collected for FFA value and 5 µl for PV values. The cuvette with sample was shaken for 2 - 3 times and placed in the cell marked with blue light. Then pressed the read button was to execute the test.

3.9.1.2 Total polar compounds

TPC of the oil was determined by using the equipment Testo 270° (Make: Italy). The Testo 270° equipment measures, TPC based on the dielectric constant of oil and its value was directly transferred into percentage weight of TPC (Guillen and Uriarte, 2012). Before testing TPC, the oil was heated at 40°C in a glass beaker.

The probe with sensor of Testo 270° was dipped into the heated oil and try to avoid the touching of the sensor at the bottom of the beaker. The TPC (%) display in the digital display of the equipment. The Testo 270° device was shown in Plate 3.7.

3.9.1.3. Color values

Hunter lab colorimeter was used to determine the color values of oil, initial and final stages of frying. The details of the colorimeter and procedure to determine the color values are explained under section 3.6.2.8. Hunter lab colorimeter was shown in Plate 3.8.

3.9.1.4 Viscosity

The viscosity of the oil was determined by using the Viscometer (model: Brookfield DVE Viscometer, United States) shown in Plate.3.9. The viscosity was expressed in (mPa-s) or centipoise. Before doing experiment, check the bubble stage in the equipment and it should be center. The selection of the spindle plays a major role in finding the viscosity. The spindle (No.2) was selected and fixed in screw to conduct the viscosity test. The oil sample (700 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 oil sample should touch the mark present on the spindle. 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 (centipoise).

3.9.1.5 Statistical Analysis for Evaluation of Oil Quality Parameters

The results obtained from the oil quality evaluation was statistically analysed by using the design experts 12.0 SPSS. The Analysis of variance (ANOVA) and mean table for different process parameters were tabulated and the level of significance was reported.

Experiment - VI

3.10 COST ANALYSIS

For commercialization of the optimized vacuum fried product, the cost economics was done. The cost economics was determined by standard method with necessary assumptions. The variable costs and fixed costs were determined. The details of the cost analysis are given in Appendix C.

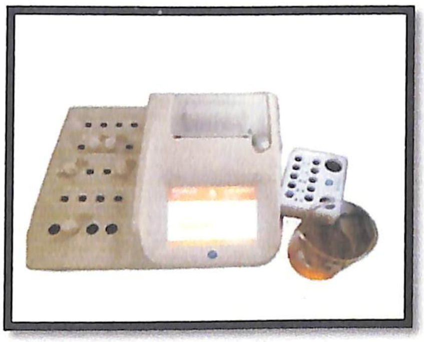


Plate 3.6. Rapid analysis equipment (CDR FoodLab, Italy)

Plate 3.7 Testo 270^0

Plate 3.8. Colorimeter

Plate 3.9. Brookfield viscometer

RESULTS & DISCUSSIONS

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results and discussion of the experiments conducted for the development of vacuum fried carrot chips. The results of the experiments conducted towards optimisation of pre-treatments, standardisation of process parameters, quality evaluation of oil and packaging & storage studies of vacuum fried carrot chips are discussed in this chapter.

EXPERIMENT 1

4.1 Physico-Chemical Properties of Raw Carrot (*Ooty-1)* Cultivar

Ooty-1 cultivar of carrot was selected for the development of vacuum fried (VF) carrot chips. Prior to vacuum frying studies, the physical and chemical properties of raw carrot were determined and the results are tabulated in Table 4.1.

Table 4.1 Physico-chemical properties of raw carrot (*Ooty-1*) cultivar

Physico-chemical properties	**Value**
Length (mm)	128.47
Width(mm)	29.1
Thickness(mm)	21.735
Arithmetic mean diameter(mm)	59.7
Geometric mean diameter (mm)	43.3
Sphericity (%)	0.33
Surface area (mm^2)	5887.15
Aspect ratio	0.22
Mass (g)	72.8
Moisture content (%)	89.7

Bulk density (g/cm^3)	0.8
True density (g/cm^3)	1.023
Fat content (g /100g)	0.35
Protein (g /100g)	0.82
Carbohydrate (g /100g)	9.08
Crude fibre (g /100g)	2.1
Ash content ((g /100g)	1

Raw carrot had an average moisture content of 89.7% (w.b). The bulk density and true density of the raw carrot were 0.8 and 1.023 g/cm^3, respectively. The average mass of the carrot was 78-80 g. The chemical/nutritional properties *viz.*, protein, fat, carbohydrate, crude fiber and total ash were 0.82g/100g, 0.35g/100g, 9.08g/100g, 2.1g/100g and 1.0g/100g, respectively. The total energy content of the raw carrot was 49 kcal/100g. These results were in agreement with Jahanbakshi *et al.*, (2018) who found the physical and mechanical properties of raw carrot. The results of chemical/nutritional properties were similar with Sharma *et al.*, (2012) who found the biochemical composition of raw carrots.

EXPERIMENT – II

4.2 OPTIMIZATION OF PRE-TREATMENTS FOR VACUUM FRYING OF CARROT CHIPS

Based on the previous research studies reviewed, refined palm oil (RPO) had been selected for the preparation of vacuum fried (VF) carrot chips. The different types of pre-treatments selected for the study were blanching, blanching cum drying, blanching cum freezing, freezing and edible gum coating. Untreated VF carrot chips was taken as control. The symbolic representation of various pre-treatments considered is listed below.

CB - Carrot with blanching

CBD-Carrot with blanching cum drying

CBF- Carrot with blanching cum freezing

CF- Carrot with freezing

CGG-Carrot with edible gum coating

CC- Carrot with untreated (control sample)

CAF- Carrot with atmospheric frying

The pre-treatments were optimized based on the quality attributes of vacuum fried (VF) chips. Based on preliminary trails, the processing conditions of VF carrot chips were set at frying temperature 100°C, frying pressure 13 kPa and frying time 25 min. The pre-treated VF carrot chips as well as the control sample were compared with atmospheric frying in-terms of quality parameters and sensory studies. The outright details of the quality parameters of pre-treated, control and atmospheric fried samples are presented in Appendix-D (Table D1.1 and D1.2). The pre-treated VF-carrot chips are shown in Plate 4.1.

4.2.1 Effect of Pre-Treatments on Quality Parameters of Vacuum Fried Carrot Chips

The quality parameters of the pre-treated VF-carrot chips *viz.,* moisture content, fat/oil content, water activity, true density, bulk density, thickness expansion, hardness, total yields and color values (L*, a* and b*) are discussed in the following section.

4.2.1.1 Moisture Content

Moisture content represents the total amount of moisture present in food. It is one of the important parameters which indicate the stability of the product during storage. The moisture content of VF-carrot chips is graphically shown in Fig 4.1 and the results are tabulated in Appendix-D. The effect of pre-treatments had a significant ($p<0.01$) effect on moisture content of vacuum fried carrot chips. From

Fig 4.1, it is observed that the moisture content of the pre-treated VF-carrot chips ranged from 2.15 % to 10.25%. The moisture content of pre-treated VF-carrot chips *viz.,* blanching, blanching cum drying, blanching cum freezing, freezing and edible gum coated were 3.59 %, 2.15 %, 2.93 %, 2.67 %, and 6.82 %, respectively. The untreated (control) and atmospheric fried chips had a moisture content of 3.27 % and 10.25 %, respectively. The highest moisture content of 10.25 % was observed in the atmospheric fried chips followed by edible gum coated VF-carrot chips (6.82%). Higher frying temperature under atmospheric frying causes charring of fruit and negligible moisture removal from fruit. The higher moisture content of 6.82% under edible gum pre-treated vacuum fried chips might be due to the formation of a thin layer of gum solution over the chips resulted in high moisture content. The obtained results were like Pooja (2018), who found the highest moisture content for gum coated bitter gourd chips, during vacuum frying. Lowest moisture content of 2.15 % was noted in VF-carrot chips, pre-treated with blanching cum drying. This may be due to the removal of moisture from the carrot strips during drying resulted in low moisture content of chips. Similar trend of results was noticed in VF-banana chips that were dried prior to frying by Ranasalva and Sudheer (2017b).

4.2.1.2 Oil Content

The oil content is one of the most important parameters in snack food. The lowest oil content in the food helps to reduce health diseases. The oil content of pre-treated VF-carrot chips are tabulated in Table D1.2 and graphically shown in Fig 4.2. The oil content of the VF-carrot chips significantly ($p<0.01$) varied with the pre-treatments.

From Fig 4.2, it is revealed that the oil content of pre-treated VF-carrot chips ranged between 10.04 to 30.05 %. The maximum oil content of 30.05 % was observed in the atmospheric fried carrot chips followed by control sample (25.11%) and frozen (14.48%) pre-treated VF-carrot chips. The highest oil absorption in the atmospheric fried chips is not good for consumption of human body and considered as unsafe. The maximum absorption of oil content in the atmospheric fried chips might be due to high frying temperature and frying time. The oil content in the VF-chips was less than atmospheric fried chips (Fig. 4.2). The reason for the absorption of more oil content in frozen pre-treated chips might be due to increase in porosity caused by the evaporation of ice crystals during frying (Fan *et al.* 2006). The obtained results were in agreement with Ranasalva and Sudheer (2017b), who observed similar trend of oil absorption in the frozen pre-treated VF-banana chips. The lowest oil content of 10.04% was noted in the VF-carrot chips that was pre-treated with edible gum coating. This may be due to the coating of carrot slices (1.5% w/v) with guar gum produced a significant reduction in oil absorption. Sothornvit (2011) reported the similar trend of oil reduction (17.31%) in guar gum coated VF-carrot chips. The oil content of the VF-carrot chips pre-treated with blanching, blanching cum drying and blanching cum freezing were 13.24, 12.64 and 13.98 %, respectively. The basic mechanism of oil absorption in the chips or amount of loss of moisture from the chips was directly proportional to amount of oil entering into the chips (Maity *et al.* 2014). Higher frying temperature during atmospheric frying process resulted in scorching of sample, more oil absorption and negligible moisture removal from it.

4.2.1.3 Water Activity

Water activity plays a vital role in the food, which is used to facilitate the safety and stability of the food w.r.t to the growth of microorganisms and chemical reactions. The threshold value of water activity in any fried foods is less than 0.6 (Fan *et al.*, 2006). The water activity of VF-carrot chips varied significantly ($p<0.01$) with the pre-treatments.

The water activity of pre-treated VF-carrot chips are displayed in Table D1.2 (Appendix D) and graphically represented in Fig 4.3. Water activity of the pre-treated VF-carrot chips ranged between 0.214 to 0.324 (Fig 4.3). The water activity of the pre-treated VF-carrot chips *viz.*, blanching, blanching cum drying, blanching cum freezing, freezing and edible gum coating were 0.316, 0.214, 0.292, 0.225 and 0.324, respectively. The water activity of 0.287 and 0.310 were observed in untreated (control) chips and atmospheric fried chips, respectively. The highest water activity of 0.324 was observed in vacuum fried carrot chips, pre-treated with edible gum coating. This may be due to the formation of a thin layer of gum solution over the chips and led to high moisture content in the chips, (Ranasalva and Sudheer 2017b). The lowest water activity was noticed for VF-carrot chips (0.214), pre-treated with blanching cum drying. This may be caused by moisture removal during drying (Fan *et al.*, 2006). The moisture content and water activity of the chips exhibited the same trend with respect to the pre-treatments. The observed water activity values of VF-carrot chips were below the threshold limit and considered as safe. The results obtained were supported with Ren *et al.*, (2018) and Perez-Tinoco *et al.*, (2008), who observed the closest values of a_w for VF-shiitake mushroom chips (0.38 a_w) and pineapple chips (0.29 a_w), respectively. Ren *et al.* (2018) observed that both vacuum frying as well as atmospheric frying exhibited the safe level of water activity values for storage.

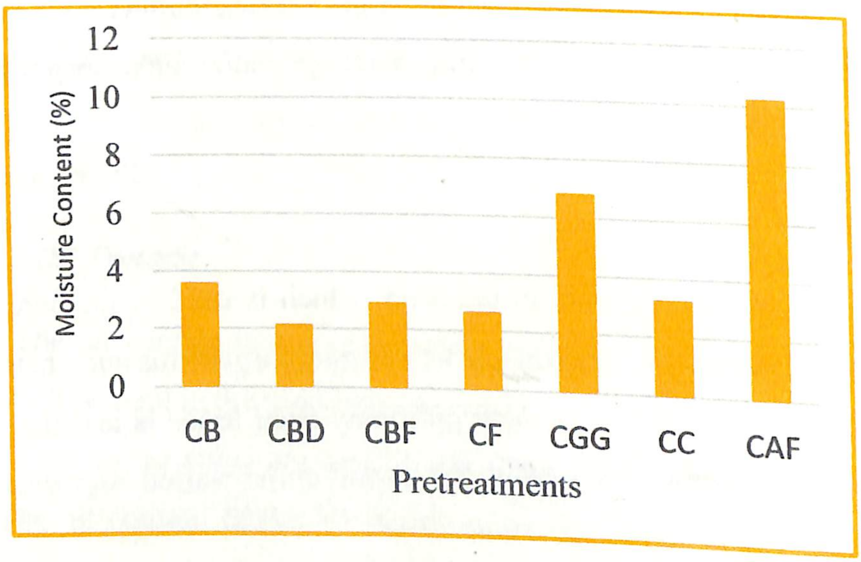


Fig.4.1 Effect of pre-treatment on moisture content of VF-carrot chips

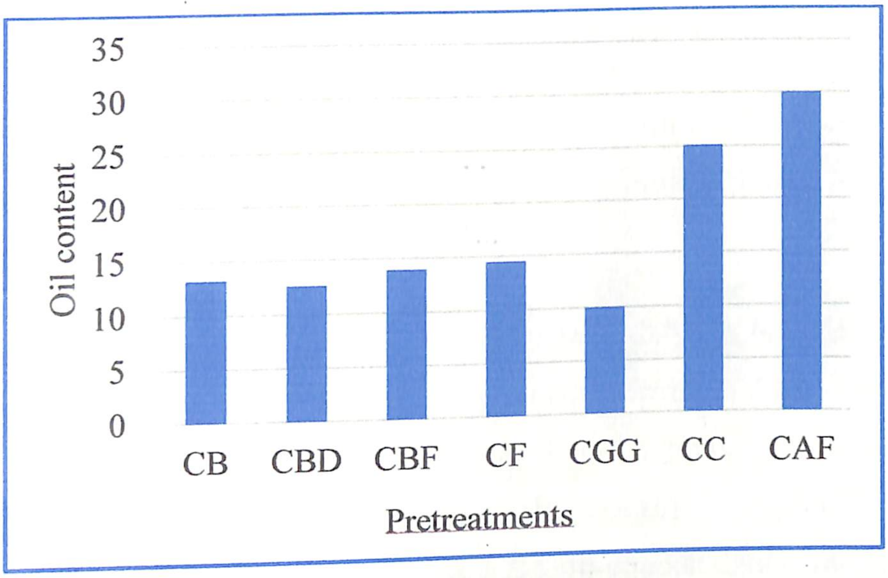


Fig.4.2. Effect of pre-treatments on oil content of VF-carrot chips

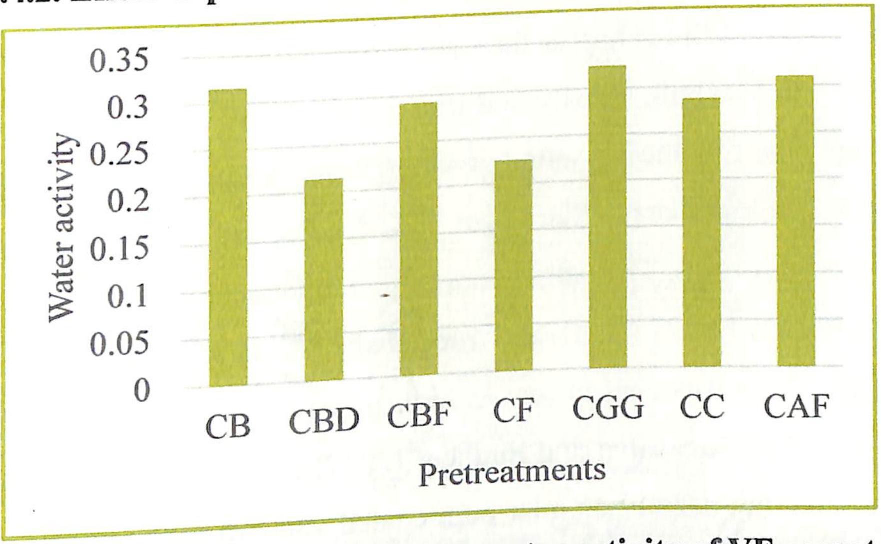


Fig.4.3. Effect of pre-treatments on water activity of VF-carrot chips

Symbolic Represenation of Pretreatments

CB – Blanching

CBD – Blanching cum Drying

CBF – Blanching with Freezing

CF-Freezing

CGG- Edible gum coating

CC- Control (untreated)

CAF-Atmospheric frying

4.2.1.4 Bulk Density & True Density

The effect of pre-treatments on bulk density and true density of VF-carrot chips are tabulated in Table D1.2 (Appendix-D) and graphically depicted in Fig 4.4 and 4.5.

From Fig 4.4 and 4.5, it was recorded that the bulk density and true density of the pre-treated VF-carrot chips ranged from 0.332 to 1.327 g/cm^3 and 1.282 to 1.942 g/cm^3, respectively. The lowest bulk density and true density of 0.332 g/cm^{3}and 1.282 g/cm^3, respectively, were observed in the VF-carrot chips, pre-treated with freezing. Though the oil content was maximum in VF-carrot chips of frozen pre-treatment which added the bulk weight to the chips, the thickness expansion was 3 to 4 times higher than atmospheric fried carrot chips. This might be contributed to low bulk density and true density in VF-carrot chips pre-treated with freezing. The obtained results agreed with Ren *et al.* (2018) who found the pre-treated frozen samples had the lower bulk density and true density for the VF-shiitake mushroom chips. The edible gum coated VF-carrot chips were noted as the highest bulk density (1.327 g/cm^3) and true density (1.942 g/cm^3) compared to other pre-treatments. This was caused due to high moisture content and low thickness expansion in chips. Ranasalva and Sudheer (2017b) obtained the similar trend of bulk density and true density on guar gum coated vacuum fried banana chips. The bulk density and true density of VF-carrot chips of other pre-treatments *viz.*, blanching, blanching cum drying, blanching cum freezing were 0.392, 0.368, 0.374 g/cm^3, and 1.298,1.513,1.421 g/cm^3, respectively. The control sample had the bulk density (0.398 g/cm^3) and true density (1.481 g/cm^3) which were closer to the values of blanching and blanching cum freezing pre-treatments, respectively. Ravli *et al.* (2013) obtained similar results of true density and bulk density for pre-treated VF- potato chips. The atmospheric fried carrot chips were recorded as the highest bulk and true densities as compared to the control and pre-treated VF-carrot chips. The effect of pre-treatments had a significant ($p \leq 0.01$) effect on bulk density and true density of VF-carrot chips.

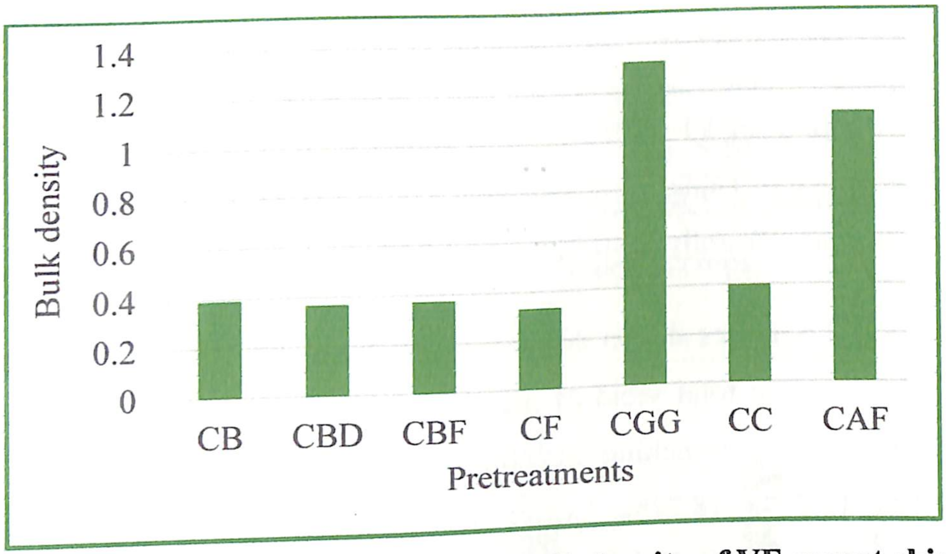


Fig.4.4. Effect of pre-treatments on bulk density of VF-carrot chips

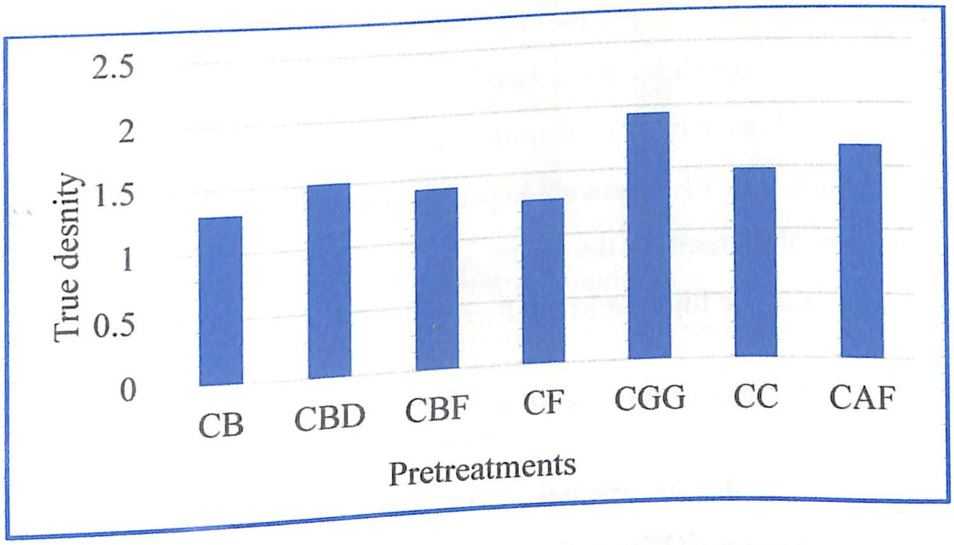


Fig.4.5. Effect of pre-treatments on true density of VF-carrot chips

Symbolic Represenation of Pretreatments

CB – Blanching

CBF – Blanching with Freezing

CGG- Edible gum coating

CAF-Atmospheric frying

CBD – Blanching cum Drying

CF-Freezing

CC- Control (untreated)

4.2.1.5 Total Yield

The total yield of VF-carrot chips is graphically shown in Fig.4.6 and the results are tabulated in Table D1.2(Appendix - D). The total yield of the pre-treated VF-carrot chips significantly ($p<0.01$) varied with pre-treatments.

From Fig 4.6, it was shown that the total yield of VF-carrot ranged between 12.43 to 23.27%. The total yield of pre-treated VF-carrot chips *viz.,* blanching, blanching cum drying, blanching cum freezing, freezing and edible gum coating were 15.38%, 13.33%, 18.21%, 23.27% and 12.43%, respectively. The control (20.45%) and atmospheric fried chips (16.67%) obtained good yield compared to chips with blanching (15.38%) pre-treatment. The highest total yield of 23.27% was observed in the VF-carrot chips, pre-treated with freezing. This may be due to high oil content in the chips which contribute high yield. The lowest total yield of 12.43% and was noted in VF-carrot chips pre-treated with edible gum coating. This may be due to low oil content in the chips. The obtained results agreed with Fan *et al.,* (2006) who found the high yield for frozen pre-treated vacuum fried chips.

4.2.1.6 Textural Changes

The hardness of the pre-treated vacuum fried carrot chips is depicted in Fig.4.7 and the results are shown in the Table D1.2(Appendix-D).

From Fig 4.7, it is observed that hardness of VF-carrot ranged from 1.282 to 1.969 N. The lowest hardness of 1.212 N was obtained in VF-carrot chips pre-treated with freezing. Fan *et al.* 2006 stated that during frying of frozen treated samples, free water between the cells would vaporize, the interspaces left by water evaporation expanded resulted an increase in porosity and reduction in hardness. Arlai *et al.* (2014) reported that VF-okra chips had obtained less hardness value for frozen pre-treated samples. The highest hardness value of 1.969 N was noted in VF-carrot chips, pre-treated with blanching cum drying. This was caused due to removal of moisture before the frying, made the chips was compact and hard. Ren *et al.* (2005) reported that the samples having low hardness values (breaking force) corresponds to high crispiness. The ascending order of hardness values of VF-carrot chips for other pre-treatments *viz.*, blanching cum freezing, blanching and edible gum coating were 1.432N, 1.512N and 1.358 respectively. The control and atmospheric fried chips had the hardness value of 1.301 N and 1.452 N which was lesser than edible gum coated VF-carrot chips. The effect of pre-treatments had a significant (p≤0.01) effect on hardness of the VF-carrot chips.

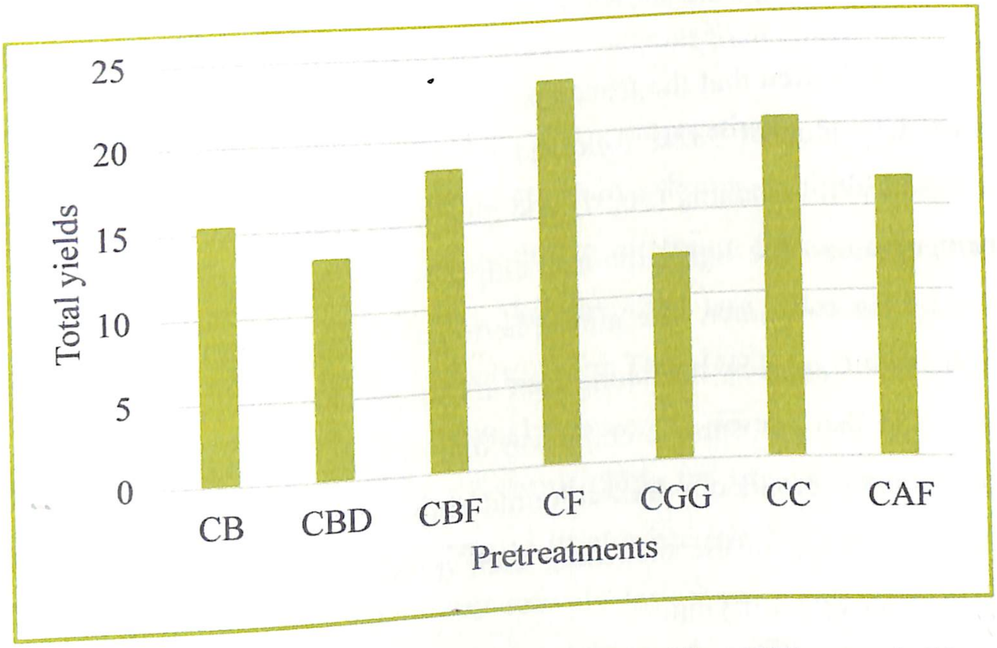


Fig.4.6. Effect of pre-treatments on total yields of VF-carrot chips

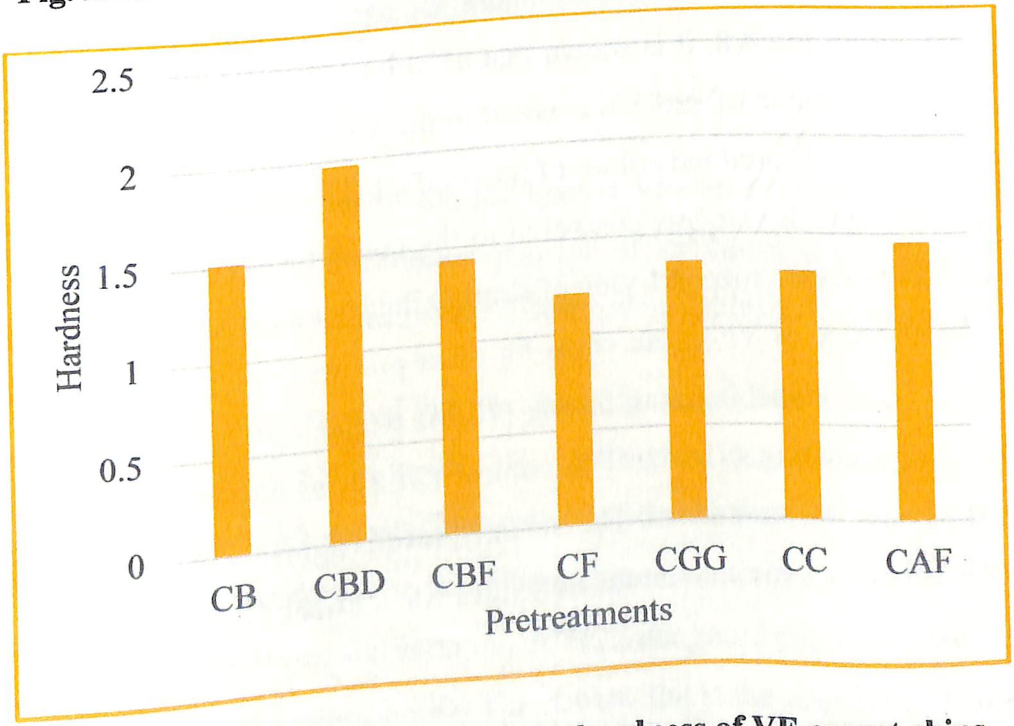


Fig.4.7. Effect of pre-treatments on hardness of VF-carrot chips

4.2.1.7 Color Values

The color values (L*, a* and b*) of the VF-carrot chips varied significantly($p<0.01$) with pre-treatments. The Fig 4.8 represents the effect of the color values of pre-treated VF-carrot chips. The results of the color values of pre-treated VF- carrot chips are shown in Table D1.2(Appendix-D).

Fig 4.8 showed that the frozen pre-treated VF- carrot chips was recorded as maximum L* value of 38.92 followed by the blanching cum freezing (37.38), untreated (37.08), blanching (36.37) and guar gum coated (35.15).The frozen pre-treatment obtained the light-coloured chips, which is a desirable character and accepted by the consumer. The atmospheric fried carrot chips had the lowest L* value (30.28) followed by blanching cum drying pre-treatment (34.58). The lowest value of L* in the atmospheric chips was due to nonuniform frying and frying at high temperatures resulted a dark-coloured chips. Fan *et al.* (2006) stated that L* value was decreased in the blanching cum drying pre-treatment due to loss of carotene content by air drying.

Due to the presence of carotene content, the carrot chips obtained yellowness and redness. From Fig 4.8, it is shown that a* value ranged from 17.24 to 22.85. The maximum a* value of 22.85 was noted in the VF-carrot chips for frozen pre-treatment, which indicated red colour of the product. The atmospheric frying chips had a* (16.44), which was less compared to the control and pre-treatments. This was caused due to non-uniform frying of chips in the frying pan during atmospheric frying. The a* value of VF-carrot chips for other pre-treatments were recorded as blanching (18.02), blanching cum drying (17.24) blanching cum freezing (20.42) and edible gum coating (18.61). The control (21.87) sample had better values compared to other pre-treatments. The obtained results agreed with the Maity *et al.* (2014) who observed the maximum a* values for VF-jackfruit bulbs pre-treated with freezing.

The b* value of the VF-carrot chips was observed maximum for the frozen (27.86) pre-treatment from the Fig.4.8, followed by blanching cum freezing (26.71), control (25.48), edible gum coating (23.94) and blanching (23.28). The minimum b* values was observed in the VF-carrot chips for the blanching cum drying pre-treatment (19.91). The decrease in the b* values might be due to reduction of carotenes present in the carrot chips (Maity *et al.*, 2014). Lin *et al.* (2006) observed the similar trend of results for vacuum fried chips.

The change in color difference was comparatively less in VF than atmospheric fried chips. The pre-treatments hadn't shown significant variation on ΔE value of the VF chips. This may be due to minimum frying temperature and lower pressure during vacuum frying, that favoured less color change in fried product than atmospheric fried products. From TableD1.2(Appendix D), it was observed that change in color was ranged between 11.15 to 22.8. The change in color was found lowest (11.15) in VF-carrot chips for frozen pre-treatment and highest color change (22.8) was observed in atmospheric fried chips. The color variation on vacuum frying was comparatively less than atmospheric fried VF-carrot chips. Maity *et al.* (2014) reported similar results on the colour analysis of vacuum and atmospheric fried jackfruit bulbs.

4.2.1.8 Thickness Expansion

The thickness expansion of the pre-treated VF-carrot chips had significant effect at 1% ($p \leq 0.01$). The thickness expansion of VF-carrot chips is graphically represented in Fig.4.9 and the results are displayed in TableD1.2(Appendix-D).

From Fig 4.9, it is revealed that the thickness expansion of pre-treated VF-carrot chips ranged from 65.38 to 85.82%. The highest thickness expansion of - 85.82% was obtained in VF-carrot chips, pre-treated with freezing. The increase in the thickness expansion was due to more temperature and pressure gradient during frying. Similar trend of thickness variation in VF-bitter gourd chips pre-treated with freezing was stated by Pooja (2018). The lowest thickness expansion values of 65.38% was observed in the carrot chips pre-treated with edible gum coating. This was caused due to the thin layer of gum solution over the chips which reduced the expansion during vacuum frying. The obtained thickness expansion values on edible gum coated pre-treatments were in agreement with the Ranasalva and Sudheer (2017b) for VF- banana chips. The thickness expansion of VF-carrot chips of other pre-treatments *viz.,* blanching, blanching cum drying and blanching cum freezing were 70.24%, 68.23%, 80.5%, respectively. The control as well as atmospheric fried chips had the thickness expansion of 78.52% and 69.54, respectively. This may be caused due to differences in frying temperature and time.

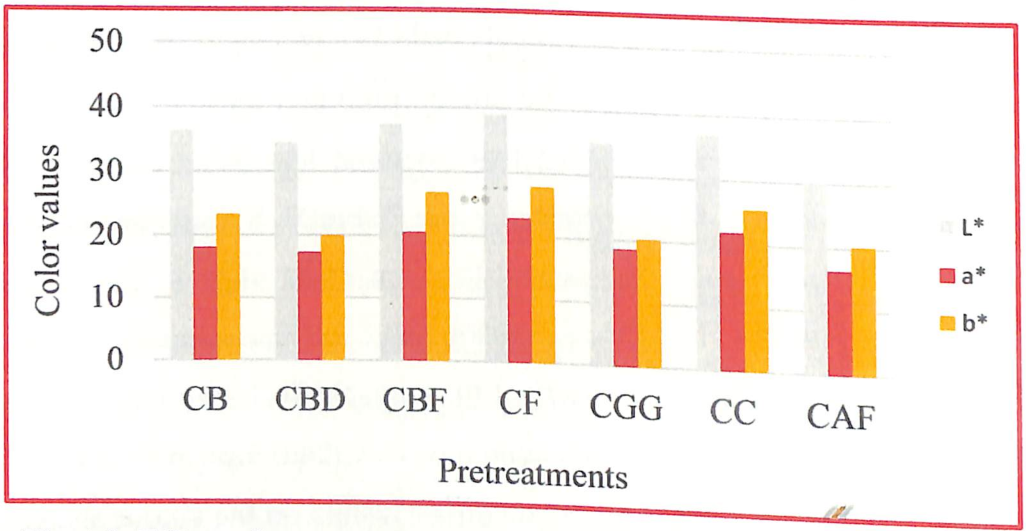


Fig.4.8. Effect of pre-treatments on color values of VF-carrot chips

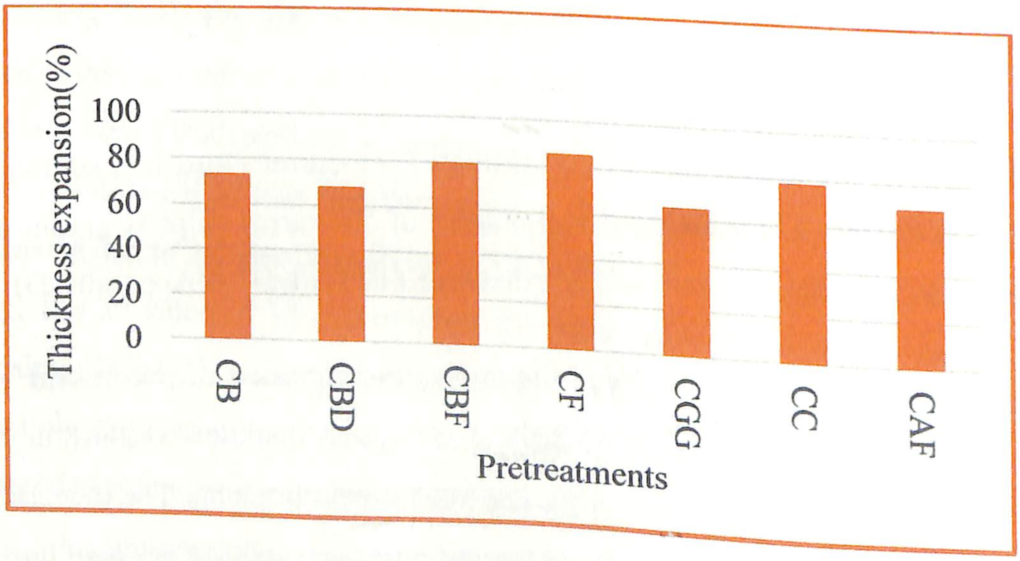


Fig.4.9. Effect of pre-treatments on thickness expansion of VF-carrot chips

4.2.1.9 Sensory Analysis

The consumer's acceptability of pre-treated VF carrot chips is described in this section. The sensory score of vacuum fried carrot chips of various pretreatments is shown in Fig. 4.10. The fuzzy logic sensory evaluation also conducted to obtain the order of ranking of carrot chips. The highest sensory score was noted for pretreated VF carrot chips compared to the control and atmospheric fried chips. The pretreatments freezing (9.0) and blanching cum freezing (8.7) were noted as the highest overall acceptability followed by other pre-treatments namely blanching (8.3) and blanching cum drying (7.6) for VF-carrot chips. The lowest sensory score was observed in atmospheric fried chips (5.8) followed by VF-carrot chips the edible gum coated sample (6.1) and untreated sample (6.7). For freezing pretreated sample, all the sensory attributes like color and appearance (8.8), texture (8.6), flavor (8.5), taste (8.8) and overall acceptability (9.0) recorded as highest values. Pre-treatments of blanching cum freezing and blanching samples have similar values. The order of ranking of the pre-treated VF-carrot chips is shown in Table 4.2. The fuzzy logic ranking for pre-treated vacuum fried carrot chips were CF>CBF=CB>CC>CBD>CGG>CAF (Frozen > Blanching cum freezing = blanching > Untreated > Blanching cum drying > Edible gum coating> atmospheric fried). The frozen VF carrot chips had a superior quality characteristic compared to other pre-treated samples.

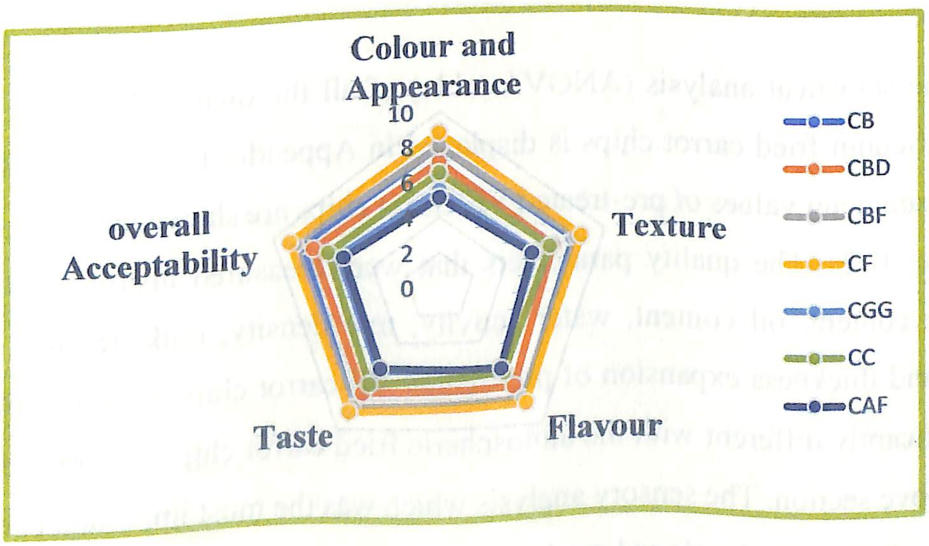


Fig.4.10. Effect of pre-treatments on sensory scores of VF-carrot chips

CB CBD CBF CF

CGG CC CAF

Plate 4.1 Pre-treated VF- chips

Symbolic Represenation of Pretreatments

CB – Blanching CBD – Blanching cum Drying

CBF – Blanching with Freezing CF-Freezing

CGG- Edible gum coating CC- Control (untreated)

CAF-Atmospheric frying

The statistical analysis (ANOVA table) of all the quality attributes of pre-treated vacuum fried carrot chips is displayed in Appendix D3. All the results of quality parameter values of pre-treated VF-carrot chips are shown in the Appendix-D (Table.D1.2). The quality parameters that were measured instrumentally *viz.*, moisture content, oil content, water activity, true density, bulk density, colour, texture and thickness expansion of pre-treated VF-carrot chips were illustrated to be significantly different with the atmospheric fried carrot chips and are discussed in the above section. The sensory analysis which was the most important parameter of marketability of a developed product. The atmospheric fried chips were rejected from the consumers based on the sensory attributes. Based on the results of quality attributes and sensory scores of pre-treated VF carrot chips, freezing pre-treatment was selected for conducting the further experiment.

Table 4.2 Fuzzy ranking of pre-treated VF-carrot chips

Treatments	Ranking of sensory attributes
CB	Taste>OA>C&A=Flavour>Texture
CBD	OA>Taste>Texture>C&A=Flavour
CBF	Taste>C&A>OA>Flavour>Texture
CF	OA>Taste>C&A>Texture=Flavour
CGG	C&A=Flavour>Taste=OA>Texture
CC	Flavour=Taste>OA>C&A>Texture
CAF	Flavour>Taste>OA>Texture>C&A

*(OA-overall acceptability and C&A – colour and appearance)

EXPERIMENT – III

4.3 STANDARDIZATION OF PROCESS PARAMETERS FOR VACUUM FRYING OF CARROT CHIPS

The central composite randomized experimental design was selected to find out the best combination of process parameters in the present vacuum frying process. The vacuum fried carrot chips were developed by vacuum frying with different combination of temperature, pressure and time as explained in section 3.3. The process parameters *viz.,* temperature, pressure and time were optimised based on the quality of the final product and sensory evaluation. Twenty experiments were conducted, and the quality of the fried products was studied concerning the physical and nutritional components. Analysis of variance (ANOVA) was studied to carry out the significant effects of independent variables on each dependent variable.

4.3.1 Effect of Process Parameters on Quality of Vacuum Fried Carrot Chips

The effect of process parameters (temperature, pressure, and time) on quality of vacuum fried carrot chipswere analyzed and discussed in the following section. The vacuum fried carrot chips prepared under different process parameters are depicted in Plate 4.2. The atmospheric fried chips fried at 185°C was considered as control sample for sensory evaluation.

4.3.1.1 Moisture Content

The effects of process parameters on moisture content of VF-carrot chips are presented in Table E1.2 (Appendix – E). Also, 3D graphs representing the response surface generated by the model (Equation. 4.1) are depicted in Fig.4.11.

Analysis of variance (Table E2.1) showed the process parameter *viz.,* frying temperature had high significant effect ($p \leq 0.01$) on final product moisture content, whereas pressure and time had a significant effect($p \leq 0.05$) on moisture content of the product. Also the second order interaction level between temperature, time and moisture content also found to be highly significant ($p \leq 0.01$). The R- squared value of the model was 0.97.

From Fig 4.11, it was found that the moisture content of the product varied between 0.656 % to 3.28 % (w.b). The maximum value of moisture content was obtained at 100⁰C frying temperature, 11kPa vacuum pressure and 16 min frying time whereas minimum obtained at 120⁰C frying temperature, 15 kPa vacuum pressure and 20 min frying time, respectively.

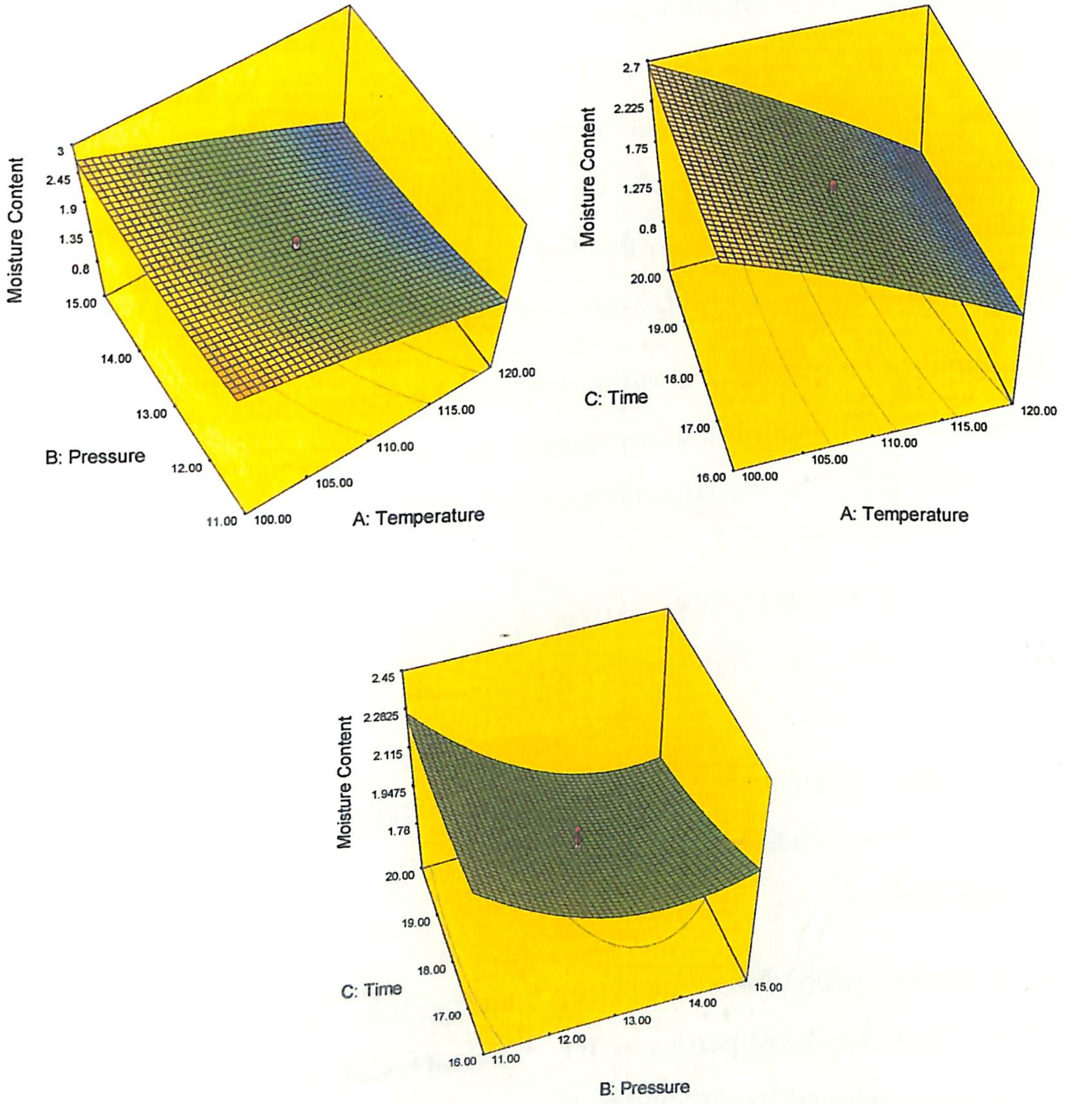


Fig. 4.11. Effect of changes in moisture content of VF-carrot chips with different process parameters

From Table E1.2(Appendix-E), it was found that frying temperature and time exerted a negative influence on moisture content of VF chips. The final moisture content of the VF chips decreased from 3.28 to 0.656 % (w.b) as the frying temperature increased from 100^0C to 120^0C and frying time increased from 16 to 20 min. Identical findings also described by Pandey and Chouhan (2017) for vacuum fried papaya chips and Tarzi *et al.*, (2011) for vacuum fried mushroom chips.

The vacuum pressure was found to be a positive effect on the product moisture content. As the vacuum pressure decreased from 15 kPa to 11 kPa, the moisture content of VF chips decreased from 3.28 % to 0.656 %. It may be due to the lowering of boiling point of moisture, so that the unbound water in the chips could be removed quickly, when the oil temperature reached the boiling point of water. Identical results were described by chen *et al.* (2014) for vacuum fried desalted grass crap fillets and Mehrjardi *et al.* (2012) for pumpkin chips.

A second-order quadratic equation was fitted between independent variables and moisture content using the experimental values. Following regression model are obtained to predict the moisture content of vacuum fried carrot chips.

$$MC = 1.91 - 0.7613\,X_1 + 0.1759\,X_2 - 0.0760\,X_3 + 0.1064\,X_1X_2 - 0.0809\,X_1X_3 - 0.0644\,X_2X_3 - 0.0486\,X_1^2 + 0.1642\,X_2^2 - 0.0329\,X_3^2 \ldots\ldots(4.1) \qquad (R^2 = 0.97)$$

Where

MC = Moisture content (%); X_1 = temperature (^0C)

X_2 = Pressure (kPa) ; X_3 = Time (min)

4.3.1.2 Water Activity

The effects of process parameters on water activity of VF-carrot chips are presented in Table E1.2 (Appendix – E). Also, 3D surface plot displayed the response surface generated by the model (Equation. 4.2) are depicted in Fig.4.12.

The results were statistically analysed and presented in Table E2.2. ANOVA table indicate that process parameters affected the water activity of VF carrot chips significantly @1% (frying temperature) and 5% (vacuum pressure and frying time), respectively. Also, the second order interaction level between temperature, time and vacuum pressure also found to be significant (p≤ 0.05). The R- squared value of the model was 0.94.

From Fig 4.11, it was observed that the water activity of the products varied from0.212 to 0.384. The maximum value of water activity obtained at 100⁰C frying temperature, 11kPa vacuum pressure and 16 min frying time whereas minimum obtained at 120⁰C frying temperature, 15kPa vacuum pressure and 20 min frying time, respectively.

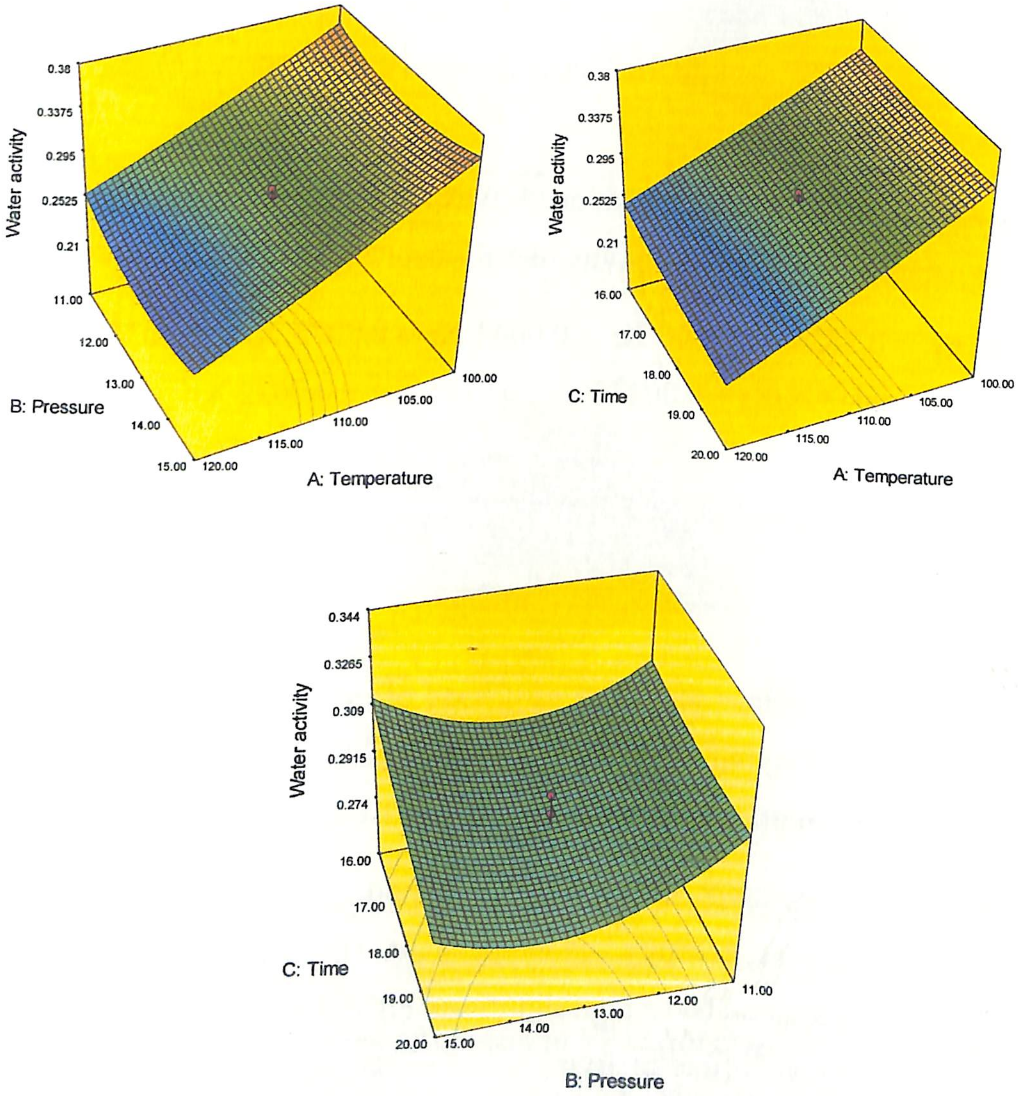


Fig. 4.12. Effect of changes in water activity of VF-carrot chips with different process parameters

From Table E1.2, it was found that frying time and temperature exerted an inverse relationship with water activity of VF chips. The water activity values of the VF chips decreased from 0.384 to 0.212 as the frying temperature increased from 100^0C to 120^0C and frying time increased from 16 to 20 min. Identical findings also described by Pooja (2018) for vacuum fried bitter gourd chips and Perez-Tinoco *et al.* (2008) for vacuum fried pineapple chips.

The vacuum pressure was found to have a positive effect on the product water activity. As the vacuum pressure decreased from 15 kPa to 11 kPa, the moisture content of VF chips decreased from 0.384 to 0.212. Identical results were noticed by Maity *et al.* (2014) for vacuum fried jackfruit chips and Shyu and Hwang (2001) for vacuum fried apple chips.

The second-order quadratic equation (4.2) explained the relationship between the process parameters and water activity of VF-carrot chips:

$$\text{Water activity} = 0.2856 - 0.0566\,X_1 + 0.0044\,X_2 - 0.0075\,X_3 - 0.0035\,X_1X_2 + 0.0043\,X_1X_3 - 0.0053\,X_2X_3 + 0.0027\,X_1^2 + 0.0165\,X_2^2 + 0.0022\,X_3^2 \quad .....(4.2)$$

$(R^2 = 0.94)$

Where, X1 = temperature (^{0} C); X2 = Pressure (kPa); X3 = Time (min)

4.3.1.3 Oil Content

The Fig. 4.13 displays the effect of change of oil content in vacuum fried carrot chips at various frying conditions. The oil content of vacuum fried chips at different operating conditions are tabulated in Table E1.2 (Appendix – E).

Analysis of variance (Table E2.3) showed that oil content strongly dependent on frying time, pressure and temperature. The process parameters *viz.*, frying time and temperature had a high significant effect ($p \leq 0.01$) on oil content of VF carrot chips, but the effect of frying pressure on oil content was significant @5%(($p \leq 0.05$). Also, the second level interactions between the process parameters were also found to be highly significant. Frying time and temperature had a possive relationship with oil content. The R- squared value of the model was 0.95.

The oil content of vacuum fried carrot chips ranged from 11.31 to 23.3 % at different operating conditions. The oil content obtained at 100^0C frying temperature, 11kPa vacuum pressure and 16 min frying time was found to be minimum where as maximum obtained at 120^{0}C frying temperature, 15kPa vacuum pressure and 20 min frying time, respectively.

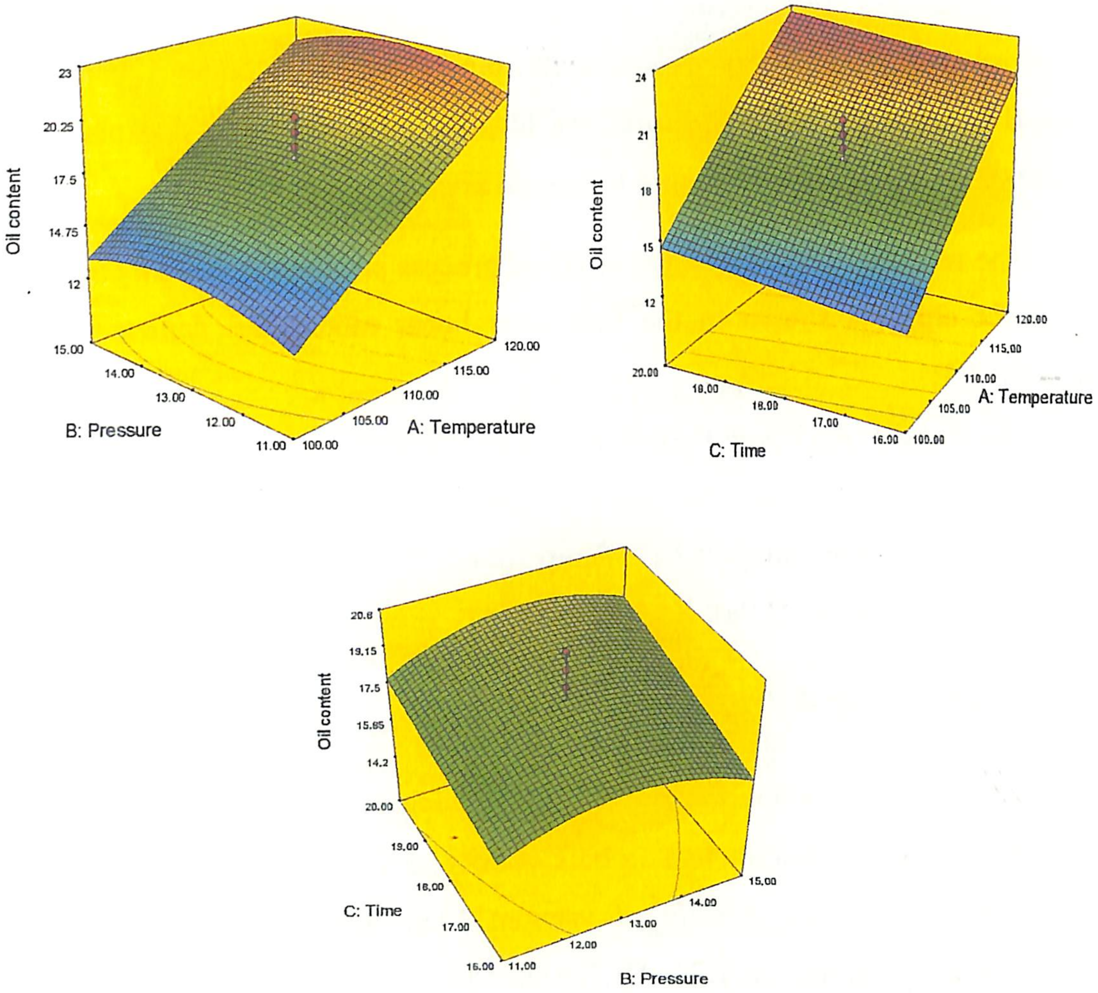


Fig. 4.13 Effect of changes in oil content of VF-carrot chips with different process parameters

Fig E1.2 showed that the oil content in VF carrot chips increased significantly with an increase in frying temperature and time. The oil content of the VF chips increased from 11.31 to 23.3 % with an increase in the frying temperature(100-120^{0}C) and frying time (16-20 min). The absorption of oil content was found to be related to the loss of moisture from the chips during frying process. This was due to the diffusion gradient created by the loss of moisture during frying. The results are in agreement with Yagua and Moreira (2011) for vacuum fried potato chips and

Pooja (2018) for vacuum fried bitter gourd chips who have reported an increase in oil content with an increase in frying temperature and frying time.

The vacuum pressure was observed to have a positive effect on oil content of VF-carrot chips. As the pressure increased from 11 to 15 kPa, the oil content of the chips also increased from 11.31 to 23.3%. Identical observations were explained by Diamante *et al.* (2011) for vacuum fried gold kiwifruit.

The relationship between the effect of process parameters and oil content of VF-carrot chips is shown in the first-order linear model and depicted by the equation 4.3:

$$OC = 18.61 + 4.41\ X_1 + 0.1841\ X_2 + 0.8011\ X_3 \quad ....(4.3) \qquad (R^2 = 0.95)$$

Where,

OC = Oil content (%); X_1 = Temperature (^0C)

X_2 = Pressure (kPa); X_3 = Time (min)

4.3.1.4 Bulk Density & True density

Bulk density is a measurable index of the degree of expansion of VF chips. The effect of process parameters on bulk density of VF carrot chips are displayed in Fig. 4.14. The bulk density of vacuum fried chips at different operating conditions are illustrated in Table E1.2(Appendix – E).

Analysis of variance (Table E2.4) showed that the process parameters viz., frying temperature ($p \leq 0.01$), frying pressure(($p \leq 0.01$) and frying time ($p \leq 0.05$) had a significant effect on bulk density of VF carrot chips with an R- squared value of 0.93.

The variations of bulk density mainly depend on the moisture content and oil content of VF-carrot chips. From Table E1.2, the bulk density of VF-carrot chips varied between 0.284 to 0.873 g/cm^3. The minimum and maximum value of bulk density of vacuum fried carrot chips was recorded at operating conditions of 120^{0}C frying temperature, 15 kPa frying pressure, 20 min frying time and 100^{0}C frying temperature, 11kPa frying pressure,16 min frying time, respectively.

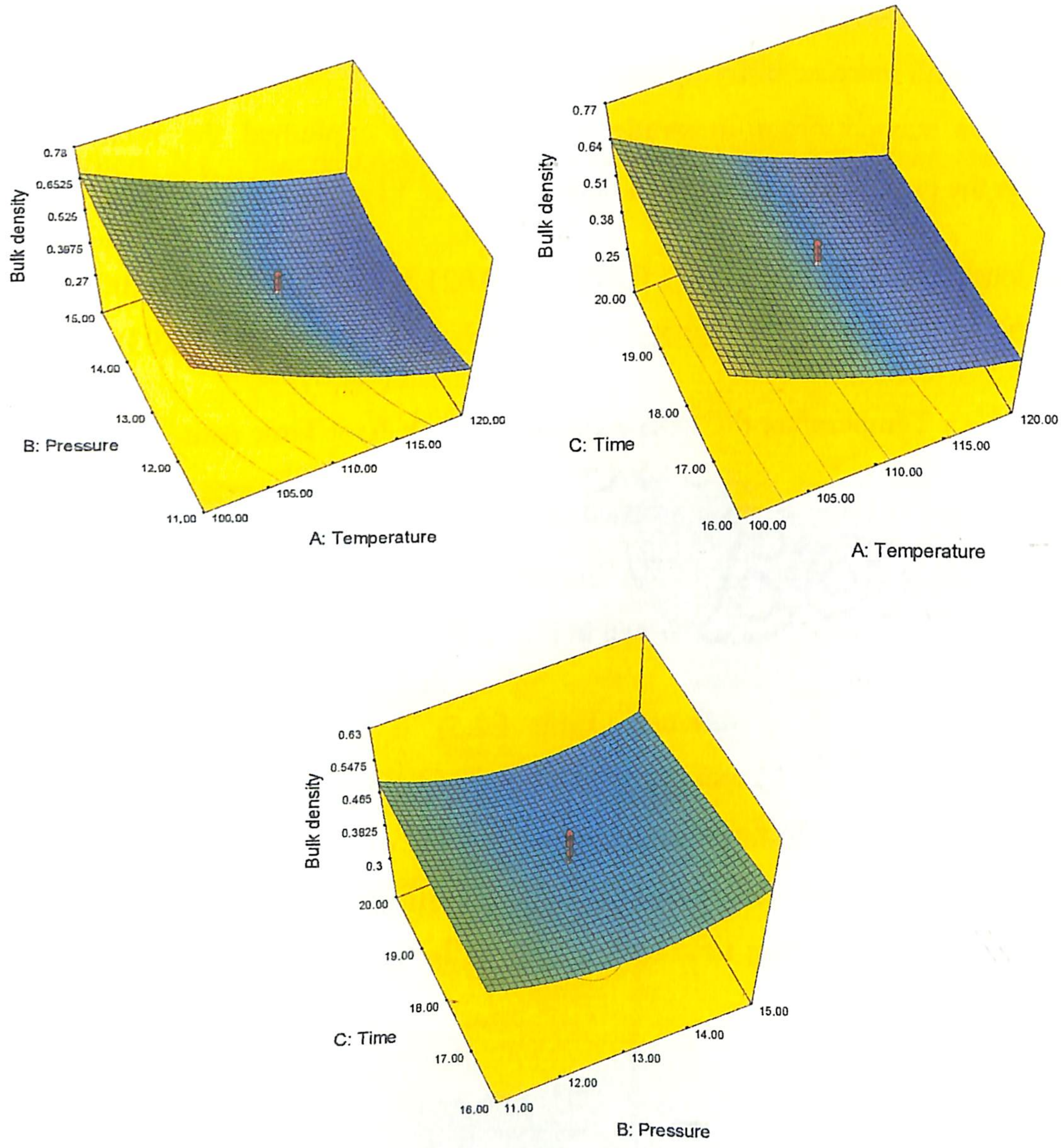


Fig. 4.14 Effect of changes in bulk density of VF-carrot chips with different process parameters

From Table E2.4, it is understood that the bulk density of VF-carrot chips exhibited an inverse relation with frying temperature, frying time and frying pressure. Initially, the bulk density was more at 100^{0}C and then reached a lower value at 120^{0}C frying temperature. The decrease in the bulk density value during high frying temperature was due to low moisture content and high expansion ratio (Maneerote *et al.*, 2009). The results were in agreement with the findings of Yagua and Moreira (2011) who reported that bulk density of vacuum fried potato chips decreased with increase in frying temperature.

The second order quadratic equation (4.4) explained the relationship between the process parameters and bulk density of VF-carrot chips:

Bulk density = $0.435 - 0.196\,X_1 - 0.016\,X_2 - 0.021\,X_3 + 0.029\,X_1X_2 - 0.005\,X_2X_3 - 0.01\,X_1X_3 + 0.038\,X_1^2 + 0.059\,X_2^2 + 0.012\,X_3^2$ ....(4.4) $(R^2 = 0.93)$

Where, X_1 = Temperature (^{0}C); X_2 = Pressure (kPa); X_3 = Time (min)

The true density of vacuum fried chips at different operating conditions are shown in Table E1.2(Appendix – E). The corresponding 3D graphs representing the response surface generated are shown in Fig. 4.15.

From analysis of variance (Table E2.5), it was apparent that process parameters *viz.,* frying temperature ($p \leq 0.01$), frying pressure($p \leq 0.01$) and frying time ($p \leq 0.05$) had a significant effect on true density of VF carrot chips with an R-squared value of 0.89. Also, all independent variables *viz.,* frying temperature, frying pressure and frying time had a negative influence on true density of VF-carrot chips (Eqn 4.5).

From Fig 4.15, it is shown that the true density of VF-carrot chips ranged from 0.842 to 1.714 g/cm^3 at different operating conditions. The minimum and maximum true density of VF-carrot chips were identified at operating conditions of frying temperature 120^{0}C, frying pressure 15 kPa, frying time 20 min and frying temperature 100^{0}C, frying pressure 11kPa and frying time 16 min, respectively. The increase in true density during frying was attributed to mass transfer phenomena as a result of water loss (Krokida *et al.,* 2000). Identical results was described by Moreria (1995) for vacuum fried tortilla chips.

The second order quadratic equation (4.5) explained the relationship between the process parameters and true density of VF-carrot chips:

True density = $1.17 + 0.3079\, X_1 + 0.021\, X_2 + 0.042\, X_3 + 0.027\, X_1X_2 - 0.008\, X_2X_3 - 0.005\, X_1X_3 + 0.032\, X_1^2 + 0.074\, X_2^2 + 0.0013\, X_3^2$ ……4.5 $(R^2 = 0.89)$

Where, X1 = Temperature (^{0}C) ; X2 = Pressure (kPa) ; X3 = Time (min)

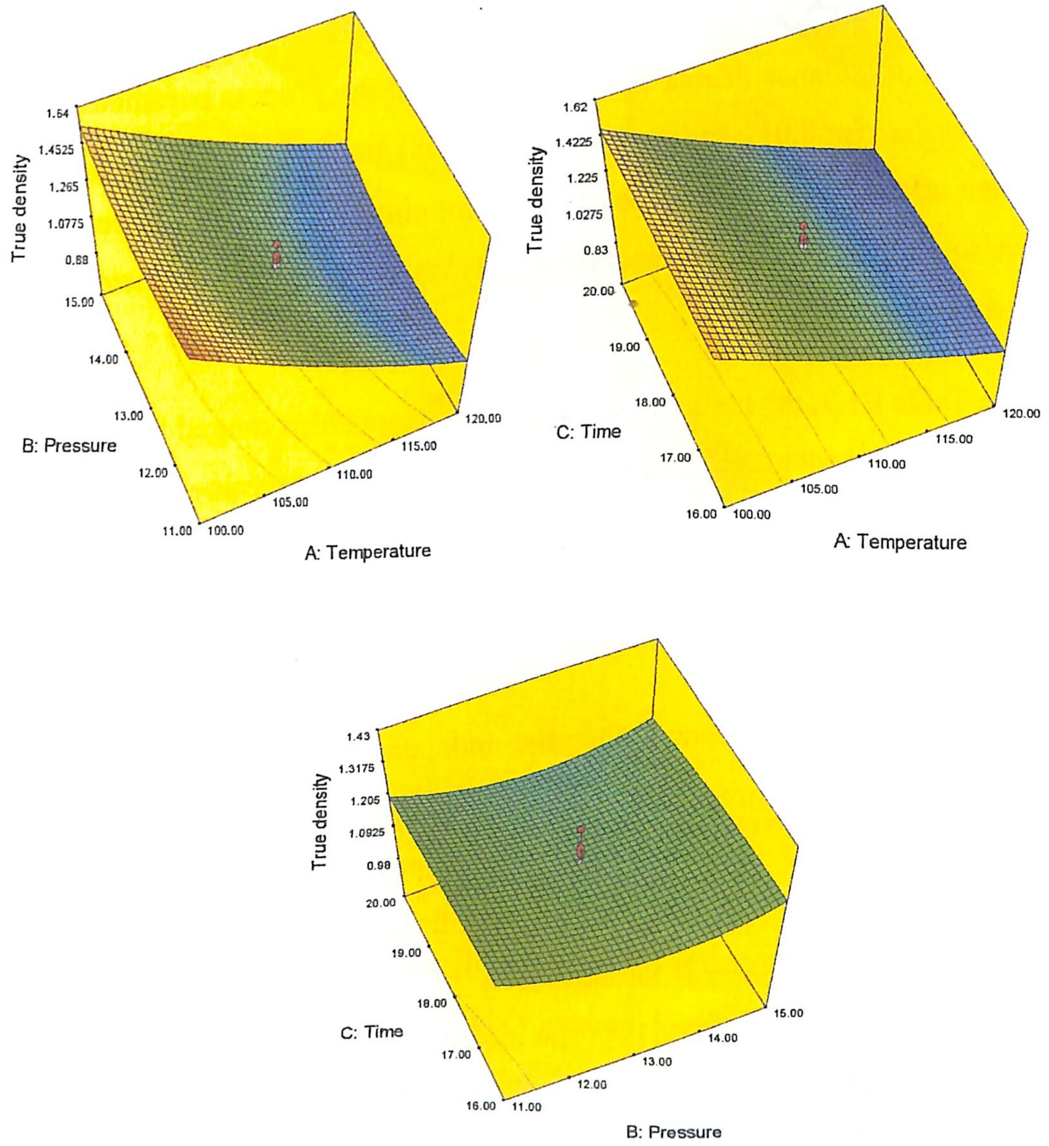


Fig. 4.15 Effect of changes in true density of VF-carrot chips with different process parameters

4.3.1.5 Textural Changes

Hardness is one of the most important textural property which indicates the peak force requires to compress a fried product (Mehrjard *et al.* 2012). The surface plot for hardness values of VF-carrot chips at different processing conditions are shown in Fig. 4.16. The hardness of vacuum fried chips at different operating conditions is also depicted in Table E1.2 (Appendix – E).

Analysis of variance (Table E2. 6), showed that the process parameters *viz.*, frying temperature ($p \leq 0.01$), frying pressure(($p \leq 0.05$) and frying time ($p \leq 0.01$) had a significant effect on hardness value of VF carrot chips with an R- squared value of 0.96. Also, the second order interactions levels between process parameters were also found to be significant.

From Table E1.2, the hardness values of VF-carrot chips ranged from 1.31 to 3.67 N at different process conditions. The highest hardness value of VF-carrot chips was noted at frying temperature of 120^{0}C, frying pressure of 15 kPa and frying time of 20 min. Similarly, the lowest hardness value of vacuum fried carrot chips was observed at 100^{0}C, 11kPaand 16 min.

From Fig 4.16, it is known that the independent variables *viz.*, frying temperature, vacuum pressure and time had a positive effect on hardness of VF chips. The hardness of VF chips increased significantly from 1.31 to 3.67 N with increase in frying temperature (100^{0}C-120^{0}C) and frying time (16 to 20 min). This phenomenon may be attributed to decreased in moisture content at greater temperature and time (Pan *et al.* 2015). The moisture content of the final product had inverse proportional with time and temperature (Bello *et al.*, 2010). Identical results described by Diamante *et al.* (2011), stated that the hardness value increased with increase in frying time and temperature in vacuum fried apricot slices.

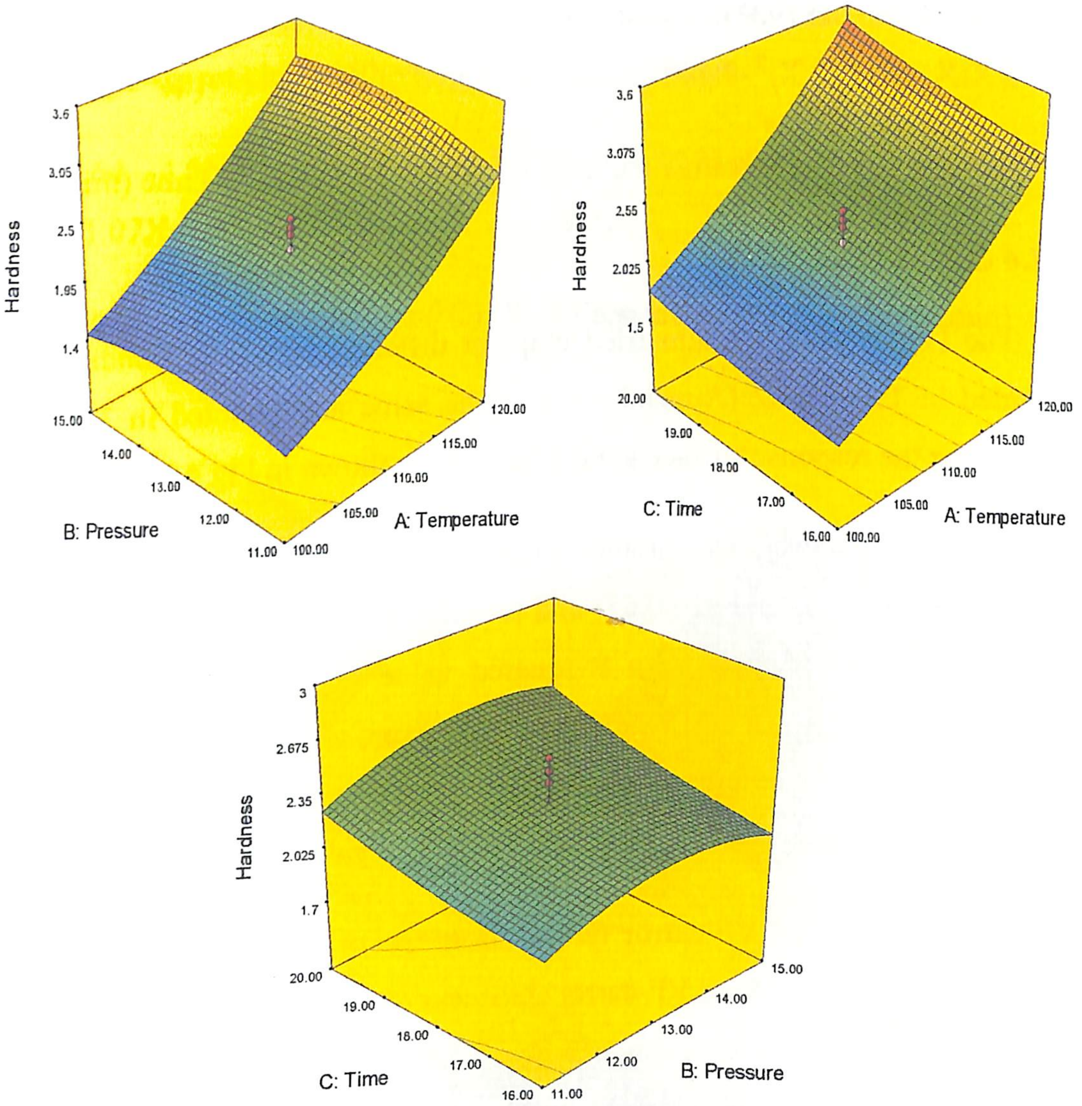


Fig. 4.16. Effect of changes in hardness of VF-carrot chips with different process parameters

The vacuum pressure also had a possive effect on hardness of VF-carrot chips. The VF chips produced at higher vacuum levels had showed higher hardness values (Ravli *et al.*, 2013). Hardness of the chips decreased from 3.67 N to 1.31 N as the vacuum pressure decreased from 15 kPa - 11kPa. Identical results was observed by Esan *et al.* (2015) for VF-sweet potato chips.

The changes in hardness values with different frying conditions was determined by using the second-order quadratic model and represented by the equation 4.6:

Hardness = $2.30 + 0.7983\ X_1 + 0.063\ X_2 + 0.1537\ X_3 + 0.080\ X_1X_2 - 0.047X_2X3 + 0.0275\ X_1X_3 + 0.1292\ X_1^2 - 0.146\ X_2^2 - 0.046X_3^2$ ....(4.6) $(R^2 = 0.96)$

Where, X_1 = Temperature (^{0}C); X_2 = Pressure (kPa); X_3 = Time (min)

4.3.1.6 Color Values

The L* value of vacuum fried chips at different operating conditions are illustrated in Table E1.2 (Appendix – E). The same are depicted in 3D graphs representing the response surface generated and are shown in Fig 4.17.

From the Analysis of variance (Table E2.7), it is concluded that frying temperature ($P \leq 0.01$), time ($P \leq 0.05$) and pressure ($P \leq 0.05$) had significant effect on L* values of VF chips with R-squared value of 0.92. The second order interaction levels between the process parameters were also found to be significant. From equation 4.7, it is noticed that the independent variables *viz.,* frying time, temperature and pressure had a negative effect on L* value of carrot chips.

The L* value of VF-carrot ranged from 29.28 to 43.48 (Fig. 4.17).The minimum L* value (29.28) of VF-carrot chips was observed at operating conditions of frying temperature 120^{0}C, frying pressure 15kPa and frying time 20 min whereas maximum L* value (43.48)of carrot chips was obtained at frying conditions of 100^{0}C frying temperature,11kPa frying pressure and 16 min frying time.

The L* values of VF chips decreased significantly from 43.48 to 29.28, with increased in frying temperatures (100-120^{0}C), pressure(11-15kPa) and frying time (16-20 min). Mariscal and Bouchon (2008) reported that VF-apple slices changed to dark coloured chips due to maillard reactions at higher temperatures and frying time. Identical results were described by Ranasalva (2017) for VF-banana chips and Maity *et al.* (2017) for VF-jackfruit chips. The lower L* value in VF carrot chips fried at higher frying temperature might be due to maillard reaction occurred during frying process.

The second-order quadratic model showed (Eqn 4.7) the best fit for the L* value of VF-carrot chips with various frying conditions.

$$L^* = 38.64 - 4.56\,X_1 - 0.2927\,X_2 - 0.2659\,X_3 + 0.0275\,X_1X_2 + 0.1975\,X_2X_3 - 0.4750\,X_1X_3 - 1.07X_1^2 - 1.17X_2^2 - 0.067X_3^2 \;\ldots\ldots..(4.7) \qquad (R^2 = 0.92)$$

Where X_1 = Temperature (^{0}C); X_2 = Pressure (kPa); X_3 = Time (min)

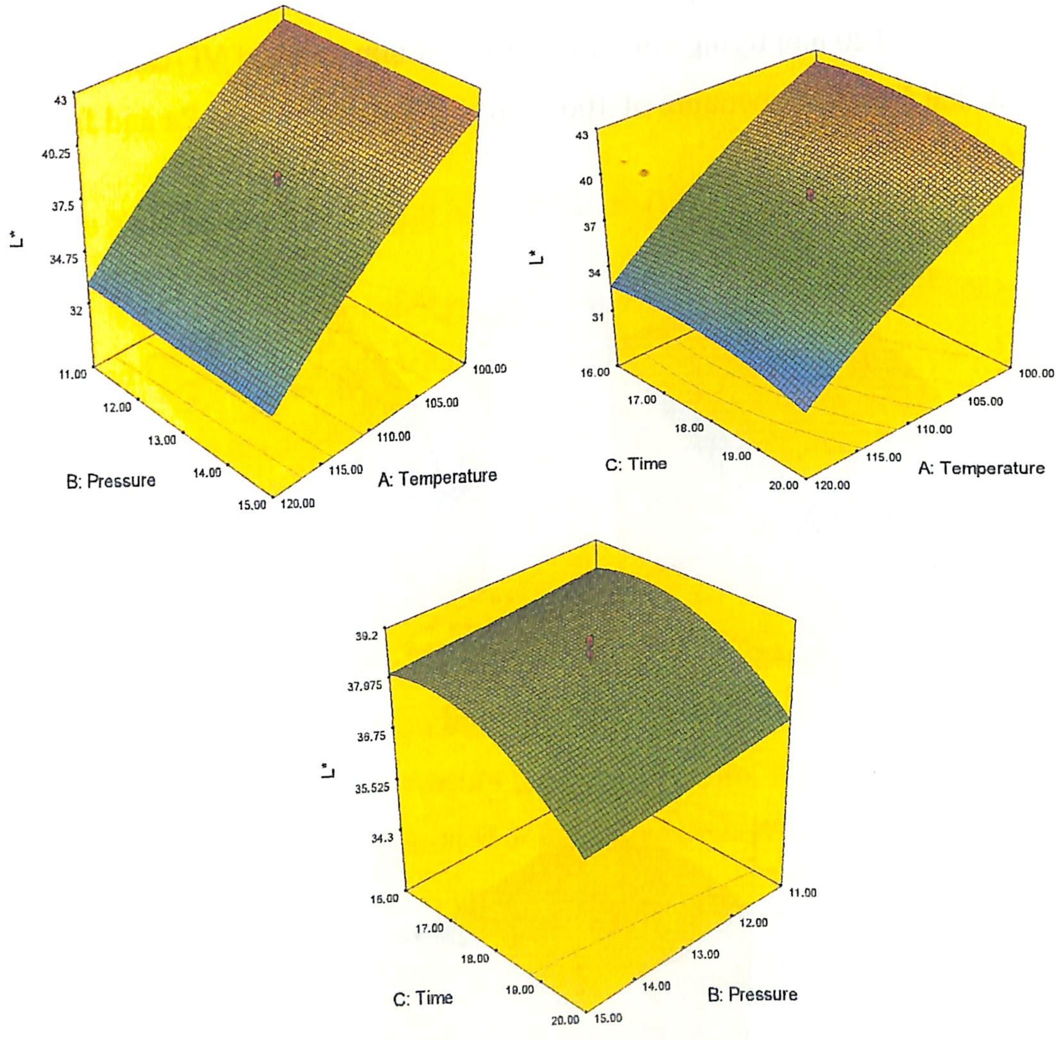


Fig. 4.17. Effect of changes in L* of VF-carrot chips with different process parameters

The effect of process parameters on a* value are tabulated in the Table E2.8 (Appendix-E) and the 3D graphs representing the response surface are depicted in Fig. 4.18.

From the analysis of variance (Table E2.8), it is apparent that all the process variables *viz.*, frying temperature ($p \leq 0.01$), time ($p \leq 0.05$) and pressure ($p \leq 0.05$) had a positive influence on a* value of VF chips with an R-squared value of 0.90. The second order interactions between the process parameters were also found to be significant.

The colour value a* represents the redness of the product. The colour value a* of VF-carrot chips ranged from 14.36 to 27.11. The maximum a* value of carrot chips was obtained at processing conditions of 120^{0}C frying temperature ,15kPa frying pressure and 20 min frying time whereas the minimum a* of VF-carrot chips was obtained at frying temperature of 100^{0}C, frying pressure of 11kPa and frying time of 16 min.

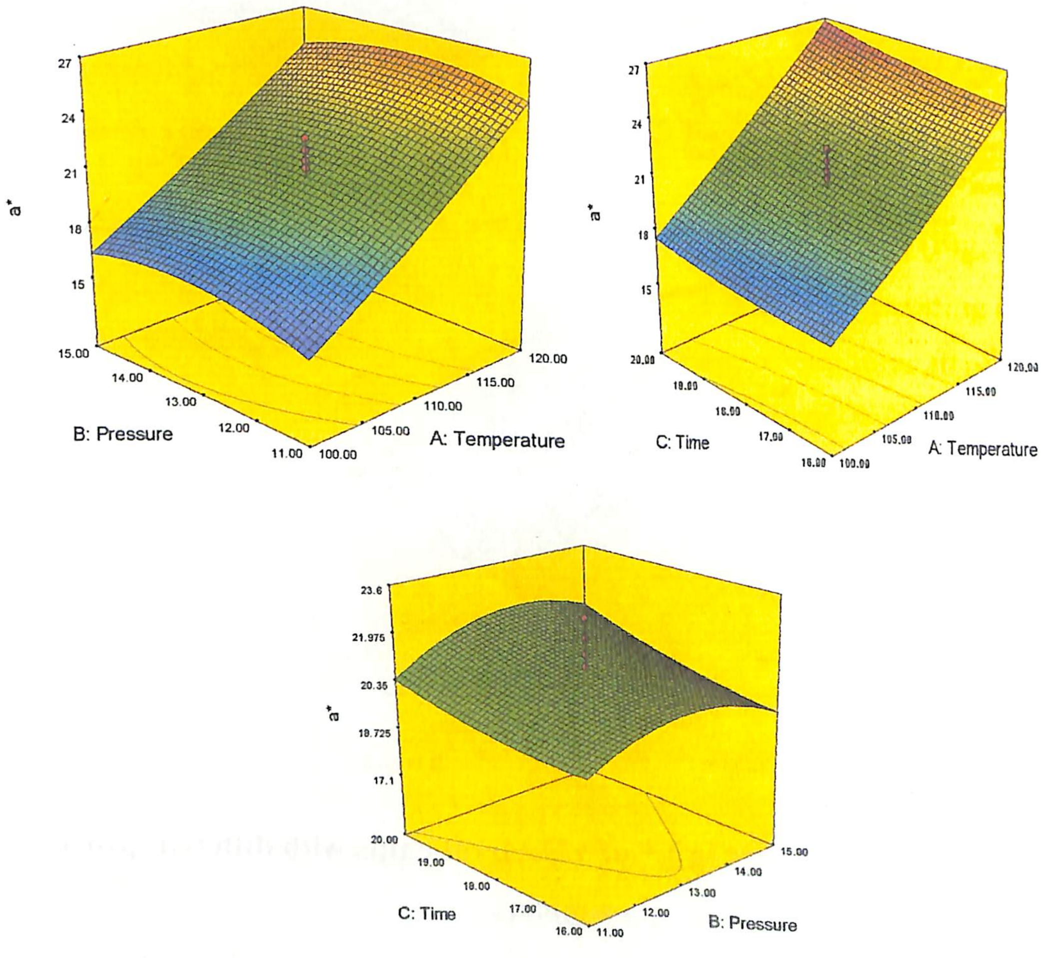


Fig. 4.18. Effect of changes in a* of VF-carrot chips with different process parameters

From Fig 4.18, it is seen that a* values increased from 14.36 to 27.11 with increase in frying temperature of 100-120⁰C and frying time of 16-18 min. The higher a* values at higher frying temperature might be due to Maillard reaction occurred on VF chips at high temperatures (120⁰C) and high frying time (20) min (shyu *et al.*, 2005). Identical results were described by Pan *et al.*, (2015) for vacuum fried breaded shrimps and Ngadi *et al.* 2007 for vacuum fried chicken nuggets.

The second order quadratic model showed a best fit for the a* value of VF-carrot chips with various frying conditions and shown in the equation 4.8:

$$a^* = 21.01+4.38\,X_1 +0.2610\,X_2 + 0.654\,X_3 +0.1625\,X_1X_3 +0.2350\,X_2X_3 + 0.2300\,X_1X_3 + 0.3037\,X_1^2 - 0.956\,X_2^2 + 0.2401\,X_3^2 \quad \text{..........(4.8)} \quad (R^2 = 0.98)$$

Where X1 = Temperature (⁰C); X2 = Pressure (kPa); X3 = Time (min)

The surface plot of changes in b* values of carrot chips are displayed in Fig .4.18 and the results were tabulated in the Table E1.2(Appendix-E).

From the analysis of variance (Table E2.9), it is observed that temperature ($p \leq 0.05$), pressure ($p \leq 0.05$) and time($p \leq 0.01$) had significant effect on b* value pf VF chips with an R- square of 0.89.

From Table E1.2, the colour value b* of VF-carrot chips ranged between 28.12 to 40.06. The maximum b* was recorded in VF-carrot chips at 120⁰C frying temperature ,15kPa frying pressure and 20 min frying time whereas the minimum b*of VF-carrot chips was obtained at frying temperature of 100⁰C, frying pressure of 11kPa and frying time of 16 min.

The yellowness (b*) of the product was increased with increase in process parameters *viz.*, temperature, time and pressure. From Fig 4.19, it is noted that the b* values of chips was increased from 28.12 to 40.06, when the process parameters *viz.*, temperature, time and pressure increased from 100-120⁰C, 16-20 min and 11-15kPa, respectively. This may be due to increase in carotene content of VF chips at high temperatures (Maity *et al.*, 2017). Identical results were explained by

Ranasalva (2017) who observed a similar trend in terms of colour values in VF-raw banana chips.

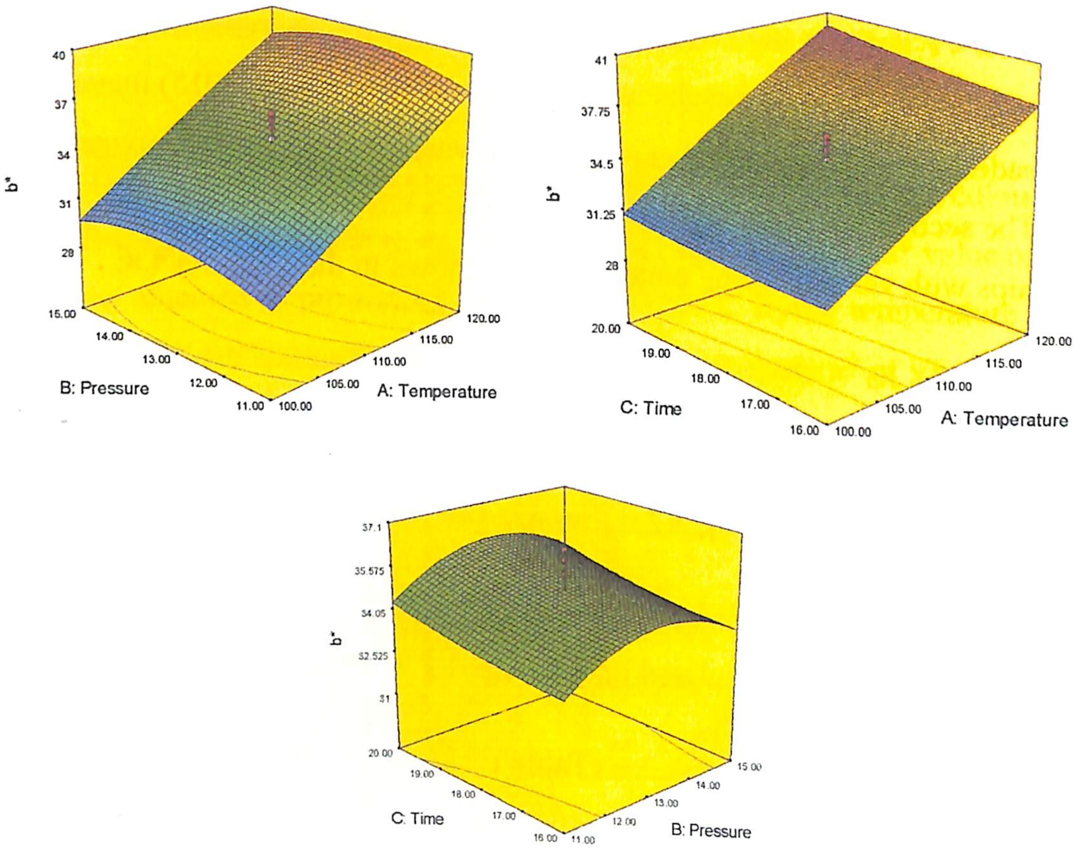


Fig. 4.19. Effect of changes in b* of VF-carrot chips with different process parameters

The second-order quadratic model (Eqn 4.9) was best suited to determine the effect of process parameters and b* value.

$$b^* = 35.06+4.25\ X_1+ 0.2510\ X_2 + 0.5616\ X_3 + 0.025\ X_1X_2 +0.2825\ X_2X_3 + 0.037\ X_1X_3 - 0.203\ X_1^2 - 1.16\ X_2^2 + 0.185\ X_3^2 \ldots\ldots..(4.9) \qquad (R^2 = 0.890)$$

Where X1 = Temperature (^{0}C); X2 = Pressure (kPa); X3 = Time (min)

4.3.1.7 Thickness Expansion

The thickness expansion of vacuum fried carrot chips at different operating conditions is shown in Table E1.2 (Appendix – E) and graphically displayed in Fig. 4.20.

From analysis of variance (Table E2.10), it was obvious that process parameters *viz.,* frying temperature($p \leq 0.01$), pressure($p \leq 0.01$) and time($p \leq 0.01$) had significant effect on thickness expansion. The R-squared coefficient of this model was 0.93. The second order interaction levels between the process parameters were also found to be significant.

From Table E1.2, the thickness expansion of VF-carrot chips ranged from 60.42 % to 83.21%. The maximum thickness expansion of VF-carrot chips was noted at frying temperature of 120^0C, frying pressure of 15kPa and frying time of 20 min whereas minimum thickness expansion of carrot chips was obtained at 100^0C frying temperature, 11kPa frying pressure and 16 min frying time.

The process parameters *viz.,* frying time, temperature and pressure showed a positive effect on thickness expansion of VF carrot chips. The thickness expansion was increased from 60.42 to 83.21% with increase in frying temperature, pressure and time. At early stages of frying, the thickness of chips was reduced and then started slowly increasing, with increase in frying temperature and time (Yagua and Moreira,2011). The thickness expansion was increased with increase in frying time, temperature. Chips fried at high frying temperatures reached the persistent thickness value quicker than those chips fried at lower temperature (Ravli *et al.,* 2013). Once the crust had been formed and vacuum pressure escalation occurred inside the product, the product expanded at the end of the frying process. Identical results were explained by Ranasalva (2017) who observed that the thickness expansion of VF-banana chips was increased by increase the frying conditions and Yamsaengsung and Moreira (2002) observed the similar trend of results for fried tortilla chips.

The changes in thickness expansion with different frying conditions were determined by using the first-order linear model and showed in the equation 4.10:

Thickness expansion (%) = $76.86 + 7.63\ X_1 + 0.692\ X_2 + 1.14\ X_3$ .... (4.10)

($R^2 = 0.93$)

Where, X_1 = Temperature (^{0}C); X_2 = Pressure (kPa); X3 = Time (min)

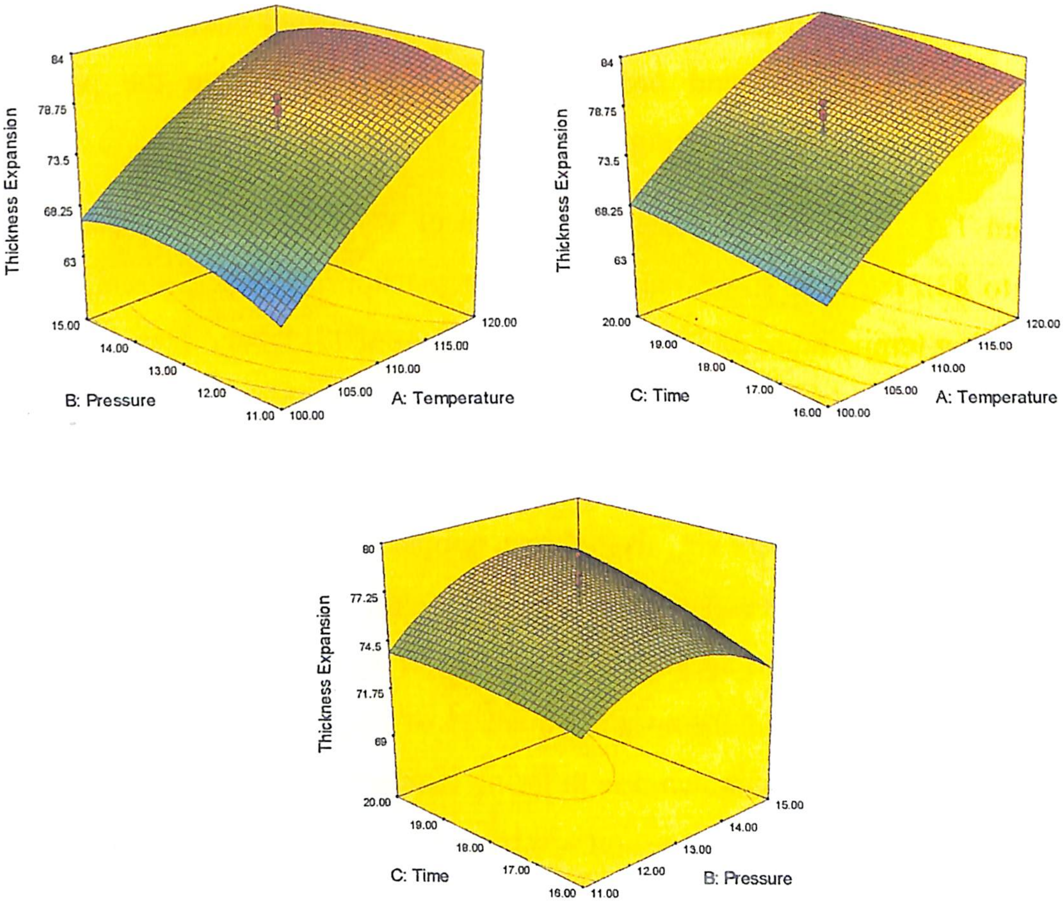


Fig. 4.20. Effect of changes in thickness expansion of VF-carrot chips with process parameters

4.3.1.8 Energy Content

The energy content of vacuum fried chips at different operating conditions are depicted in Table E1.2 (Appendix – E). Fig 4.21 shows the 3D surface plot for the energy content of VF-carrot chips at different processing conditions.

Analysis of variance (Table E2.11) showed that the operating conditions such as frying time, frying temperature and frying pressure had significantly($p \leq 0.01$) affect the energy content. From Equation 4.11, it was noticed that all the individual terms (temperature, time and pressure) exhibited positive effect on energy content of the chips. The R^2 value of 0.96 was noted for energy content value for VF-carrot chips at different processing conditions.

From Fig 4.21, the energy content of VF-carrot chips ranged from 1021 KJ/100g -1510 KJ/100g. The maximum energy content of the VF-carrot chips was observed at the processing conditions of frying temperature 120^0C, frying pressure 15 kPa and frying time 20 min. The minimum energy content of the chips was noted at frying conditions of frying temperature of 100^0C, frying pressure of 11kPa and frying time of 16 min.

The energy content of the chips was directly proportional to the amount of oil present in the chips (Stubbs *et al.,* 1995). The energy content of the chips was increased from 1021 KJ/100g - 1510 KJ/100g. The high energy content in VF carrot chips may due to increment in the oil content at maximum frying temperatures (100-120^0C), frying time (16-20 min) and frying pressure (11-15kPa).Oil content in fried chips was directly proportional to the all process parameters *viz.,* frying temperature, time and pressure (Tarzi *et al.,* 2012).The lower energy content was observed in the fried products processing at 100^0C frying temp, 11 kPa pressure and 16 min time. The oil content of the sample was found to be low compared to the VF chips processed at high frying temperature(120^0C). Identical results were found by Pooja (2018), revealed that the energy content in VF-bitter gourd chips increased with an increase in oil content.

The second-order quadratic model was best fitted with the energy content with various processing conditions.

Energy content $=1353.55 + 128.01 X_1 + 15.10 X_2 + 14.00 X_3 - 10.80 X_1X_2 + 3.25 X_2X_3 + 19.45 X_1X_3 - 13.99 X1^2 - 32.81 X2^2 - 5.73 X3^2$.......(4.11) ($R^2$ =0.96)

Where, X1 = Temperature (^{0}C); X2 = Pressure (kPa); X3 = Time (min)

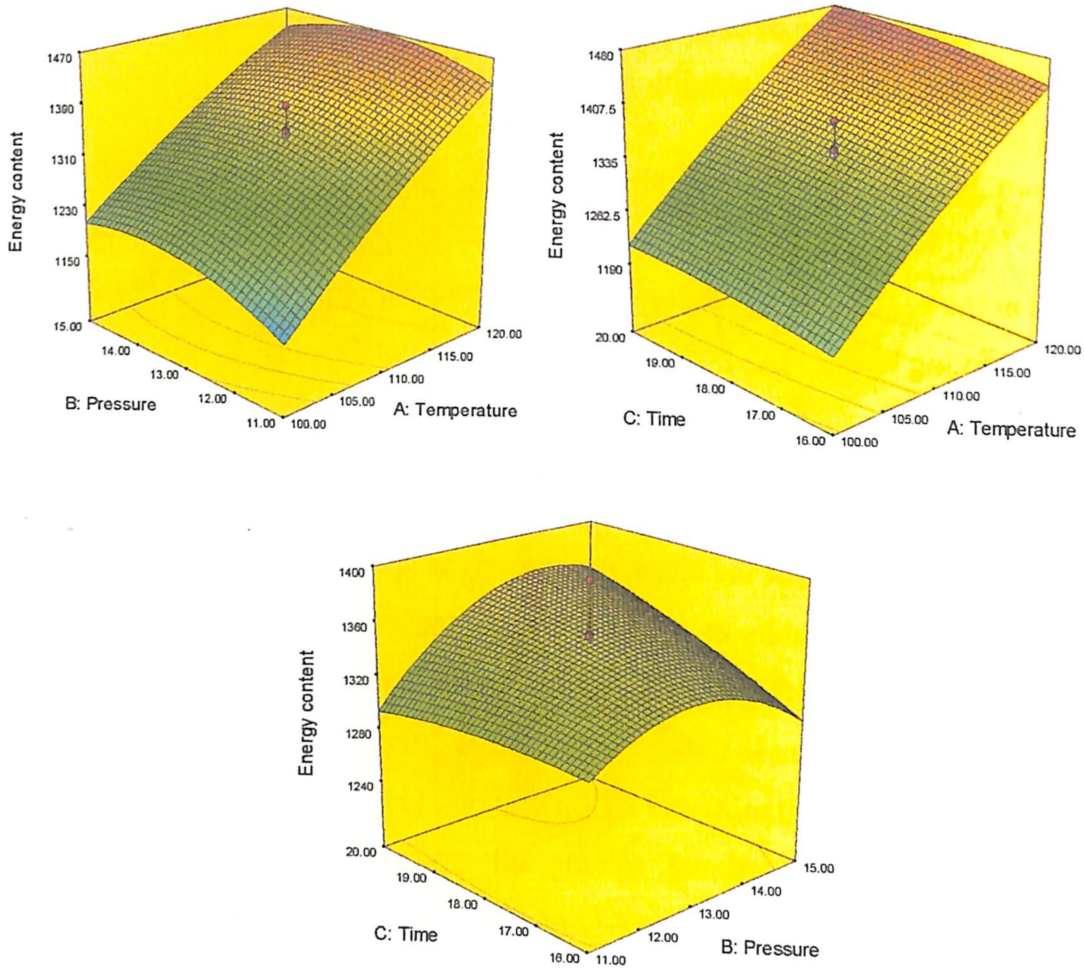


Fig. 4.21. Effect of changes in energy content of VF-carrot chips with different process parameters

4.3.1.9 Sensory Analysis

The sensory analysis was conducted for VF-carrot chips at various processing conditions with 9-point hedonic scale and is shown in Table 4.2. The sensory analysis plays an important role in the selection of product and consumer acceptance. The chips were fried under different operating conditions *viz.*, frying temperature (100-120^{0}C), vacuum pressure (11-15 kPa) and frying time (16-20 mins). Table 4.3 represents the mean sensory scores of VF-carrot chips at different operating conditions. The VF-carrot chips fried under 100-110^{0}C had great consumer's acceptance. The chips fried under temperature of 120^{0}C had less acceptance due to over frying. The atmospheric fried (6.1 score) and control samples (6.7 score) had the minimum overall acceptability among the other samples. The maximum sensory score of 8.8, 8.4, 8.3, 8.2, 8.2, 8.2, 8.2, 8.1, 8.1, 8.0, 8.0, 8.0, 8.0, which follows CT2, CT16, CT7, CT8, CT14, CT19, CT20, CT10, CT3, CT5, CT6, CT15 and CT18, respectively. The treatment details (CT1, CT2.....CT20) for optimization of process parameters for VF-carrot chips were shown in the Table 4.4, Table D1.1(Appendix D) and also displayed in the Table 3.5.

The fuzzy logic sensory analysis exhibits the same sensory score. The samples CT2, CT16, CT7, CT8, CT14, CT19, CT20, CT10, CT3, CT5, CT6, CT15 and CT18 ranked high in overall acceptability. The minimum overall acceptability showed at, CT11(7.9), CT13(7.9), CT1(7.8), CT9(7.8), CT12(7.7) and CT4 (7.5). The preference between the sensory attributes of CT2 (100^{0}C,15kPa and 20 min) treatment was: overall acceptability >color and appearance = taste > texture >flavor. The preference between the sensory attributes of CT16 (110^{0}C,13kPa and 18 min) treatment was: overall acceptability >taste>color and appearance>texture>flavor. The maximum sensory score of above ten samples was due to its color (red-yellow) and good textural property. The two treatments (CT2 and CT16) scored high sensory in the nine-point hedonic scale and fuzzy logic comprehensive model were selected for storage studies.

Table 4.3 Mean sensory score for VF-carrot chips at different operating conditions

Treatments	**Colour and Appearance**	**Texture**	**Flavour**	**Taste**	**Overall Acceptability**
CT1	7.8	7.8	7.7	7.8	7.8
CT2	8.5	8.5	9.0	9.0	**8.8**
CT3	8.2	8.1	8.1	8.2	8.1
CT4	7.5	7.4	7.5	7.5	7.5
CT5	7.9	7.8	7.8	7.9	8.0
CT6	8.0	8.1	8.1	8.1	8.0
CT7	8.0	8.1	8.2	8.2	8.3
CT8	8.0	8.1	8.2	8.2	8.2

CT9	7.9	7.8	8.0	8.0	7.8
CT10	8.1	8.0	8.0	7.9	8.1
CT11	7.5	7.8	7.8	7.9	7.9
CT12	7.5	7.5	7.6	7.7	7.7
CT13	8.0	7.7	7.8	7.8	7.9
CT14	8.0	8.3	8.0	8.4	8.2
CT15	7.8	7.9	8.1	8.0	8.0
CT16	8.0	8.1	8.0	8.2	8.4
CT17	8.0	8.2	8.0	8.1	8.1
CT18	7.9	8.0	8.0	8.0	8.0
CT19	8.1	8.0	8.2	8.1	8.2
CT20	8.0	8.2	8.0	8.1	8.2

CT1

CT2

CT3

CT4

CT5

CT6

CT7

CT8

CT9

CT10

CT11

CT12

CT13

CT14

CT15

CT16 CT17 CT18 CT19 CT20

Plate 4.2 Vacuum fried carrot chips at different operating conditions

Table 4.4 Symbolic representation and treatments details for optimisation of process parameters

	Coded values			Actual values		
Treat-ments	**Temperature**	**Pressure**	**Time**	**Temperature**	**Pressure**	**Time**
CT1	0	0	1.681	110	13	21.3636
CT2	-1	1	1	100	15	20
CT3	-1	-1	-1	100	11	16
CT4	1.681	0	0	126.818	13	18
CT5	1	1	1	120	15	20
CT6	1	-1	-1	120	11	16
CT7	0	0	0	110	13	18
CT8	0	0	0	110	13	18
CT9	0	0	-1.68	110	13	14.6364
CT10	0	1.681	0	110	16.363	18
CT11	-1.681	0	0	93.1821	13	18
CT12	1	-1	1	120	11	20
CT13	-1	-1	1	100	11	20
CT14	0	-1.681	01	110	9.6364	18
CT15	0	0	0	110	13	18
CT16	0	0	0	110	13	18

CT17	1	1	-1	120	15	16
CT18	-1	1	-1	100	15	16
CT19	0	0	0	110	13	18
CT20	0	0	0	110	13	18

4.4 PROCESS OPTIMISATION FOR THE DEVELOPMENT OF VACUUM FRIED PRODUCTS

The fried chips/snacks were developed using the vacuum frying technology and the different process parameters which affect the quality characteristics of the vacuum fried products were determined. Optimization of the process parameters was done by using the three independent variables *viz.*, temperature (100, 110 and 120^0C), pressure (11, 13 and 15 kPa) and time (16, 18 and 20 min). The optimization was done using the central composited randomized design (response surface methodology) in Design Expert Software 7.7.0. Desirability ranges were fixed from zero to one for any given response. Zero represents that more than one response fall outside desirable limits and a value of one indicates the ideal case (Maran *et al.*, 2013). In this experiment, the independent variables were kept within the range and the dependent variables were selected as maximum, minimum, or in range depending upon the requirements. From the desirability analysis, the optimal level of various parameters were found and listed in Table 4.5. The optimum processing conditions for the development of vacuum fried chips were found as temperature of 100°C, pressure of 11kPa and time of 16 min. The desirability of the optimisation of vacuum fried process parameters was found to be 0.861. Since the desirability values are nearer to one, the optimised values could be considered ideal.

4.5. QUALITY PARAMETRS OF OPTIMALLY PRODUCED VACUUM FRIED PRODUCTS

Based on the central composite randomized design of RSM, the optimum processing conditions for the development of vacuum fried carrot chips were obtained as frying temperature of 100°C, frying pressure of 11kPa and frying time of 16 min.

Table 4.5 Multi response optimisation constraints of VF-carrot chips

Sl.No	Parameters	Goal/desirability	Lower Limit	Upper Limit
1	**A:Temperature**	is in range	100	120
2	**B:Pressure**	is in range	11	15
3	**C:Time**	is in range	16	20
4	**Moisture content**	Minimize	0.656	3.28
5	**Water activity**	Minimize	0.212	0.384
6	**Oil content**	Minimize	11.31	23.3
7	**Bulk density**	Minimize	0.284	0.873
8	**True density**	Minimize	0.842	1.714
9	**Hardness**	Minimize	1.31	3.67
10	**Thickness Expansion**	Maximize	60.42	83.42
11	**L***	Maximize	29.28	43.48
12	**a***	Maximize	14.36	27.11
13	**b***	Maximize	28.12	40.06
14	**Energy content**	is in range	1021.38	1510.24

The quality parameters of optimally produced vacuum fried carrot chips are tabulated in Table 4.6. Vacuum fried chips had an average moisture content of 3.28 % (w.b) and water activity of 0.384. The oil content was found to be 11.31%. The thickness expansion and hardness values of the chips were 60.42% and 1.31N, respectively. The color values *viz.*, L*, a* and b* values of the VF-chips were 43.48, 14.36 and 28.12 respectively. The chips had an energy value of 1021 kJ/100g (244.25 kcal/100g).

Table 4.6 Quality parameters of optimally produced VF-carrot chips

Quality Parameters	**Value**
Moisture content(% w.b)	3.28
Water activity	0.384
Oil content(%)	11.31
Bulk density(g/cm^3)	0.873
True density(g/cm^3)	1.714
Hardness (N)	1.31
Thickness expansion(%)	60.42
L*	43.48
a*	14.36
b*	28.12
Energy content (KJ/100g)	1021

The developed vacuum fried carrot chips contain less amount of oil content (11.31%) which is good for health and not adversely affect the storage period. Also, the developed VF-carrot chips had good texture value of 1.31N, which indicate the better crispiness of the fried product.

EXPERIMENT-IV

4.6 PACKAGING AND STORAGE STUDIES

Storage studies were performed for the selected VF-carrot chips that scored high in sensory evaluation. The selected vacuum fried carrot chips were packed in three different packaging materials *viz.*, low-density polyethylene (LDPE) stand up pouches, laminated aluminium flexible pouches and polypropylene with and without N_2 gas flushing. The selected packaging materials were 200 micron gauge thickness. The quality analysis for the selected treatments CT2 (100^{0}C,15kPa and 20 mins) and CT16 (110^{0}C,13 kPa and 18 min) packed under various packaging materials were carried out in every 30 days interval for 4 months duration. The symbolic representation of treatments selected is shown in the following section.

The packed samples were stored at ambient temperature (25±5°C) and relative humidity (70±10%) for storage studies.

Table 4.7 Experimental details of packaging materials

S.No	Notations	Details of packaging materials	Selected treatment
1	P_{11}	LDPE stand up pouches with (95%) N_2 gas flushing	CT2 (100^0C,15kPa and 20 mins)
2	P_{12}	Laminated aluminium foil flexible pouches with (95 %) N_2 gas flushing	
3	P_{13}	Polypropylene pouches without (95%) N_2 gas flushing	
4	P_{14}	LDPE stand up pouches without N_2 gas flushing	
5	P_{15}	Laminated aluminium foil flexible pouches without N_2 gas flushing	
6	P_{16}	Polypropylene pouches without N_2 gas flushing	
7	P_{21}	LDPE stand up pouches with (95%) N_2 gas flushing	CT16 (110^0C,13Kpa and 18 mins)
8	P_{22}	Laminated aluminium foil flexible pouches with (95 %) N_2 gas flushing	
9	P_{23}	Polypropylene pouches without (95%) N_2 gas flushing	
10	P_{24}	LDPE stand up pouches without N_2 gas flushing	
11	P_{25}	Laminated aluminium foil flexible pouches without N_2 gas flushing	
12	P_{26}	Polypropylene pouches without N_2 gas flushing	

4.6.1 Effect of Different Packaging Materials & Storage Studies on Quality Parameters of Vacuum Fried Carrot Chips

4.6.1.1 *Effect of different packaging materials on moisture content during storage of VF-carrot chips*

The effect of changes in the moisture content of VF carrot chips for treatments CT2 and CT16 during storage are shown in the Fig 4.22 and 4.23 respectively, and the results are tabulated in the Table F1.1(Appendix-F)

From the Analysis of variance, it is understood that packaging materials and packaging technologies had a significant effect ($p \leq 0.01$) on moisture content during the storage period at individual level. The moisture content of VF-carrot chips increased significantly during the storage period.

From Fig 4.22, it was observed that the initial moisture of VF-carrot chips at 0th day for CT2 treatment samples packed under various packaging materials/technologies *viz.*, P11, P12, P13, P14, P15 and P16 were 2.42, 2.42, 2.41, 2.41, 2.42 and 2.42% (w.b), respectively. Similarly, the final moisture content of VF-carrot chips, after 120 days of storage for CT2 treatments *viz.*, P11, P12, P13, P14, P15 and P16 were 4.38, 4.08, 4.21, 5.02, 4.88 and 4.74%, respectively. The highest moisture content of 5.02 % was recorded in LDPE packet without nitrogen gas filling (P14) and lowest moisture content of 4.08 % was observed in the laminated aluminium pouch(P12) with nitrogen gas filling.

From Fig 4.23, it was noticed that the initial moisture of VF-carrot chips for CT16 treatments *viz.*, P21, P22, P23, P24, P25 and P26 were 1.43, 1.41, 1.38, 1.35, 1.35 and 1.36% respectively. After 120 days of storage, the final moisture content of the VF carrot chips for CT16 treatments *viz.*, P21, P22, P23, P24, P25 and P26 were 3.22, 3.01, 3.12, 4.42, 4.34 and 4.28%, respectively. The maximum moisture content of 4.42 % was recorded in (P24) LDPE without nitrogen gas and minimum moisture content of 3.01 % was noted in the laminated aluminium pouch(P22) with nitrogen gas flushing.

In both selected treatments (CT2 and CT16), the moisture content of VF-carrot chips increased significantly with increase in storage days. This might be due to the migration of moisture from the outside atmosphere through packaging materials (Molla *et al.,* 2009). Amount of moisture present in the chips, packed inside the pouch depends on the relative humidity of the surroundings. The stored product absorbed moisture from the storage atmosphere and increased the weight gradually (Adrika *et al.*,2015). The moisture content gained by the sample packed in LDPE pouches was more as compared to laminated aluminium pouch and polypropylene. When comparing moisture content gained by chips packed in different type of packaging material with nitrogen flushing and without nitrogen flushing, the result revealed that increment in moisture gain was maximum in samples packed without nitrogen flushing than with nitrogen flushing. The lesser increase in moisture during storage in nitrogen flushed package was mainly due to the flushing of nitrogen that replaced the oxygen (air) and water vapor from the package.

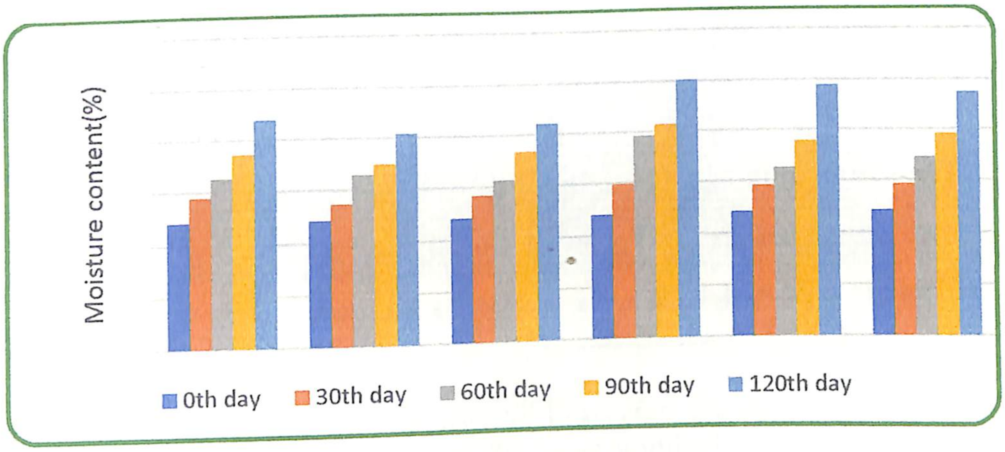


Fig. 4.22. Effect of different packaging materials on moisture content during storage of VF-carrot chips for treatment CT2

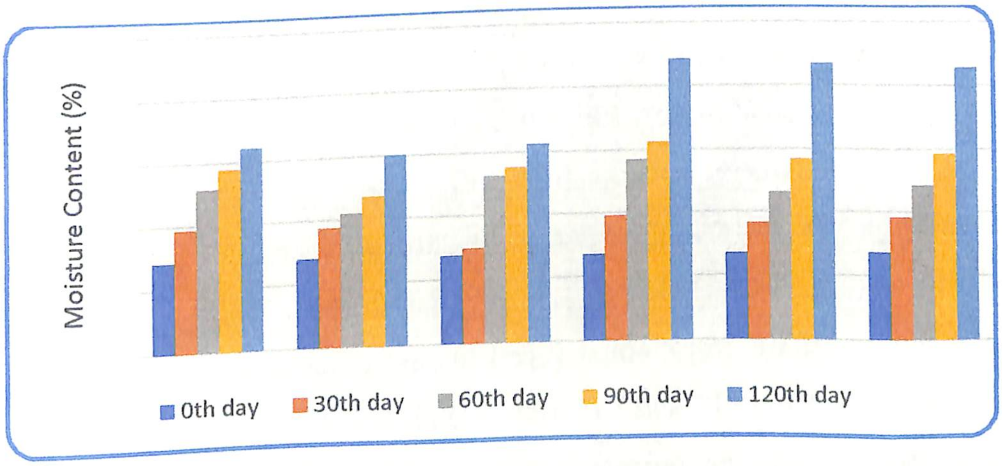


Fig. 4.23. Effect of different packaging materials on moisture content during storage of VF-carrot chips for treatment CT16

Ammawath *et al.* (2002) found that the similar results for deep-fat frying of banana chips, LDPE got the highest moisture content and lowest packed using laminated aluminium foil. Sathish Kumar *et al.* (2016) also reported that moisture content slightly increased in the jackfruit chips in laminated aluminium packaging material during storage.

4.6.1.2 Effect of different packaging materials on water activity during storage of VF-carrot chips

Water activity plays a major role in food, which is used to forecast the safety and stability of the product w.r.t to the growth of microorganisms and chemical reactions. The threshold value of any fried foods which expressed in water activity was less than 0.6 (Fan *et al.,*2006).

The variation in water activity of the VF-carrot chips during storage period is tabulated in Appendix-F (Table F1.1) and its graphical representations are displayed in Fig 4.24 and 4.25.

From Analysis of variance (Table F2.2), it is understood that the packaging materials and packaging technologies influenced the water activity of VF-carrot chips @1% ($p \leq 0.01$) significant level during the storage period.

The water activity of VF-carrot chips significantly increased during storage time. From Table F1.1(Appendix-F), it was observed that after 120 days of storage, the water activity in the VF-carrot chips (CT2 treatment) ranged from 0.511-0.561. The initial water activity of vacuum fried carrot chips for CT2 treatment sample packed under various packaging materials/technologies *viz.,* P11, P12, P13, P14, P15 and P16 were 0.314, 0.314, 0.312, 0.316, 0.310 and 0.317, respectively. The final water activity of VF-carrot chips after 120 days of storage for CT2 treatments *viz.,* P11, P12, P13, P14, P15 and P16 were 0.534, 0.511, 0.527, 0.561, 0.545 and 0.552, respectively.

From Table F1.1(Appendix-F), it was noticed that during the storage period (120 days), the water activity of VF carrot chips for CT16 treatment sample packed under various packaging materials/technique ranged from 0.491-0.527. The initial water activity of VF-carrot chips for CT16 treatment sample packed under various packaging materials/technologies *viz.,* P21, P22, P23, P24, P25 and P26 were 0.29, 0.24, 0.25, 0.26, 0.24 and 0.28, respectively. Similarly, the final water activity of VF carrot chips (CT16) after 120 days of storage under various packaging treatments *viz.*, P21, P22, P23, P24, P25 and P26 were 0.504, 0.491, 0.499, 0.527, 0.512 and 0.518, respectively.

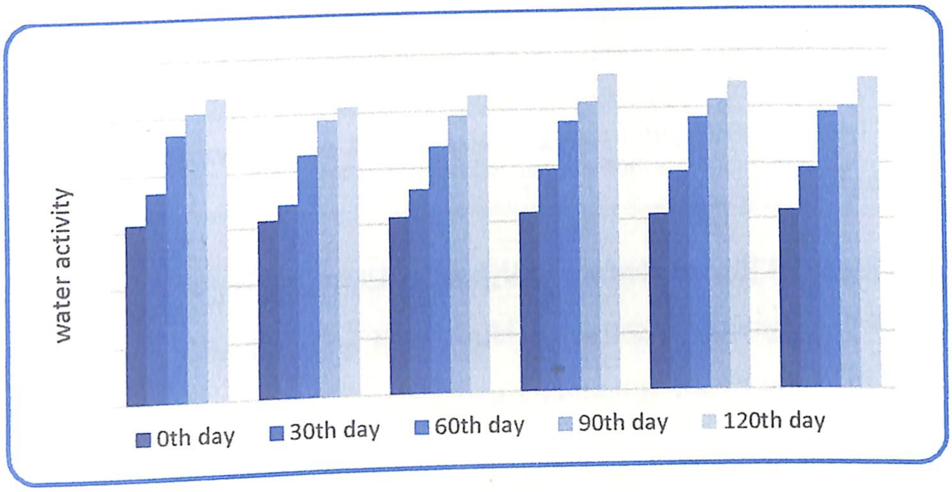


Fig. 4.24. Effect of different packaging materials on water activity during storage of VF-carrot chips for treatment CT2

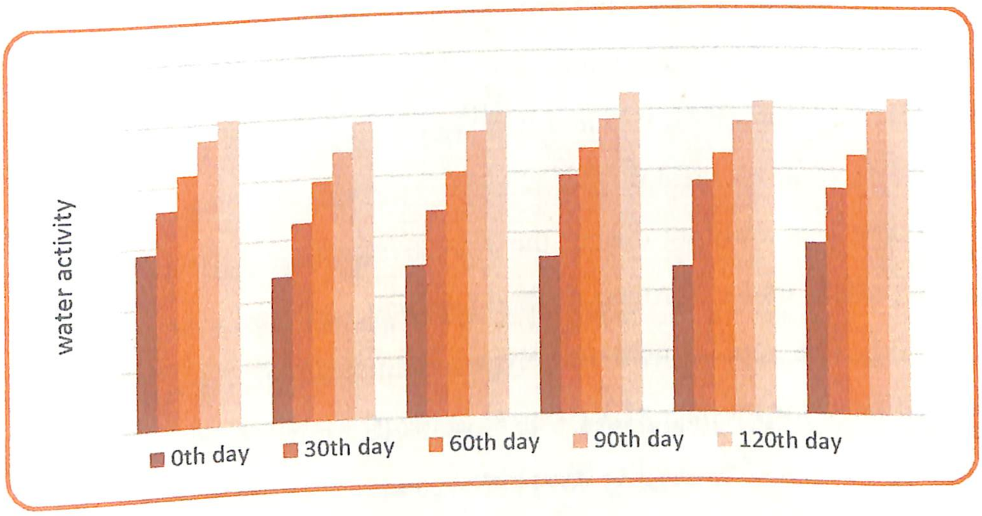


Fig. 4.25. Effect of different packaging materials on water activity during storage of VF-carrot chips for treatment CT16

In both the treatments (CT2 and CT16), the maximum water activity was observed in LDPE without nitrogen gas (P14 and P24) and minimum water activity was found in laminated aluminium pouches with nitrogen gas flushing (P12 and P22). The water activity was significantly increased in both treatments and this might be due to the diffusion of moisture in to the packets from surrounding atmosphere during the storage period. An increase in water activity represented that the water vapour was able to permeate from outside atmosphere (Manikantan *et al.*, 2012). These results were in agreement with Ranasalva (2017) who found similar results in the storage studies of vacuum fried banana chips. In both cases, the water activity was less than 0.6 and hence considered as safe products.

4.6.1.3 Effect of different packaging materials on oil content during storage of VF-carrot chips

The changes in the oil content of VF-carrot chips for samples CT2 and CT16 under various packaging treatments are shown in Fig.4.26 and 4.27 and the results are tabulated in Table F1.2 (Appendix-F).

Analysis of variance showed that the effect of packaging materials on oil content had no significant effect during storage period. The oil content of VF-carrot chips was almost constant during the storage period. From Table F1.1(Appendix-F), the initial oil content of the VF-carrot chips for both the samples CT2 and CT16 packed under various packaging materials/techniques *viz.,* P11, P12, P13, P14, P15, P16 and P21, P22, P23, P24, P25 and P26 were 13.51, 13.52, 13.53, 13.52, 13.51, 13.52 and 23.1, 23.2, 23.1, 23.0, 23.2, 23.1%, respectively. The oil content in the VF-carrot chips was constant during the 120 days storage period. The quality of carrot chips packed under nitrogen flushed package was retained during the entire storage period. The replacement of oxygen with inert nitrogen gas inside the package facilitated the storage of VF-carrot chips (Presswood,2012). Pooja (2018) obtained similar results for vacuum fried bitter gourd chips and there was no change in the oil content during the storage period. Manikantan *et al.* (2012) observed that there was no difference in oil content of stored *nendran* banana chips that were packed in polypropylene based nanocomposite packaging film.

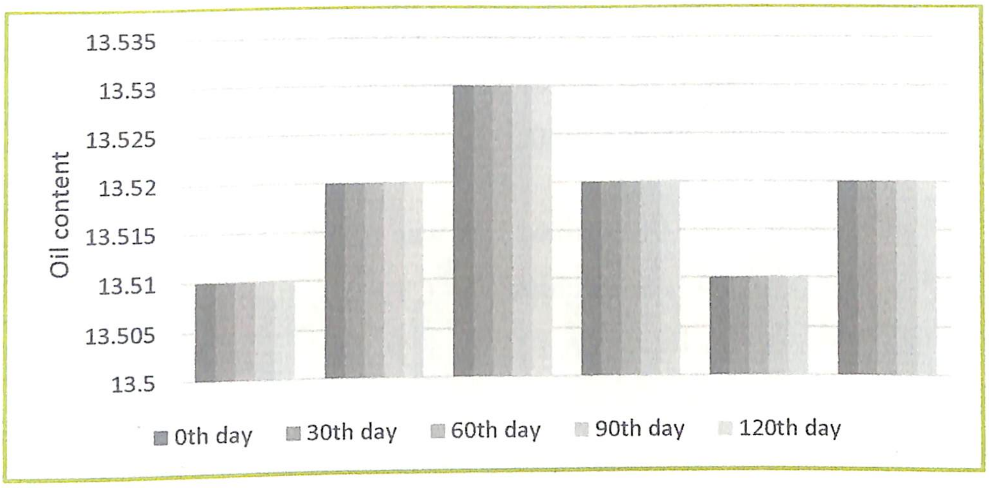


Fig. 4.26. Effect of different packaging materials on oil content during storage of VF-carrot chips for treatment CT2

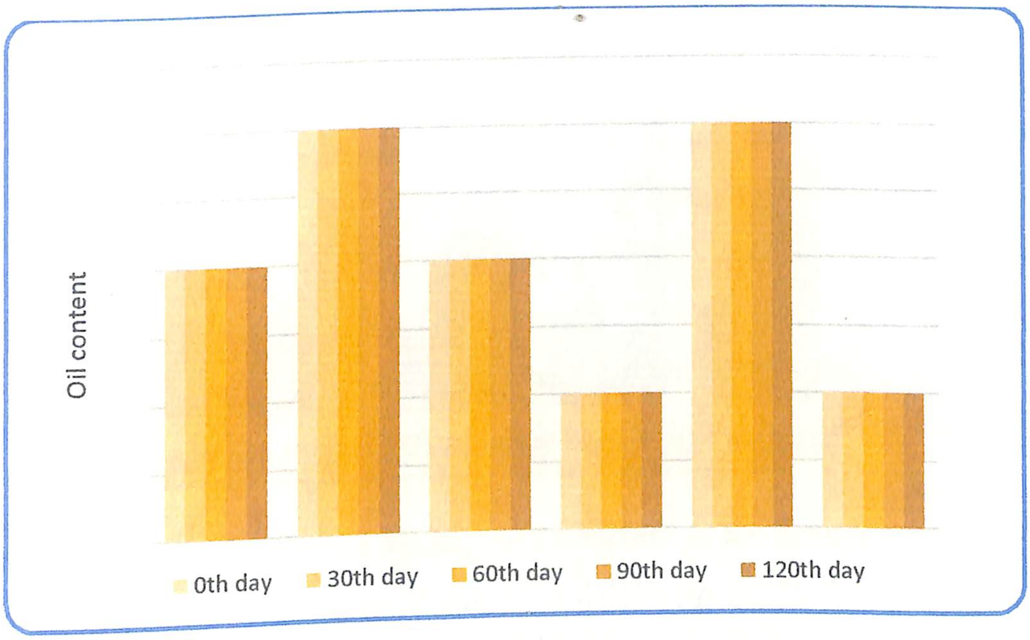


Fig. 4.27. Effect of different packaging materials on oil content during storage of VF- carrot chips for treatment CT16

4.6.1.4 Effect of different packaging materials on texture during storage of VF-carrot chips

The effect of changes in the hardness of VF carrot chips for samples CT2 and CT16 under various packaging materials/techniques during storage is presented in the Fig 4.28 and 4.29 respectively.

Analysis of variance (Table F2.3) showed that the effect of packaging materials and packaging technologies on hardness of stored products was found to be highly significant at 1% level($p \leq 0.01$).

From Table F1.2 (Appendix-F), it was observed that the initial hardness values of vacuum fried carrot chips for CT2 samples packed under various packaging materials *viz.,* P11, P12, P13, P14, P15 and P16 were 1.52, 1.54, 1.53, 1.51, 1.52, and 1.52 N, respectively. After 120 days of storage the corresponding hardness values of VF-carrot chips were 4.97, 4.41, 4.82, 5.44, 5.08, and 5.18N, respectively. The highest hardness was observed in P14 (LDPE without nitrogen gas) and lowest hardness was noted in P12 (laminated aluminium pouch with nitrogen gas).

From Table F1.2 (Appendix-F), it was noticed that the initial hardness values of vacuum fried carrot chips for CT2 samples packed under various packaging materials/techniques *viz.,* P21, P22, P23, P24, P25 and P26 were 2.24, 2.25, 2.24, 2.25, 2.25 and 2.24 N, respectively. After 120 days of storage, the corresponding hardness values of VF carrot chips were 6.48, 6.02, 6.25, 7.01, 6.84 and 6.93 N, respectively. The highest hardness was observed in P24 (LDPE without nitrogen gas) and lowest hardness was noted in P22 (laminated aluminium pouch with nitrogen gas).

In both samples (CT2 and CT16), hardness property was superior in laminated aluminium standard pouch with N_2 gas filling. The increase in moisture content and water activity during the storage period might be influenced the hardness value of the VF-chips (Manikantan *et al.,* 2012). The increase in hardness indicated the reduction in degree of crispness (shyu and Hwang, 2001). Ammawath *et al.* (2002) observed the similar results of maximum hardness values found in samples packed under laminated aluminium pouches compared to LDPE pouch during storage of vacuum fried banana chips and deep-fried banana chips.

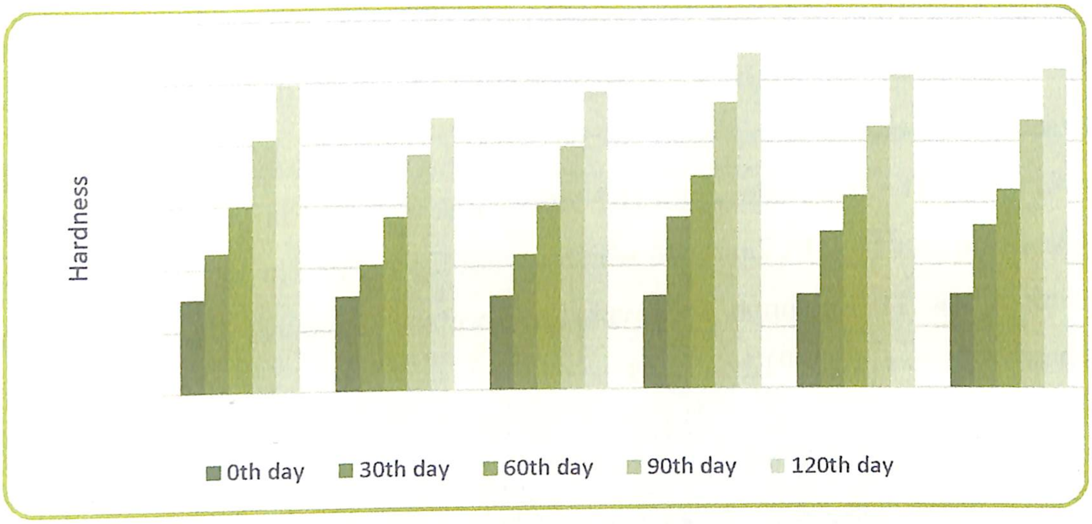


Fig. 4.28. Effect of different packaging materials on hardness during storage of VF- carrot chips for treatment CT2

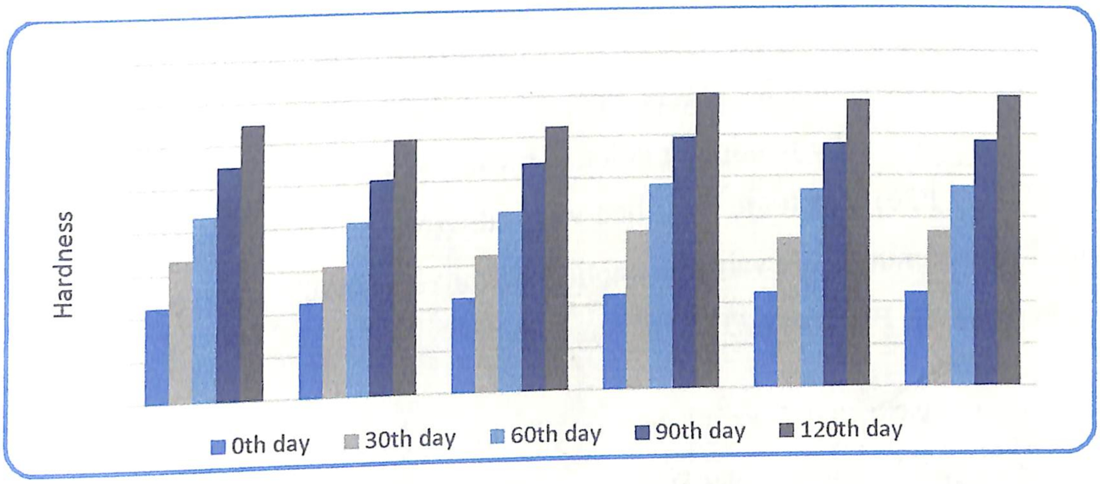


Fig. 4.29. Effect of different packaging materials on hardness during storage of VF- carrot chips for treatment CT16

4.6.1.5 Effect of different packaging materials on color values during storage of VF-carrot chips

The color values (L*, a* and b*) values showed significant variation @ 1% ($p \leq 0.01$) during the storage period. The changes in the L* values of VF-carrot chips (CT2) during the storage period is shown in Fig. 4.30 and the results are tabulated in the Table F1.3. L* value of vacuum fried chips increased during the storage period. From Table F1.3(Appendix -F), it was observed that the initial L* values of vacuum fried carrot chips for CT2 samples packed under various packaging materials *viz.,* P11, P12, P13, P14, P15 and P16 were 32.28, 38.28, 38.27, 38.28 38.28, and 38.27, respectively. After 120 days of storage the corresponding L* values of VF-carrot chips were 35.39, 35.51, 35.28, 34.77, 34.4 and 34.54, respectively. The maximum color (L* value) was observed in the samples stored under treatments P14, P15 and P16 which are not filled with nitrogen gas which led to dark colour. The minimum color value was noticed in packets which were filled with nitrogen gas (P11, P12 and P13).

The changes in the L* values of VF-carrot chips (CT16) during the storage period is shown in Fig. 4.31. From Table F1.3(Appendix-F), it was noticed that the initial L* values of vacuum fried carrot chips for CT16 samples packed under various packaging materials/techniques *viz.,* P21, P22, P23, P24, P25 and P26 were 38.67, 38.67, 38.66, 38.67, 38.67 and 38.66 respectively. After 120 days of storage period, the corresponding L* values were 40.45, 40.79, 40.23, 39.95, 39.98, and 39.45, respectively. The maximum color (L* value) was observed in the packets (P24, P25 and P26) which are not filled with nitrogen gas which resulted in dark colour. The minimum color value was noticed in the packets which were filled with nitrogen gas (P21, P22 and P23).

The increase in L* value was due to transmission of light through the packaging material (Mariscal and Bouchon, 2008). Due to filling of nitrogen gas in the packets, chips retained the good colour. The results were in agreement with the Ammawath *et al.* (2002) who had obtained a similar trend of increasing the L* values in the deep-fried banana chips.

The color value a* was inversely proportional with storage period. The change of a* values of the vacuum fried carrot chips (CT2 & CT16) during the storage period is displayed in the Fig.4.32 and 4.33. From Table F1.4 (Appendix-F), it was noticed that the initial a* values of VF-carrot chips for CT2 treatment *viz.,* P11, P12, P13, P14, P15 and P16 were 15.21, 15.21, 15.21, 15.22, 15.22 and 15.22 respectively. After 120 days of storage, the corresponding a* values were 13.25, 12.45, 12.01,12.78,11.45 and 10.87. The maximum reduction of a* value (10.87) was observed in the polypropylene without N2 gas and there was minimum reduction (P12 and P14) in LDPE packages.

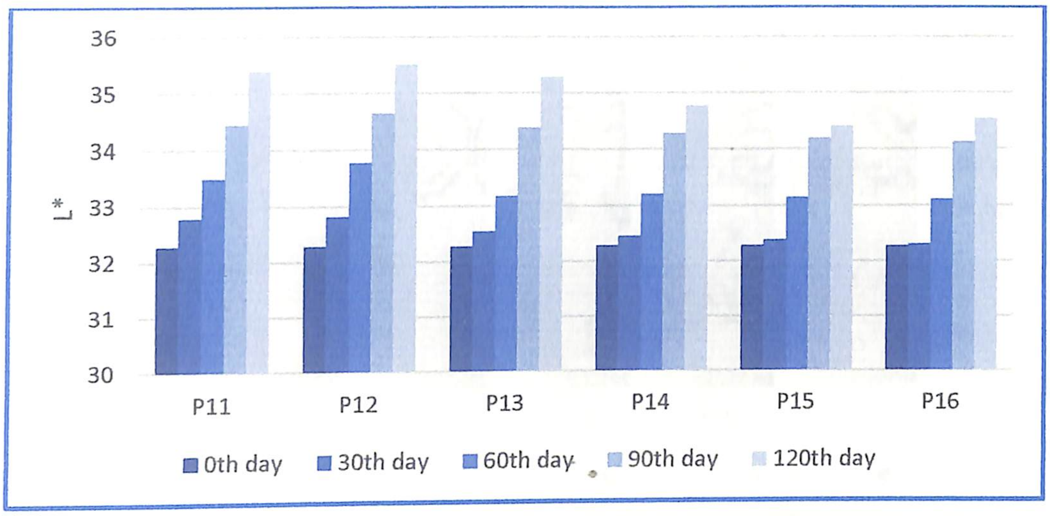


Fig. 4.30. Effect of different packaging materials on L*during storage of VF-carrot chips for treatment CT2

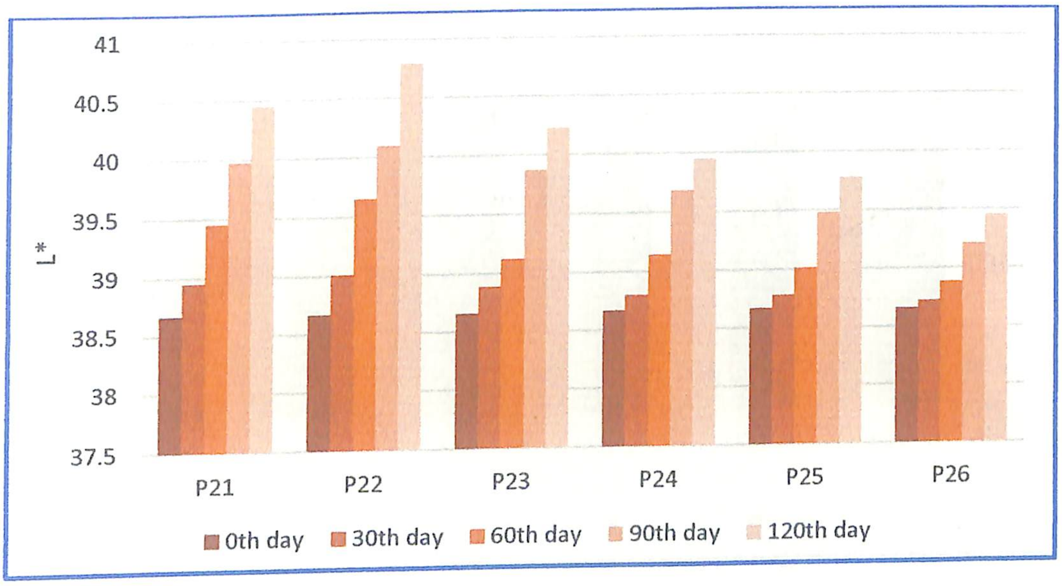


Fig. 4.31. Effect of different packaging materials on L*during storage of VF-carrot chips for treatment CT16

From Fig 4.33, it was observed that the initial a* values of carrot chips for CT16 treatments *viz.*, P21, P22, P23, P24, P25 and P26 were 22.04, 22.06, 22.04, 22.04, 22.06 and 22.06 respectively. The corresponding a* values after 120 days of storage period were 18.28, 17.77, 17.12, 18.1, 16.98 and 16.12 respectively. The maximum reduction of a* values (P26) was observed in the polypropylene without N2 gas and the minimum reduction of a* values (P22 and P24) was obtained in LDPE packages.

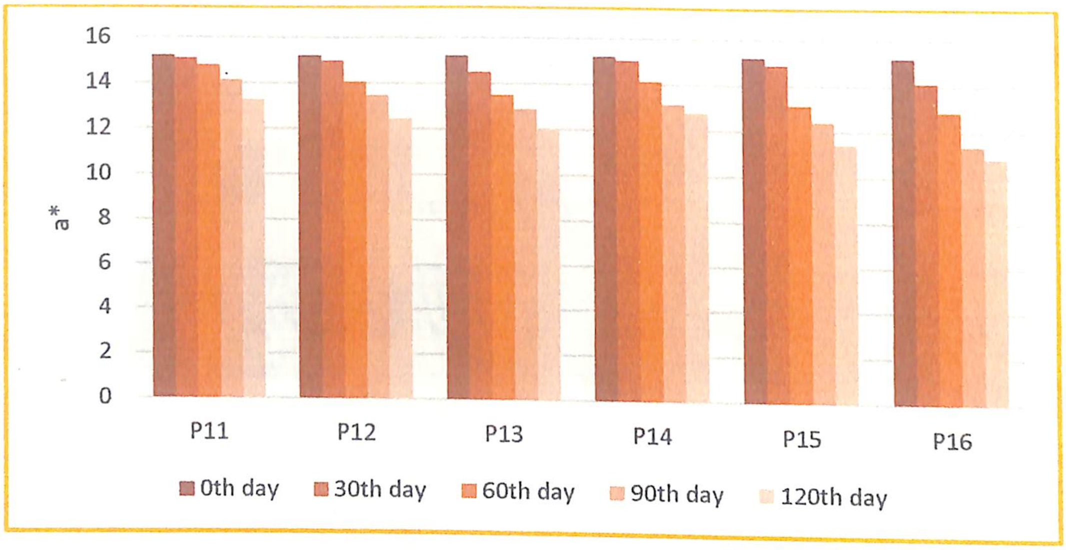


Fig. 4.32. Effect of different packaging materials on a*during storage of VF-carrot chips for treatment CT2

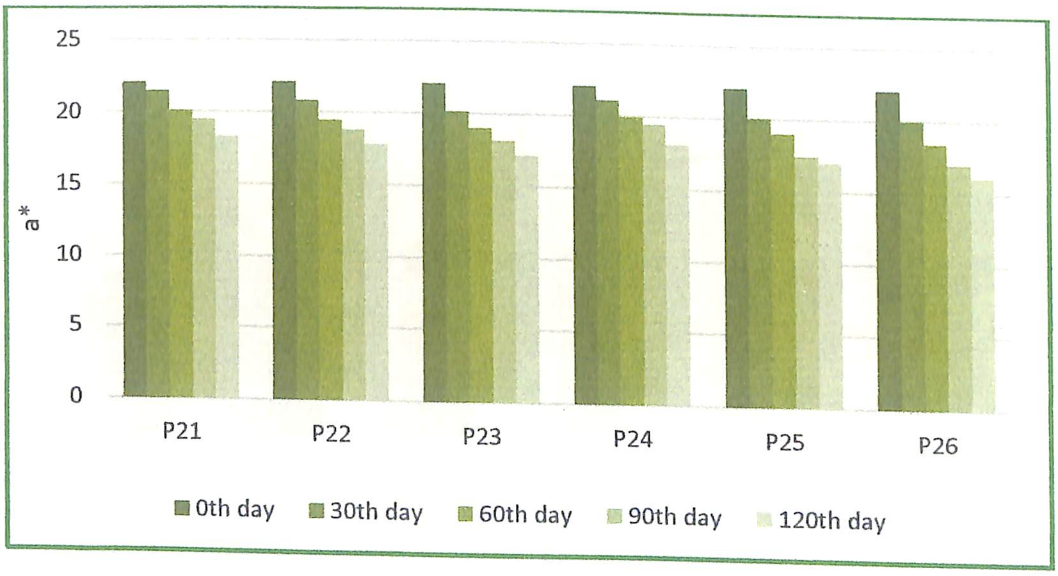


Fig. 4.33. Effect of different packaging materials on a*during storage of VF-carrot chips for treatment CT16

The color value b* was inversely proportional with storage period. The effect of changes in b* values of the vacuum fried carrot chips (CT2 & CT16) during the storage period is displayed in the Fig.4.34 and 4.35. From Table F1.5, it was observed that the initial b* values of CT2 treatments *viz.*, P11, P12, P13, P14, P15 and P16 were 27.81, 27.82, 27.81, 27.81, 27.82 and 27.81 respectively. After 120 days of storage, the corresponding b* values of VF-carrot chips for CT2 treatments were 20.05, 19.64, 19.22, 18.85, 18.97 and 18.79 respectively. The maximum reduction of b* values was observed in packets (P14, P15 and P16) which were not filling with nitrogen gas and the minimum reduction of b* values was noted in LDPE with N2 gas flushing(P12). From Fig 4.35, it was noticed that the initial b* values of carrot chips for CT16 treatments *viz.,* P21, P22, P23, P24, P25 and P26 were 32.24, 32.22, 34.22, 34.24, 34.22 and 34.22, respectively. After 120 days of storage period, the corresponding b* values were 25.27, 23.87, 23.28, 22.84, 23.66 and 22.41 respectively. The maximum reduction of b* value was found in the in the packets viz., P24, P25 and P26 respectively. The minimum reduction of b* value was found in LDPE filed with nitrogen gas(P22).

Decrease in yellowness (b* value) was closely associated with degradation of carotenoids during storage which could be due to their isomerisation and oxidation (Provesi *et al.,* 2011). The decrease in color (a* value) was due to oxidation of brown compounds resulting in slight fading of color. The product slightly got dried up due to evaporation of moisture which also resulted in decrease in color (Adedeji and Oluwalana,2018). Similar trend of colour values was observed by Ranasalva (2017) for VF-banana chips.

Based on the quality parameters and sensory evaluation, the good results were shown in the laminated aluminium flexible pouches with N_2 gas with the treatment of CT2 (100^0C,15kPa and 20 mins). The moisture content, water activity and hardness values were less in laminated aluminium pouches with N_2 gas flushing compared to polypropylene and LDPE.

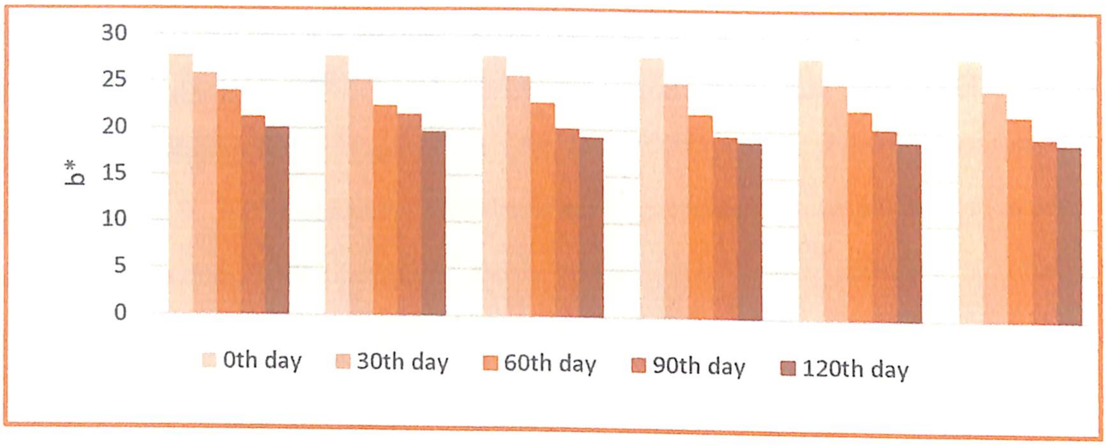


Fig. 4.34. Effect of different packaging materials on b*during storage of VF-carrot chips for treatment CT2

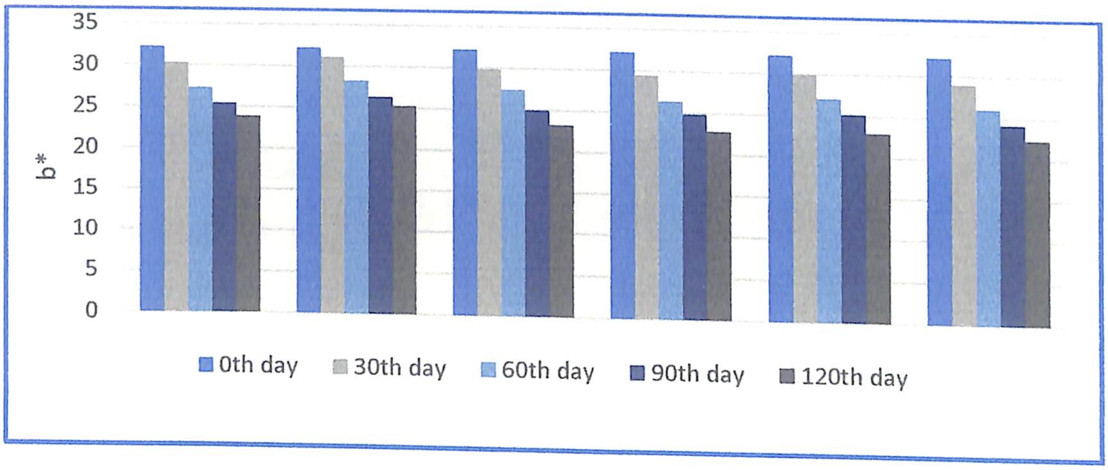


Fig. 4.35. Effect of different packaging materials on b*during storage of VF-carrot chips for treatment CT16

A. LDPE

B. Laminated Al

C. Polypropylene

Plate 4.3 Different packaging materials used for VF-carrot chips

EXPERIMENT – V

4.7 EFFECT OF PROCESSING PARAMETERS ON OIL QUALITY DURING VACUUM FRYING

The refined palm oil was evaluated for testing the oil quality after its frequent use of multiple batches of vacuum frying. After completion of vacuum frying, every batch of the fried oil was tested for its quality assessment. Repeated use of fried oil undergo some changes in oil quality parameters *viz.,* viscosity, total polar compounds, free fatty acids, peroxide and colour values. The refined palm oil was heated under different processing conditions *viz.,* frying temperature (100°C), pressure (13 kPa) and time (25 min). Quality evaluation of the used oil was conducted after every batch of vacuum frying. After frying, the oil was kept idle for 10-15 min to cool and was subjected to quality evaluation. The effect of changes in the oil quality parameters of frying oil are discussed in the below section.

4.7.1 Viscosity

Fig 4.36 displays the effect of processing parameters on viscosity of frying oil during VF. The results of the viscosity of the fried oil are tabulated in Table G1 (Appendix-G). The viscosity of the fried oil increased significantly ($p \leq 0.01$) with increase in the number of batches of frying. From Table G1 (Appendix-G), it is known that the initial viscosity of the palm oil was 35.4 cP. The viscosity of the frying oil was increased from 35.4 cP to 43.12 cP, after 40 batches of vacuum frying. The viscosity of the oil was increased linearly with increase in number of batches of frying. When frying oil used for multiple times, oxidation reaction takes place due to the formation of the carbon in the fatty acid molecules (which are elements of triglyceride) causes cross-linking of the carbon to form cyclic compounds, dimers and polymers with higher molecular weight, resulting in increased oil viscosity (Shyu *et al.,* 1998). Shyu *et al.* (1998) observed that viscosity of palm oil was increased from 38 to 50 cP after 48 h of vacuum frying of potato chips. The viscosity in the oil was increased due to the formation of greater molecular weight compounds by polymerisation of unsaturated fatty acids (Tsaknis *et al.*, 2002). Kusucharid *et al.* (2009) showed a similar trend of increasing viscosity value by increase the number of frying and concluded that fried oil was used up to 60 batches. The less viscosity value was observed under vacuum frying compared to atmospheric frying.

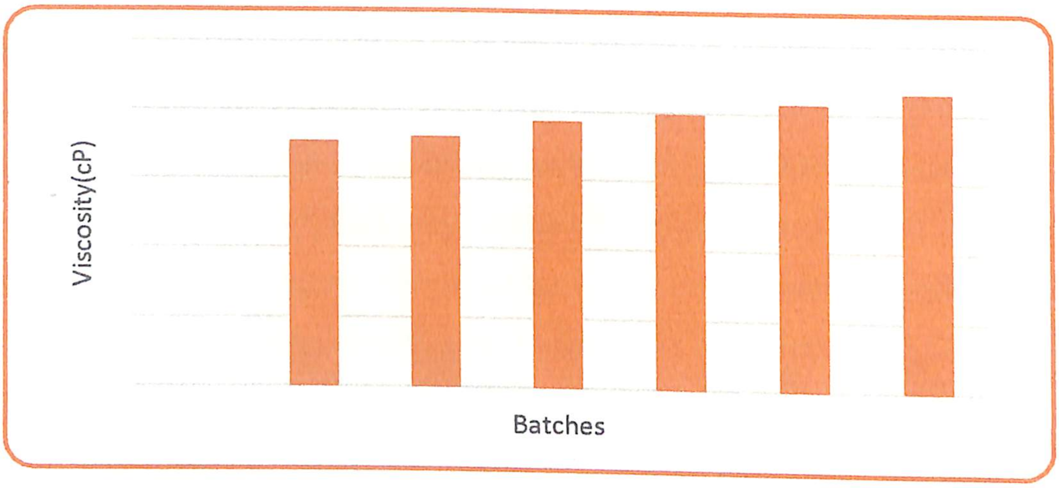


Fig. 4.36. Effect of processing parameters on viscosity of frying oil during VF

4.7.2 Total Polar Compounds (TPC)

Total polar compounds(TPC) is the most important parameter to measure the extent of oxidative deterioration of frying oil quality. Total polar compounds can easily measurable and decide the usability of the oil. The limiting value of TPC in edible oil is 25-27%. Fig. 4.37 illustrated the effect of processing parameters on total polar compounds in palm oil during VF. The results of TPC values are shown in Table G1(Appendix-G). The TPC of fried oil increased significantly($p \leq 0.01$) with increase in number of batches of frying.

From Fig 4.36, it is observed that the TPC of fried oil was increased from 5.54 % to 15.81 %, up to 40 batches of vacuum frying. The TPC value was below the limiting value of 25-27% and was safe. The TPC value was increased in the frying oil due to the formation of compounds such as triacylglycerols, secondary oxidation of oil (Latha and Nasirullah, 2011). The obtained results were in agreement with Pooja (2018), who observed that the TPC value of blended oil (rice bran and palm oil) ranged from 9.3% to 24.21% after 70 batches of vacuum frying.

Fig. 4.37. Effect of processing parameters on TPC of frying oil during VF

4.7.3 Free Fatty Acids (FFA)

One of the most important oil quality parameters for the indicator of oil deterioration is free fatty acids (FFA). Fig. 4.38 represents the effect of processing parameters on FFA of palm oil during vacuum frying. The FFA of fried oil increased significantly ($p \leq 0.01$) with increase in number of batches of frying. The results of FFA values are depicted in Table G1(Appendix-G). The threshold value of FFA in edible oils is less than 1 mg KOH/g.

Fig. 4.38. Effect of processing parameters on FFA of frying oil during VF

From Table G1, it is understood that the initial value of FFA in palm oil was 0.18 mg KOH/g. From Fig 4.38, it was observed that the FFA value was increased from 0.18 to 0.90 mg KOH/g, after 40 batches of vacuum frying. The increased value FFA in fried oil was due to the hydrolysis of triglycerides and partly by hydroperoxide decomposition of frying oil at high temperature in presence of moisture and air (Bensmira *et al.*, 2007). Similar trend of the results was obtained by shyu *et al.* (1995), who found that increased in the FFA values, while using the oil repeatedly for frying. Kusucharid *et al.* (2009) concluded that the FFA value of palm oil during atmospheric frying was higher compared to the VF. Due to the reduced frying parameters of temperature and pressure in vacuum frying than atmospheric frying, the increase in FFA was extremely low in vacuum than atmospheric frying.

4.7.4 Peroxide Values

Peroxide is one of the oil quality parameters and is used to measure the content of hyperoxides, which decompose spontaneously at high temperature (Tarmizi *et al.*, 2012). Fig 4.39 displays the effect of processing parameters on peroxides of palm oil during VF. The peroxides of the fried oil significantly increase ($p \leq 0.01$) with increase in number of batches of frying.

From Fig 4.39, it is understood that the peroxide value (PV) of the palm oil was increased from 0.21 m eq O_2/kg to 30.4 m eq O_2/kg, after forty batches of vacuum frying. The threshold value of peroxides in palm oil was 35.0 m eq O_2/kg (Fan *et al.*,2012). The increase in PV was due to the reduction in unsaturated fatty acid due to oxidation at higher frying temperature (Sunisa *et al.*, 2011). The increase in PV of palm oil was within the permissible level after forty batches of frying. The results were in agreement with the Fan *et al.* (2012) who reported that the final peroxide value of palm oil was in the range of 33-35 m eq O_2/kg after 35 batches of frying.

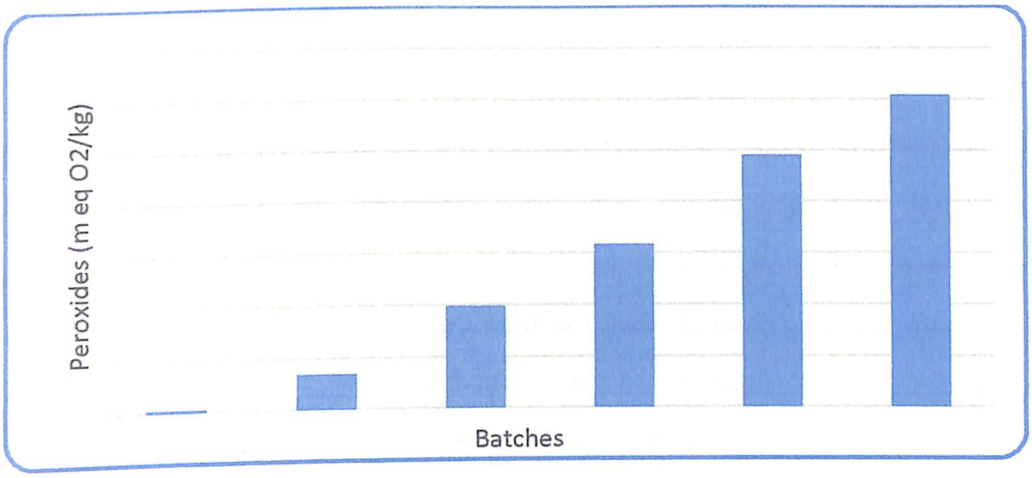


Fig. 4.39. Effect of processing parameters on peroxides of frying oil during VF

4.7.5 Color Values

Color is a subjective indicator used by the food industry for rapid monitoring of frying oil quality. Generally, the colour of the used oil is darkened due to the formation of pigments. The effect of processing parameters on color values (L*, a* and b*) of palm oil are represented in Fig. 4.40.

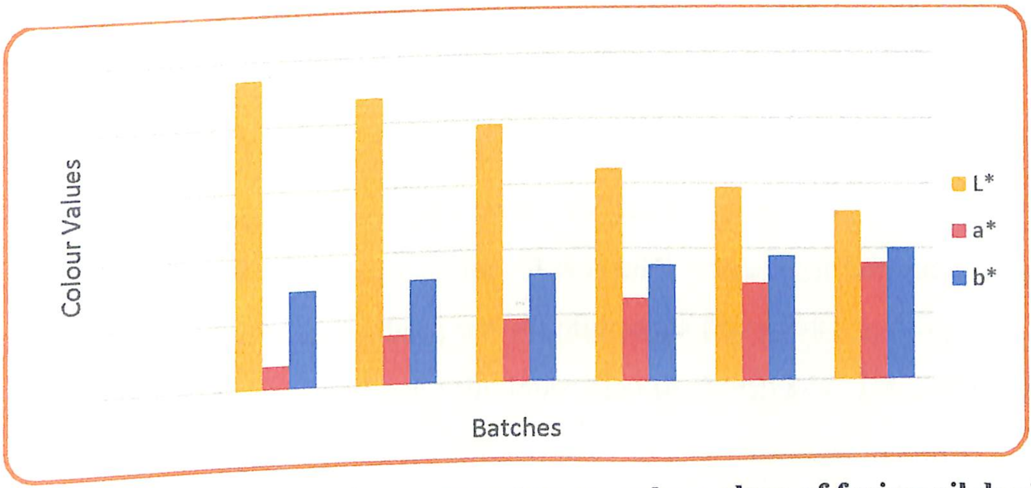


Fig. 4.40. Effect of processing parameters on color values of frying oil during VF

The colour values(L*) of the fried oil decreased significantly ($p \leq 0.01$) with increase in number of batches of frying whereas a* value increased significantly ($p \leq 0.01$) with increase in number of batches of frying. The b * value was found to be less significant with increase in number of batches of frying. From Fig 4.39, it is known that the color values *viz.*, L*, a* and b* ranged from 4.72 to 2.58, 0.35 to 1.78 and 1.48 to 2.01, respectively after 40 batch of frying. The decrease in L* value was mainly due to the chemical reactions occurs in the frying oil, *viz.*, oxidation, hydrolysis, polymerization and other chemical changes (Maskan, 2003). Kusucharid *et al.* (2009) found the similar results of colour values after 60 batches of vacuum frying of sweet potato chips. Sahin (2000) suggested that during the frying of the potato slices, there was an increase in a* value was due to browning, which indicated the red colour to oil. Tarmizi *et al.* (2013) concluded that darkening was more in atmospheric conditions than at vacuum conditions.

The oil quality parameters were analysed by statistical software using Design experts12.0. The ANOVA table for the changes in oil quality parameters were shown in Appendix-G. Statistical results revealed that after the 40 batches of vacuum frying, increase in TPC, viscosity, peroxide, FFA and colour values were within the limiting values prescribed by FSSAI standards. Hence, palm oil could be recommended up to forty batches of VF for carrot chips.

EXPERIMENT – VI

4.8 COST ECONOMICS

The cost economics of the VF-carrot chips was determined based on the variable costs and fixed costs. The cost for production of the VF- carrot chips was Rs.355/ - per kg. The benefit-cost ratio for the production of VF- carrot chips was found to be 2.8:1. The details of cost economics is described in the Appendix-C

SUMMARY & CONCLUSION

Chapter V

SUMMARY AND CONCLUSION

Carrot (*Daucus carota L*) is one of the most important cool season root crop vegetable cultivated in tropical region and temperate regions during winter and summer season, respectively. Carrots are biannuals belongs to the Apiaceae (*Umbelliferae*) family, with a crispy texture when fresh. During last 30 years, the world-wide carrot production was significantly increased. According to NHB 2018, the area under carrot in India was 96,510 ha with an annual production of 1648 thousand tones with Haryana, Punjab, Uttar pradesh, Bihar, Madhya Pradesh and Tamil Nadu being the major producing states during 2017-18. The area and production of carrot in Kerala was 800 ha and 9610 tonnes, respectively during 2017-18. The production ranking of Kerala occupies 15th place in India (NHB,2018).

Carrots are highly nutritious vegetable, which can be consumed in raw and processed form throughout the world. Carrots contains vitamins *viz.*, B1(Thiamine), B2(Riboflavin), B6(Niacin) and B12 (Cobalamin), besides rich in source of β-carotene and dietary fibres which are helpful to prevent cancer and other diseases from human body. Carotene, a source of provitamin A, are helpful to reduce the occurrence of various diseases associated with oxidative stress and damage caused due to Reactive Oxygen Species (ROS), thereby protect cells from cancer development.

In Kerala state, carrot production is very limited, but its consumption is more. The post-harvest losses of carrot were noted as 18-20%. Carrot is a seasonal crop and perishable. Due to seasonal variations, the price of carrots varies with time. The preparation of value-added products from carrot is an idealistic solution to reduce its postharvest loss especially during the glut season.

Now a days, there is an increasing demand for healthy snacks, which provides healthy and nutritious food consumption to reduce obesity. The acceptability and consumption of carrots in the market is increased by producing crispy and crunchy snacks using different frying, freezing, drying, and processing methods. Carrot chips, with its unique sensory attributes are a popular variety of snacks, dry and crispy. So far, there is a limited availability of ready-to-eat carrots chips in the market.

Frying is a simple method for cooking any kind of foods such as chips, french fries, meat fruits and vegetables. In the present era of junk foods, fried foods are gaining much market importance. Snack food market has registered an enormous growth among food processing sector in India. Deep fat frying is also known as immersion frying, most common technologies in food sector to produce the fried items. The frying process involves immersion of a food material into 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 process. The main disadvantage for consumption of deep fat fried food items contains more amount of oil content. High oil uptake associated with several health diseases and also leads to obesity, cardiovascular diseases, cancer, hypertension and other health problems and is incompatible with recent consumer trends.

Due to the health consciousness of present-day consumers, there is a high demand for healthy and tasty snack products with less oil content, since it provides good health and prevents health problems. Vacuum frying is a novel technology that fulfils all these objectives. Vacuum frying technology is a promising alternative frying technology to improve the quality of fried products. During vacuum frying, the sample is heated under a low pressure (< 6 kPa). At such reduced pressure, the boiling point as well as smoke point of oil gets reduced. The absence of air during the frying process inhibits oxidation including lipid oxidation and enzymatic browning and thus could retain color and flavor. Vacuum frying offers a minimal change in oil quality and desired organoleptic properties without loss in nutritional value. It is widely used for processing various foods, mostly vegetables and fruits. Vacuum frying offers to improve the quality attributes of fried foods rather than atmospheric frying. It maintains color and flavor of the product. Moreover, oil used in vacuum frying can be reused to several times without affecting its quality, thus increasing its economic feasibility.

The investigation on "Development and evaluation of process protocol for vacuum fried carrot chips" was under taken with objectives: i)To study the physicochemical properties of raw carrot cultivar (*ooty-1*) ii) To optimize the pre-treatment of vacuum fried carrot chips iii)To optimize the process parameters of vacuum fried carrot chips and evaluation of oil quality iv) To conduct shelf-life studies of vacuum fried carrot chips.

The raw carrot of *Ooty-1* variety was selected for the development of the vacuum fried carrot chips. Prior to the development of vacuum fried chips, the physical and chemical properties of the raw carrot were determined. Based on the preliminary trials conducted on vacuum frying of carrot and review of literature, a combination of temperature (100°C), pressure (13 kPa) and time (25 min) were selected for the pre-treatment study. Optimization of pretreatments *viz.*, blanching, blanching cum drying, blanching cum freezing, freezing and edible gum coating were done based on the quality and sensory analysis of vacuum fried products. The best pretreatment was only selected for the conduct of further experiments. The standardization of process parameters of vacuum fried product was done by three different combinations of frying temperature (100,110 and 120^{0}C), frying pressure (11,13 and 15 kPa) and frying time (16,18 and 20 min). The optimization was done using the central composite randomized design (response surface methodology) in Design Expert Software 7.7.0. The process parameters *viz.*, temperature, pressure and time were optimised based on the quality of the final product and sensory evaluation. Packaging and storage studies was conducted for the best treatments which were high scored in sensory study. Different packaging materials *viz.*, LDPE, laminate aluminium pouch and polypropylene with and without N_2 flushing were used for packaging of vacuum fried chips. The chips packed with different packaging materials were stored under ambient conditions and the quality analysis was periodically done at 30 days interval for 4 months. Based on the quality analysis and sensory study, the best packaging material was optimized. The quality of the used oil was tested after the conduct of every batch of frying and the quality parameters of oil *viz.*, FFA, TPC, peroxide, viscosity and color were determined. Cost analysis of optimally produced vacuum fried carrot chips was also performed.

The results of the above experiments are summarized as following:

The average mass of the raw carrot was 72.8 g. The bulk density and true density of the raw carrot was 0.81 and 1.023 g/cm^3.The average moisture content of the raw carrot was 89.7%. The nutritional properties of the raw carrot *viz.*, protein (0.82 g/100g), fat (0.35 g/100g), carbohydrate (9.08 g/100g), fibre (2.1 g/100g) and ash content (1.0g/100g). The total energy content of the raw carrot was 49 kcal/100g.

Optimization of the various pre-treatments by using blanching (85°C for 3.5 min), blanching cum drying (85°C for 3.5 min and dried at 70^{0}C for 1 h 30 min), blanching cum freezing(85°C for 3.5 min and frozen at –20^{0}C for 4 to 5 h), freezing(-18 °C for overnight) and edible gum coating(dipping in 1.5% guar gum for 5 min), were compared with untreated(control) and atmospheric fried chips. The refined palm oil was used for vacuum frying and de-oiling was carried out at 1000rpm for 10 min. The operating conditions such as frying temperature(100^{0}C), frying pressure(13kPa) and frying time (25 min) was selected for the conduct of pretreatment study. The freezing pretreatment of vacuum fried carrot chips had an oil content (14.48 %),water activity (0.214),moisture content (2.67%),bulk density (0.332 g/cm^3), true density (1.282 g/cm^3), thickness expansion(85.82%), total yields (23.27%), L*(38.92), a*(22.85),b*(27.86) and hardness 1.282N. Based on the quality parameters of vacuum fried chips, freezing pretreatment had found to be superior among the other pretreatments. Hence freezing pretreatment was only considered for further experiments.

Central composite randomized design (CCRD) was used for the selection of best combination of process parameters in vacuum frying process. Carrot chips were prepared by vacuum frying process with different combination of frying temperature, frying pressure, and frying time. The physical and nutritional components of the developed vacuum fried carrot chips were determined, and optimisation was done by using response surface methodology. The optimum operating condition for the development of vacuum fried carrot chips was obtained at frying temperature 100°C, frying pressure 11 kPa and frying time of 16 min. The vacuum frying was performed at optimised condition and the quality parameters of the optimally produced vacuum fried carrot chips were noted. The oil content (11.31%), bulk density (0.873 g/cm^3), true density (1.714 g/cm^3), moisture content (3.28%), water activity (0.384), hardness (1.31 N), thickness expansion (60.42%), L*(43.48), a* (14.36), b*(28.12) and energy content(1021 KJ/100g). Packaging and storage studies were conducted for treatments that scored maximum in the sensory analysis (nine-point hedonic scale) and fuzzy logic comprehensive model.

The storage studies were performed for the VF-carrot chips that scored high in sensory study. The quality analyses for the selected treatments CT2 (100^{0}C,15kPa and 20 min) and CT16 (110^{0}C,13 kPa and 18 min) were carried out in 30 days interval for 4 months duration. The vacuum fried carrot chips were packed into three different packaging materials namely low-density polyethylene stand pouch (LDPE), laminated aluminium flexible pouch and polypropylene with and without N_2 gas flushing. The packed samples were stored at the ambient temperature (25±5°C) and relative humidity (70±10%) for storage studies. In both treatments, the oil content remained constant throughout 120 days of storage period. The water activity, moisture content, hardness and colour values got increased with increase in storage time. The moisture content, water activity and hardness values were less in laminated aluminium pouches with N_2 gas flushing compared to polypropylene and LDPE.

The quality of the used oil was tested after the conduct of every batch of frying and the quality parameters of oil *viz.,* FFA, TPC, peroxide, viscosity and color were determined. The oil quality parameters *viz.,* viscosity, total polar compounds, peroxide value, free fatty acids increased during vacuum frying but within the threshold limits after 40 batches of vacuum frying. The total polar compounds (TPC) increased from 5.54 to 15.81 after forty batches of vacuum frying, which was below the limiting value for usage of oil. The colour value of L* was decreased and a* and b* value of oil were slightly increased during vacuum frying. The cost economics for the production of vacuum fried carrot chips was estimated as Rs.355/- per kg and benefit cost ratio was found to be 2.81:1.

Based on the results following conclusions were made:

- Vacuum frying technology is a promising and novel technology for production of carrot chips.
- The freezing pre-treatment had better quality parameters and high sensory score compared to the other pre-treatments.
- The optimum operating condition for the development of vacuum fried carrot chips was obtained at frying temperature 100°C, frying pressure 11 kPa and frying time of 16 min produced the best healthy snacks with low oil content and good crispiness.
- The laminated aluminium flexible pouch of thickness 200 micron with N_2 gas filling was found to be the best packaging technique to enhance the shelf life of VF carrot chips to a storage period of 4 months without affects its quality.
- The oil quality parameters *viz.,* total polar compounds (TPC), viscosity, peroxide, free fatty acids (FFA) etc., were within the allowable limits even after 40 batches of vacuum frying.
- Cost of vacuum fried carrot chips was estimated as Rs. 355 /- per kg.

Future line of work

- Conduct packaging studies using novel packaging techniques
- Pretreatment studies can be repeated with more edible coatings *viz., Xanthamum gum, Maltodextrin, sodium carboxymethyl cellulose, Hydroxypropyl methylcellulose etc.,*
- Explore the possibility of conducting vacuum frying for different sea foods, meat, and peas.

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CHAPTER VI

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Appendix – A

Sensory score for vacuum fried carrot chips

Sample code	Colour and appearance	Texture	Flavour	Taste	Overall acceptability
T1					
T2					
T3					
T4					
T5					
T6					
T7					

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

Signature of sensory panel:

Name :

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 carrot chips

Sensory attributes	Scale factor	T1	T1 FMF	T1 NFMF	T2	T2 FMF	T2 NFMF	T3	T3 FMF	T3 NFMF	T4	T4 FMF	T4 NFMF	T5	T5 FMF	T5 NFMF
Colour and appearance	EX															
	GD															
	MD															
	FR															
	NS															
	Total															
Texture	EX															
	GD															
	MD															
	FR															
	NS															
	Total															
Flavour	EX															
	GD															
	MD															
	FR															
	NS															
	Total															
Taste	EX															
	GD															
	MD															

	FR															
	NS															
	Total															
Overall acceptability	EX															
	GD															
	MD															
	FR															
	NS															
	Total															

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

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

Sensory parameters	T1	T2	T3	T4	T5
Colour and appearance					
Texture					
Flavour					
Taste					
Overall acceptability					

Table B.3 Quality ranking for the vacuum fried carrot chips

Sensory parameters	Scores ofattributes	T1:QR	T2:QR	T3:QR	T4:QR	T5:QR
Colour and appearance	0.300					
Texture	0.300					
Flavour	0.100					
Taste	0.100					
Overall acceptability	0.200					
Ranking						

Appendix – C

Cost Economics of Developed Vacuum Fried Carrot chips

Estimation of cost of production for vacuum fried carrot chips

Cost of machineries and building **Rupees /-**

Cost of vacuum frying machine = 1000000

Cost of slicer = 50000

Cost of cooling chamber = 50000

Cost of packaging machine = 30000

Building cost (2000 sq.ft)@ 1500/sq.ft = 3000000
Miscellaneous items = 100000

Total cost = 4230000

Assumptions

Life Span (L) = 10 years

Annual Working Hours (H) = 275 days(per 8 hrs)

= 2200 hrs

Salvage Value (S) = 10% of initial cost

Interest on Initial Cost (I) = 15 % annually

Repair and Maintenance = 10 % initial cost

Insurances and Taxes = 2 % of initial cost

Electricity Charges = Rs.8/- per unit

Labour Wages/Person **(5 Ns/Rs.400/ Day)** = Rs.2000/-
Skilled Assistants **(2 Ns/500/Day)** = Rs.1000/-

One Manager (@ **600 / Day**) = Rs.600/-

1. **Total costs**

a. Depreciation = $\frac{C-S}{L\times H} = \frac{4230000-423000}{10\times 2200}$ = **Rs.173.04/-**

b. Interest = $\frac{C+S}{2}\times\frac{i}{H} = \frac{4230000+423000}{2}\times\frac{15}{100\times 2200}$ = **Rs.158.62/-**

c. Insurances & Taxes = 2 % initial cost

$= \frac{2}{100\times 2200}\times 4230000$= **Rs.38.45/-**

Total cost = a + b + c = 173.04 + 158.62 + 38.45 =**Rs.370.11/-**

2. **Variable costs**

i. Repair and maintenance = 5 % of initial cost

$= \frac{5}{100\times 2200}\times 2115000$= **Rs.48.06/-**

ii. Electricity cost

a. Energy consumed by the vacuum fryer = 30kw/h

Cost of energy consumption/h = power × duration ×cost of 1 unit

= 30× 8 × 8 = **Rs. 1920 /-**

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

Cost of energy consumption/h = power × duration ×cost of 1 unit

= 2 × 8 × 8 = **Rs.128/-**

iii. Labour cost(5 persons @Rs. 400) = **Rs.2000/day**

iv. Packaging cost = **Rs.4000/- per day**

v. Skilled assistants (2 persons @ Rs.500) = **Rs.1000/-**

vi. Manager = **Rs. 600/day**

vii. Cost of raw material for preparation of vacuumed fried carrot chips

Sl.no	**Raw materials**	**Quantity(kg)**	**Unit rate (per kg)**	**Total amount (Rs.)**
1.	Carrot	700	70	49000
2.	Frying oil	120	100	12000

Therefore variable cost (carrot chips) = i+ ii+ iii+ iv+ v

= **Rs.70,696/ day**

Therefore total cost of production of 200 kg vacuum fried carrot chips

= Fixed cost + Variable cost

= 370.11 + 70696.06

= Rs.71066.17 / 200 kg of VF- carrot chips

= **Rs. 355.33/ kg** of vacuum fried carrot chips.

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

benefit-cost ratio = $\frac{1000}{355.33}$ = 2.81

The benefit- cost ratio for the production of vacuum fried carrot chips was found to be 2.81:1.

APPENDIX-D1

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

Pre-treatments	Notations
Blanching	CB
Blanching cum Drying	CBD
Blanching cum Freezing	CBF
Freezing	CF
Guar Gum	CGG
Control (Untreated)	CC
Atmospheric Frying	CAF

Table D1.2 Changes in quality parameters of pre-treated VF-carrot chips

Sl.No	Parameters	CB	CBD	CBF	CF	CGG	CC	CAF
1	Moisture Content (%)	3.59	2.15	2.93	2.67	6.82	3.27	10.25
2	Water Activity	0.324	0.225	0.292	0.214	0.316	0.287	0.31
3	Oil Content (%)	13.24	12.64	13.98	14.48	10.04	25.11	30.05
4	Bulk Density (g/cm^3)	0.392	0.368	0.374	0.332	1.327	0.398	1.108
5	True Density (g/cm^3)	1.298	1.513	1.421	1.282	1.942	1.481	1.671
6	Thickness Ratio (%)	70.2	68.2	80.5	85.53	65.83	78.52	63.23
7	Total Yield (%)	15.38	13.33	18.21	23.27	12.43	20.45	16.67
8	Hardness (N)	1.812	1.969	1.432	1.282	1.942	1.518	1.904
	Colour Values							
9	L*	36.37	34.58	37.38	38.92	35.15	37.08	30.2
10	a*	18.02	17.24	20.42	22.85	18.61	21.87	16.44
11	b*	23.28	19.91	26.71	27.86	23.94	25.48	20.28
12	ΔE	11.41	21.89	15.43	17.89	13.98	10.15	22.8
	Sensory Evaluation							

13	Colour & Appearance	8	7.1	8	8.8	5.5	6.5	5.1
14	Texture	8.1	6.9	8.3	8.6	5.8	6.7	5.6
15	Flavour	8.3	7.3	8.2	8.5	5.9	6.3	6
16	Taste	8.5	7.5	8.5	8.8	6	6.9	5.8
17	Overall Acceptability	8.3	7.6	8.7	9	6.1	6.7	5.8
	Fuzzy Logic							
	Taste>OA>C&A=Flavour>Texture			**CB**				
	OA>Taste>Texture>C&A=Flavour			**CBD**				
	Taste>C&A>OA>Flavour>Texture			**CBF**				
	OA>Taste>C&A>Texture=Flavour			**CF**				
	C&A=Flavour>Taste=OA>Texture			**CGG**				
	Flavour=Taste>OA>C&A>Texture			**CC**				
	Flavour>Taste>OA>Texture>C&A			**CAF**				

13	Colour & Appearance	8	7.1	8	8.8	5.5	6.5	5.1
14	Texture	8.1	6.9	8.3	8.6	5.8	6.7	5.6
15	Flavour	8.3	7.3	8.2	8.5	5.9	6.3	6
16	Taste	8.5	7.5	8.5	8.8	6	6.9	5.8
17	Overall Acceptability	8.3	7.6	8.7	9	6.1	6.7	5.8
	Fuzzy Logic							
	Taste>OA>C&A=Flavour>Texture			**CB**				
	OA>Taste>Texture>C&A=Flavour			**CBD**				
	Taste>C&A>OA>Flavour>Texture			**CBF**				
	OA>Taste>C&A>Texture=Flavour			**CF**				
	C&A=Flavour>Taste=OA>Texture			**CGG**				
	Flavour=Taste>OA>C&A>Texture			**CC**				
	Flavour>Taste>OA>Texture>C&A			**CAF**				

Appendix – D2

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

Sl.No	Parameters	Goal	Lower limit	Upper limit
Pretreatments VF-carrot chips		**Is in range**		
1	**Moisture content**	Minimise	2.15	10.25
2	**Water activity**	Minimise	0.21	0.33
3	**Oil content**	Minimise	12.64	30.05
4	**Bulk density**	Minimise	0.332	1.327
5	**True density**	Minimise	1.282	1.942
6	**Thickness expansion**	Maximise	63.23	85.82
7	**Hardness**	Minimise	1.282	1.942
8	**L***	Maximise	30.2	38.92
9	**a***	Maximise	17.24	22.85
10	**b***	Maximise	19.91	27.86
11	**ΔE**	In range	10.15	21.89
12	**Total yields**	Maximize	12.43	20.45

APPENDIX-D3

ANOVA table for quality parameters of the vacuum fried carrot chips

Table D3.1 Moisture content

Source	Type III Sum of Squares	df	Mean Square	F value	p value	R^2
Model	149.205	6	24.868	865.174	<.0001	0.98
Intercept	443.165	1	443.165	15418.259	<.0001	
Pretreatment	149.205	6	24.868	865.174	<.0001	
Error	.402	14	.029			
Total	592.773	21			significant	
Corrected Total	149.608	20				

Table D3.2 Water activity

Source	Type III Sum of Squares	df	Mean Square	F value	p value	R^2
Model	137.027	6	21.005	5.094	<.0001	0.95
Intercept	441.538	1	441.538	1735.489	<.0001	
Pretreatment	128.027	6	21.005	5.094	<.0001	
Error	.012	14	.014			
Total	569.578	21			significant	
Corrected Total	.040	20				

Table D3.3 Oil content

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Corrected Model	1002.308	6	167.051	213907.102	<.0001	0.96
Intercept	6119.424	1	6119.424	7835848.195	<.0001	
Pretreatment	1002.308	6	167.051	213907.102	<.0001	
Error	.011	14	.001			
Total	7121.743	21			significant	

Corrected Total	1002.318	20				

Table D3.4 Bulk density

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F value**	**P value**	**R^2**
Model	3.143	6	.524	29896.537	<.0001	0.97
Intercept	7.874	1	7.874	449331.198	<.0001	
Pretreatment	3.143	6	.524	29896.537	<.0001	
Error	.000	14	1.752			
Total	11.018	21			significant	
Corrected Total	3.144	20				

Table D3.5 True density

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F value**	**P value**	**R^2**
Model	.957	6	.159	108023.387	<.0001	0.94
Intercept	48.233	1	48.233	32674008.90	<.0001	
Pretreatment	.957	6	.159	108023.387	<.0001	
Error	2.067	14	1.476			
Total	49.190	21			significant	
Corrected Total	.957	20				

Table D3.6 Hardness

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F value**	**P value**	**R^2**
Model	1.591	6	.265	60.697	<.0001	0.98
Intercept	59.280	1	59.280	13572.278	<.0001	
Pretreatment	1.591	6	.265	60.697	<.0001	
Error	.061	14	.004			
Total	60.932	21			significant	
Corrected Total	1.652	20				

Table D3.7 Total yields

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Model	267.926	6	44.654	23689.935	<.0001	0.94
Intercept	6162.929	1	6162.929	3269540.762	<.0001	
Pretreatment	267.926	6	44.654	23689.935	<.0001	
Error	.026	14	.002			
Total	6430.881	21			significant	
Corrected Total	267.953	20				

Table D3.8 Thickness expansion

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Model	1302.350	6	217.058	3822.846	<.0001	0.99
Intercept	111967.700	1	111967.700	1971983.131	<.0001	
Pretreatment	1302.350	6	217.058	3822.846	<.0001	
Error	.795	14	.057			
Total	113270.844	21			significant	
Corrected Total	1303.145	20				

Table D3.9 L*

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Model	133.569	6	22.261	1634.584	<.0001	0.93
Intercept	26773.573	1	26773.573	1965891.7	<.0001	
Pretreatment	133.569	6	22.261	1634.584	<.0001	
Error	.191	14	.014			
Total	26907.332	21			Significant	
Corrected Total	133.759	20				

Table D3.10 a*

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Model	104.177	6	17.363	68796.107	<.0001	0.92
Intercept	7867.904	1	7867.904	31174715.17	<.0001	
Pretreatment	104.177	6	17.363	68796.107	<.0001	
Error	.004	14	.000			
Total	7972.085	21			significant	
Corrected Total	104.180	20				

Table D3.11b*

Source	Type III Sum of Squares	df	Mean Square	F value	P value	R^2
Model	165.919	6	27.653	72589.429	<.0001	0.97
Intercept	12018.365	1	12018.365	31548208.05	<.0001	
Pretreatment	165.919	6	27.653	72589.429	<.0001	
Error	.005	14	.000			
Total	12184.289	21			significant	
Corrected Total	165.924	20				

APPENDIX-E

Table E1.1 Treatments details for optimisation of process parameters

		Coded values			Actual values		
Treat-ments	**Run**	**Temperature**	**Pressure**	**Time**	**Temperature**	**Pressure**	**Time**
CT1	**1**	0	0	1.681	110	13	21.3636
CT2	**2**	-1	1	1	100	15	20
CT3	**3**	-1	-1	-1	100	11	16
CT4	**4**	1.681	0	0	126.818	13	18
CT5	**5**	1	1	1	120	15	20
CT6	**6**	1	-1	-1	120	11	16
CT7	**7**	0	0	0	110	13	18
CT8	**8**	0	0	0	110	13	18
CT9	**9**	0	0	-1.68	110	13	14.6364
CT10	**10**	0	1.681	0	110	16.363	18
CT11	**11**	-1.681	0	0	93.1821	13	18
CT12	**12**	1	-1	1	120	11	20
CT13	**13**	-1	-1	1	100	11	20
CT14	**14**	0	-1.681	01	110	9.6364	18
CT15	**15**	0	0	0	110	13	18
CT16	**16**	0	0	0	110	13	18
CT17	**17**	1	1	-1	120	15	16
CT18	**18**	-1	1	-1	100	15	16
CT19	**19**	0	0	0	110	13	18
CT20	**20**	0	0	0	110	13	18

Table E1.2 Quality attributes of the vacuum fried carrot chips

Treatments	Tempe-rature	Pressure	Time	M.C	aw	O.C	B.D	T.D	H	T.E	L*	a*	b*	Total Energy
CT1	110	13	21.3	1.84	0.274	20.8	0.346	0.963	2.84	79.43	34.43	23.52	37.01	1364.4
CT2	100	15	20	2.741	0.356	13.5	0.698	1.593	1.54	68.27	41.06	16.93	29.81	1202.9
CT3	100	11	16	3.28	0.384	11.3	0.873	1.714	1.31	60.42	43.48	14.36	28.12	1021.38
CT4	126.8	13	18	0818	0.218	22.7	0.321	0.956	3.51	82.77	32.28	26.84	38.95	1396.21
CT5	120	15	20	0.656	0.212	23.3	0.284	0.842	3.67	83.21	29.28	27.11	40.06	1510.24
CT6	120	11	16	1.694	0.261	22.1	0.304	0.914	3.04	80.21	31.04	25.23	38.25	1439.8
CT7	110	13	18	1.985	0.28	20.4	0.303	1.102	2.53	78.29	36.37	22.63	36.31	1393.2
CT8	110	13	18	1.946	0.284	19.6	0.418	1.114	2.45	79.32	37.9	21.98	35.96	1354.91
CT9	110	13	14.6	2.08	0.312	15.3	0.532	1.313	1.83	72.21	38.78	18.94	33.08	1308.9
CT10	110	16.3	18	2.22	0.344	14.2	0.621	1.421	1.72	69.43	39.12	17.21	31.09	1248.87
CT11	93.18	13	18	2.64	0.371	12.0	0.769	1.614	1.63	6.321	40.95	15.98	28.94	1248.37
CT12	120	11	20	1.38	0.253	22.8	0.296	0.881	3.24	81.32	30.52	25.91	39.59	1475.23
CT13	100	11	20	3.03	0.374	11.9	0.812	1.713	1.42	62.84	42.08	15.34	29.08	1102.43
CT14	110	9.63	18	2.45	0.323	15.0	0.584	1.368	1.86	71.83	38.64	18.48	31.41	1291.29

CT15	110	13	18	1.902	0.289	18.9	0.444	1.154	2.38	76.01	38.42	21.42	35.47	1348.42
CT16	110	13	18	1.865	0.296	18.2	0.468	1.185	2.24	77.82	38.76	21.02	34.83	1353.5
CT17	120	15	16	0.987	0.24	23.1	0.287	0.853	3.48	82.48	30.28	26.23	39.74	1500.4
CT18	100	15	16	2.987	0.368	12.1	0.724	1.568	1.42	64.32	42.25	16.27	29.45	1102.81
CT19	110	13	18	1.872	0.28	17.6	0.494	1.207	2.13	75.41	38.76	19.84	34.25	1339.83
CT20	110	13	18	1.934	0.284	17.0	0.488	1.269	2.08	74.32	38.67	19.33	33.71	1328.08

(* M.C- Moisture content (%); O.C-Oil content (%); Aw-Water activity; B.D-Bulk density(g/cm^3); T.D- True density(g/cm^3);

H-Hardness(N); T.E-Thickness expansion(%))

APPENDIX-E2

ANOVA for optimised process parameters

Table E2.1 Moisture Content

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	9.05	9	1.01	16.05	< 0.0001	0.25	12.51
A-temp	7.91	1	7.91	126.37	< 0.0001		
B-pressure	0.4224	1	0.4224	6.74	0.0266		
C-time	0.0788	1	0.0788	1.26	<0.0001		
AB	0.0905	1	0.0905	1.45	0.2570		
AC	0.0523	1	0.0523	0.8354	0.3822		
BC	0.0332	1	0.0332	0.5293	0.4836		
A^2	0.0341	1	0.0341	0.5437	0.4778		
B^2	0.3887	1	0.3887	6.21	0.0319		
C^2	0.0156	1	0.0156	0.2488	0.6287		
Residual	0.6263	10	0.0626				
Lack of Fit	0.6156	5	0.1231	57.50	0.0002	**	
Pure Error	0.0107	5	0.0021				
Cor Total	9.68	19			*		

(*- significant;** - Not significant)

TableE2.2 Water activity

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	0.0508	9	0.0056	18.46	< 0.0001	0.01	15.76
A-temp	0.0438	1	0.0438	143.15	< 0.0001		
B-pressure	0.0009	1	0.0009	2.87	0.1212		
C-time	0.0008	1	0.0008	2.49	<0.0001		
AB	0.0001	1	0.0001	0.3204	0.5839		
AC	0.0001	1	0.0001	0.4724	0.5075		
BC	0.0002	1	0.0002	0.7209	0.4157		
A^2	9.883E-06	1	9.883E-06	0.0323	0.8609		
B^2	0.0047	1	0.0047	15.41	0.0028		
C^2	0.0000	1	0.0000	0.0869	0.7741		
Residual	0.0031	10	0.0003				
Lack of Fit	0.0018	5	0.0004	1.44	0.3503	**	
Pure Error	0.0013	5	0.0003				
Cor Total	0.0539	19			*		

Table E2.3. Oil content

Source	Sum of Squares	Df	Mean Square	F-value	p-value	Std.Dev	C.V (%)
Model	289.53	9	32.17	8.77	<0.0001	0.92	10.91
A-temp	258.41	1	258.41	70.43	< 0.0001		
B-pressure	0.5434	1	0.5434	0.1481	0.7084		
C-time	8.12	1	8.12	2.21	<0.0001		
AB	0.0128	1	0.0128	0.0035	0.9541		
AC	0.0018	1	0.0018	0.0005	0.9828		
BC	0.3280	1	0.3280	0.0894	0.7710		
A^2	1.48	1	1.48	0.4029	0.5398		
B^2	21.27	1	21.27	5.80	0.0368		
C^2	0.0002	1	0.0002	0.0001	0.9941		
Residual	36.69	10	3.67				
Lack of Fit	28.88	5	5.78	3.70	0.0888	**	
Pure Error	7.81	5	1.56				
Cor Total	326.21	19			*		

Table E2.4 Bulk density

Source	Sum of Squares	Df	Mean Square	F-value	p-value	Std .Dev	C.V(%)
Model	0.6053	9	0.0673	9.75	<0.0001	0.10	16.39
A-temp	0.5296	1	0.5296	76.77	< 0.0001		
B-pressure	0.0039	1	0.0039	0.5604	0.4713		
C-time	0.0061	1	0.0061	0.8853	0.3689		
AB	0.0068	1	0.0068	0.9921	0.3427		
AC	0.0003	1	0.0003	0.0383	0.8487		
BC	0.0008	1	0.0008	0.1218	0.7343		
A^2	0.0173	1	0.0173	2.51	0.1440		
B^2	0.0436	1	0.0436	6.32	0.0307		
C^2	0.0001	1	0.0001	0.0164	0.9008		
Residual	0.0690	10	0.0069				
Lack of Fit	0.0590	5	0.0118	5.93	0.0365	**	
Pure Error	0.0100	5	0.0020				
Cor Total	0.6743	19			*		

Table E2.5 True density

Source	Sum of Squares	Df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	1.36	9	0.1516	8.87	< 0.0001	0.13	10.69
A-temp	1.23	1	1.23	71.77	< 0.0001		
B-pressure	0.0082	1	0.0082	0.4800	<0.0001		
C-time	0.0303	1	0.0303	1.77	<0.0001		
AB	0.0063	1	0.0063	0.3667	0.5583		
AC	0.0000	1	0.0000	0.0000	1.0000		
BC	0.0007	1	0.0007	0.0422	0.8413		
A^2	0.0151	1	0.0151	0.8805	0.3702		
B^2	0.0727	1	0.0727	4.25	0.0662		
C^2	0.0037	1	0.0037	0.2187	0.6501		
Residual	0.1710	10	0.0171				
Lack of Fit	0.1516	5	0.0303	7.81	0.0208	**	
Pure Error	0.0194	5	0.0039				
Cor Total	1.54	19			*		

Table E2.6 Hardness

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	10.23	9	1.14	12.86	< 0.0001	0.29	12.86
A-temp	9.33	1	9.33	105.54	< 0.0001		
B-pressure	0.0547	1	0.0547	0.6193	0.4496		
C-time	0.2729	1	0.2729	3.09	0.1094		
AB	0.0512	1	0.0512	0.5793	0.4642		
AC	0.0181	1	0.0181	0.2042	0.6610		
BC	0.0013	1	0.0013	0.0141	0.9077		
A^2	0.1085	1	0.1085	1.23	0.2938		
B^2	0.2664	1	0.2664	3.01	0.1132		
C^2	0.0798	1	0.0798	0.9025	0.3645		
Residual	0.8838	10	0.0884				
Lack of Fit	0.7211	5	0.1442	4.43	0.0640	**	
Pure Error	0.1627	5	0.0325				
Cor Total	11.11	19			*		

Table E2.7 L*

Source	Sum of Squares	Df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	321.04	9	35.67	14.00	<0.0001	0.98	10.28
A-temp	284.11	1	284.11	111.51	< 0.0001		
B-pressure	1.17	1	1.17	0.4592	0.5134		
C-time	0.9658	1	0.9658	0.3791	0.5519		
AB	0.0061	1	0.0061	0.0024	0.9621		
AC	0.3120	1	0.3120	0.1225	0.7336		
BC	1.81	1	1.81	0.7084	0.4196		
A^2	16.26	1	16.26	6.38	0.0301		
B^2	19.32	1	19.32	7.58	0.0204		
C^2	0.0489	1	0.0489	0.0192	0.8926		
Residual	25.48	10	2.55				
Lack of Fit	25.35	5	5.07	198.13	< 0.0001	**	
Pure Error	0.1279	5	0.0256				
Cor Total	346.52	19			*		

Table E2.8 a*

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	C.V (%)
Model	286.92	9	31.88	9.99	< 0.0001	1.79	8.62
A-temp	262.24	1	262.24	82.20	< 0.0001		
B-pressure	0.9302	1	0.9302	0.2916	0.6010		
C-time	5.86	1	5.86	1.84	0.2053		
AB	0.2113	1	0.2113	0.0662	0.8021		
AC	0.4418	1	0.4418	0.1385	0.7176		
BC	0.4232	1	0.4232	0.1327	0.7233		
A^2	1.33	1	1.33	0.4168	0.5331		
B^2	13.19	1	13.19	4.13	0.0694		
C^2	0.8308	1	0.8308	0.2604	0.6209		
Residual	31.90	10	3.19				
Lack of Fit	23.98	5	4.80	3.03	0.1247	**	
Pure Error	7.92	5	1.58				
Cor Total	318.82	19			*		

Table E2.9 b*

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	C.V(%)
Model	273.07	9	30.3	10.46	<0.0001	1.70	4.97
A-Temp	246.45	1	246.45	84.97	< 0.0001		
B-Pressure	0.8877	1	0.8877	0.3061	0.5923		
C-Time	4.31	1	4.31	1.48	0.2510		
AB	0.0013	1	0.0013	0.0004	0.9838		
AC	0.6385	1	0.6385	0.2201	0.6490		
BC	0.0113	1	0.0113	0.0039	0.9516		
A^2	0.5974	1	0.5974	0.2060	0.6596		
B^2	19.27	1	19.27	6.64	0.0275		
C^2	0.4949	1	0.4949	0.1706	0.6883		
Residual	29.00	10	2.90				
Lack of Fit	23.94	5	4.79	4.72	0.0568	**	
Pure Error	5.07	5	1.01				
Cor Total	302.08	19			*		

Table E2.10 Thickness Expansion

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	CV(%)
Model	918.03	9	102.00	12.01	<0.0001	1.91	3.93
A-Temp	796.04	1	796.04	93.75	< 0.0001		
B-Pressure	6.54	1	6.54	0.7707	<0.0001		
C-Time	17.62	1	17.62	2.08	<0.0001		
AB	3.34	1	3.34	0.3935	0.5445		
AC	0.0120	1	0.0120	0.0014	0.9707		
BC	4.49	1	4.49	0.5282	0.4840		
A^2	27.32	1	27.32	3.22	0.1031		
B^2	70.46	1	70.46	8.30	0.0164		
C^2	2.04	1	2.04	0.2402	0.6346		
Residual	84.91	10	8.49				
Lack of Fit	66.62	5	13.32	3.64	0.0912	**	
Pure Error	18.29	5	3.66				
Cor Total	1002.94	19			*		

Table E2.11 Energy content

Source	Sum of Squares	df	Mean Square	F-value	p-value	Std.Dev	CV(%)
Model	2.508E+05	9	27872.10	3.32	<0.0001	0.34	6.96
A-Temp	2.238E+05	1	2.238E+05	26.63	<0.0001		
B-Pressure	3115.10	1	3115.10	0.3707	<0.0.001		
C-Time	2678.23	1	2678.23	0.3187	<0.0001		
AB	932.26	1	932.26	0.1109	0.7460		
AC	84.50	1	84.50	0.0101	0.9221		
BC	3027.20	1	3027.20	0.3602	0.5617		
A^2	2822.19	1	2822.19	0.3358	0.5751		
B^2	15510.45	1	15510.45	1.85	0.2041		
C^2	472.82	1	472.82	0.0563	0.8173		
Residual	84036.07	10	8403.61				
Lack of Fit	81594.18	5	16318.84	33.41	0.0008	**	
Pure Error	2441.88	5	488.38				
Cor Total	3.349E+05	19			*		

Appendix-E3

Table E3.1 Multi response optimisation constraints of VF-carrot chips

Sl.NO	Parameters	Goal	Lower Limit	Upper Limit
1	**A:Temperature**	is in range	100	120
2	**B:Pressure**	is in range	11	15
3	**C:Time**	is in range	16	20
4	**Moisture content**	Minimize	0.656	3.28
5	**Water activity**	Minimize	0.212	0.384
6	**Oil content**	Minimize	11.31	23.3
7	**Bulk density**	Minimize	0.284	0.873
8	**True density**	Minimize	0.842	1.714
9	**Hardness**	Minimize	1.31	3.67
10	**Thickness Expansion**	Maximize	60.42	83.21
11	**L***	Maximize	29.28	43.48
12	**a***	Minimize	14.36	27.11
13	**b***	Minimize	28.12	40.06
14	**Energy content**	is in range	1021.38	1510.24

APPENDIX-F

Packaging and storage studies

TableF0. Experimental details of packaging materials

S.No	Notations	Details of packaging materials	Selected treatment
1	P_{11}	LDPE stand up pouches with (95%) N_2 gas flushing	CT2 (100^{0}C,15kPa and 20 mins)
2	P_{12}	Laminated aluminium foil flexible pouches with (95 %) N_2 gas flushing	
3	P_{13}	Polypropylene pouches without (95%) N_2 gas flushing	
4	P_{14}	LDPE stand up pouches without N_2 gas flushing	
5	P_{15}	Laminated aluminium foil flexible pouches without N_2 gas flushing	
6	P_{16}	Polypropylene pouches without N_2 gas flushing	
7	P_{21}	LDPE stand up pouches with (95%) N_2 gas flushing	CT16 (110^{0}C,13Kpa and 18 mins)
8	P_{22}	Laminated aluminium foil flexible pouches with (95 %) N_2 gas flushing	
9	P_{23}	Polypropylene pouches without (95%) N_2 gas flushing	
10	P_{24}	LDPE stand up pouches without N_2 gas flushing	
11	P_{25}	Laminated aluminium foil flexible pouches without N_2 gas flushing	
12	P_{26}	Polypropylene pouches without N_2 gas flushing	

Table F1.1 Effect of different packaging materials on moisture content and water activity of the VF carrot chips during the storage

	Moisture content					**water activity**				
	0th day	**30th day**	**60th day**	**90th day**	**120th day**	**0th day**	**30th day**	**60th day**	**90th day**	**120th day**
P11	2.42	2.89	3.26	3.72	4.38	0.314	0.37	0.471	0.508	0.534
P12	2.42	2.73	3.29	3.48	4.08	0.314	0.341	0.428	0.489	0.511
P13	2.41	2.84	3.12	3.67	4.21	0.312	0.362	0.437	0.491	0.527
P14	2.4	2.98	3.92	4.14	5.02	0.316	0.394	0.478	0.512	0.561

P15	2.41	2.91	3.25	3.78	4.88	0.31	0.387	0.482	0.514	0.545
P16	2.42	2.92	3.45	3.91	4.74	0.317	0.392	0.491	0.502	0.552
P21	1.43	1.94	2.58	2.89	3.22	0.29	0.361	0.418	0.474	0.504
P22	1.41	1.87	2.1	2.36	3.01	0.24	0.328	0.396	0.442	0.491
P23	1.38	1.49	2.62	2.76	3.12	0.25	0.341	0.403	0.469	0.499
P24	1.35	1.95	2.85	3.12	4.42	0.26	0.394	0.438	0.485	0.527
P25	1.35	1.82	2.31	2.84	4.34	0.24	0.382	0.427	0.479	0.512
P26	1.36	1.91	2.42	2.93	4.28	0.28	0.371	0.425	0.497	0.518

Table F1.2 Effect of different packaging materials on oil content and hardness of the VF carrot chips during the storage

	Oil content					**Hardness**				
	0th day	**30th day**	**60th day**	**90th day**	**120th day**	**0th day**	**30th day**	**60th day**	**90th day**	**120th day**
P11	13.51	13.51	13.51	13.51	13.51	1.52	2.25	3.01	4.08	4.97
P12	13.52	13.52	13.52	13.52	13.52	1.54	2.04	2.81	3.82	4.41
P13	13.53	13.53	13.53	13.53	13.53	1.53	2.18	2.97	3.94	4.82
P14	13.52	13.52	13.52	13.52	13.52	1.51	2.78	3.45	4.64	5.44
P15	13.51	13.51	13.51	13.51	13.51	1.52	2.54	3.12	4.25	5.08
P16	13.52	13.52	13.52	13.52	13.52	1.52	2.64	3.22	4.35	5.18
P21	23.1	23.1	23.1	23.1	23.1	2.24	3.35	4.35	5.5	6.48
P22	23.2	23.2	23.2	23.2	23.2	2.25	3.1	4.11	5.08	6.02
P23	23.1	23.1	23.1	23.1	23.1	2.24	3.24	4.24	5.38	6.25
P24	23	23	23	23	23	2.25	3.74	4.84	5.95	7.01
P25	23.2	23.2	23.2	23.2	23.2	2.25	3.53	4.68	5.78	6.84
P26	23	23	23	23	23	2.24	3.67	4.75	5.84	6.93

Table F1.3 Effect of different packaging materials on L* values of the VF carrot chips during the storage

	0th day	**30th day**	**60th day**	**90th day**	**120th day**
P11	32.28	32.78	33.5	34.45	35.39
P12	32.28	32.81	33.78	34.65	35.51
P13	32.27	32.54	33.18	34.38	35.28
P14	32.28	32.45	33.21	34.28	34.77
P15	32.28	32.38	33.15	34.19	34.4
P16	32.27	32.3	33.1	34.12	34.54
P21	38.67	38.95	39.45	39.98	40.45
P22	38.67	39.01	39.65	40.1	40.79
P23	38.66	38.89	39.12	39.87	40.23
P24	38.67	38.8	39.14	39.68	39.95
P25	38.67	38.78	39.01	39.48	39.78
P26	38.66	38.72	38.88	39.21	39.45

Table F1.4 Effect of different packaging materials on a* value of the VF carrot chips during the storage

	0th day	30th day	60th day	90th day	120th day
P11	27.81	25.84	23.98	21.24	20.05
P12	27.82	25.22	22.48	21.54	19.64
P13	27.81	25.63	22.84	20.12	19.22
P14	27.81	24.97	21.81	19.45	18.85
P15	27.82	25.02	22.25	20.34	18.97
P16	27.81	24.42	21.74	19.38	18.79
P21	32.24	30.98	28.24	26.34	25.27
P22	32.22	30.28	27.28	25.42	23.87
P23	32.22	29.87	27.42	25.01	23.28
P24	32.24	29.43	26.41	24.87	22.84
P25	32.22	29.97	27.1	25.21	22.66
P26	32.22	29.01	26.1	24.21	22.41

Table F1.5 Effect of different packaging materials on b* of the VF carrot chips during the storage

	0th day	30th day	60th day	90th day	120th day
P11	15.21	15.07	14.78	14.11	13.25
P12	15.21	14.98	14.04	13.47	12.45
P13	15.21	14.47	13.48	12.87	12.01
P14	15.22	15.01	14.12	13.11	12.78
P15	15.22	14.87	13.12	12.42	11.45
P16	15.22	14.11	12.87	11.42	10.87
P21	22.04	21.45	20.08	19.45	18.28
P22	22.06	20.78	19.42	18.78	17.77
P23	22.04	20.12	19.01	18.14	17.12
P24	22.04	21.08	19.97	19.47	18.1
P25	22.06	20.02	18.98	17.45	16.98
P26	22.06	19.98	18.41	17.01	16.12

APPENDIX- F2

ANOVA table for storage studies

Table F2.1 Moisture content

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R^2
Model	.346	5	.069	401.781	<.0001	0.99
Intercept	393.495	1	393.495	2284808.258	<.0001	
Moisture content	.346	5	.069	401.781	<.0001	
Error	.002	12	.000			
Total	393.843	18			Significant	
Corrected Total	.348	17				

TableF2.2 Water activity

Source	Type III Sum of Squares	Df	Mean Square	F	P value	R^2
Model	.006	5	.001	8.776	<.0001	0.94
Intercept	5.109	1	5.109	36787.240	<.0001	
VAR00001	.006	5	.001	8.776	<.0001	
Error	.002	12	.000			
Total	5.117	18			Significant	
Corrected Total	.008	17				

Table F2.3 Oil content

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R^2
Model	.002	5	.000	1.971	<.0001	0.89
Intercept	3291.850	1	3291.850	21161891.57	<.0001	
Oil content	.002	5	.000	1.971	<.0001	
Error	.002	12	.000			
Total	3291.853	18			Significant	
Corrected Total	.003	17				

Table F2.4 Hardness

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R^2
Model	3.776	5	.755	70.984	<.0001	0.96
Intercept	504.984	1	504.984	47465.878	<.0001	
VAR00001	3.776	5	.755	70.984	<.0001	
Error	.128	12	.011			
Total	508.888	18				
Corrected Total	3.904	17			Significant	

Table F2.5 L*

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R^2
Model	30.575	5	6.115	18655.851	<.0001	0.99
Intercept	28684.91	1	28684.915	87513300.61	<.0001	
VAR00001	30.575	5	6.115	18655.851	<.0001	
Error	.004	12	.000			
Total	28715.49	18				
Corrected Total	30.579	17			Significant	

Table F2.6 a*

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R^2
Model	287.892	5	57.578	141974.126	<.0001	0.97
Intercept	7723.588	1	7723.588	19044462.95	<.0001	
VAR00001	287.892	5	57.578	141974.126	<.0001	
Error	.005	12	.000			
Total	8011.485	18				
Corrected Total	287.897	17			Significant	

Table F2.7 b*

Source	Type III Sum of Squares	Df	Mean Square	F value	P value	R²
Model	48.846	5	9.769	11.151	<.0001	0.92
Intercept	28034.752	1	28034.752	32000.097	<.0001	
VAR00001	48.846	5	9.769	11.151	<.0001	
Error	10.513	12	.876			
Total	28094.111	18			significant	
Corrected Total	59.359	17				

Appendix-G

Table G1. Evaluation of fried oil quality parameters

Batches	Viscosity (cP)	TPC (%)	Peroxide (meq O_2/kg)	FFA (mg KOH/g)	L*	a*	b*
0	35.4	5.54	0.21	0.18	4.72	0.35	1.48
8	36.21	7.21	3.4	0.38	4.47	0.55	1.58
16	39.42	10.38	10.8	0.47	4.04	0.79	1.62
24	41.08	12.18	16.92	0.69	3.13	1.24	1.75
32	42.57	14.45	28.1	0.84	3.01	1.59	1.89
40	43.12	15.81	30.4	0.90	2.73	2.21	2.01

Table G2. ANOVA for Response Linear model –palm oil on vacuum frying

Table G2.1 Viscosity

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R²	
Model	43.80	1	43.80	403.65	< 0.0001	0.324	10.84	0.99	Significant
A-Batches	43.80	1	43.80	403.65	< 0.0001				
Residual	0.4340	4	0.1085						
Cor Total	44.23	5							

Table G2.2 TPC

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	80.08	1	80.08	363.39	< 0.0001	0.496	14.30	0.98	significant
A-Batches	80.08	1	80.08	363.39	< 0.0001				
Residual	0.8815	4	0.2204						
Cor Total	80.96	5							

Table G2.3 Peroxides

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	693.00	1	693.00	289.25	< 0.0001	0.55	11.03	0.98	Significant
A-Batches	693.00	1	693.00	289.25	< 0.0001				
Residual	9.58	4	2.40						
Cor Total	702.58	5							

TableG2.4 FFA

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	0.4321	1	0.4321	456.03	< 0.0001	0.03	15.25	0.99	Significant
A-Batches	0.4321	1	0.4321	456.03	< 0.0001				
Residual	0.0038	4	0.0009						
Cor Total	0.4359	5							

Table G2.5 L*

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	3.53	1	3.53	309.89	< 0.0001	0.10	12.6	0.99	Significant
A-Batches	3.53	1	3.53	309.89	< 0.0001				
Residual	0.0455	4	0.0114						
Cor Total	3.57	5							

Table G2.6 a*

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	1.33	1	1.33	601.10	< 0.0001	0.04	14.31	0.99	Significant
A-Batches	1.33	1	1.33	601.10	< 0.0001				
Residual	0.0088	4	0.0022						
Cor Total	1.34	5							

Table G2.7 b*

Source	SS	df	Mean square	F-value	p-value prob>F	Std. Dev	C.V (%)	R^2	
Model	4.75	1	4.75	291.09	< 0.0001	0.12	10.57	0.98	Significant
A-Batches	4.75	1	4.75	291.09	< 0.0001				
Residual	0.0653	4	0.0163						
Cor Total	4.82	5							

DEVELOPMENT AND EVALUATION OF PROCESS PROTOCOL FOR VACUUM FRIED CARROT CHIPS (*DAUCUS CAROTA L*)

By

P. BABU

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679 573

KERALA, INDIA

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ABSTRACT

Carrots are highly nutritious vegetable, which can be consumed in raw and processed form throughout the world. Carrot plays a vital role in the development and protection of human body. Carrot contains vitamins *viz.,* B1(Thiamine), B2(Riboflavin), B6(Niacin) and B12 (Cobalamin) besides rich in source of β-carotene and dietary fibre which are helpful to prevent cancer and other dreadful diseases occur in human body. In Kerala state, carrot production is very limited, but its consumption is more. The postharvest losses of carrot were estimated as 18-20%. The development of value-added products from carrot was an idealistic solution to reduce the postharvest losses by adopting new processing technologies. At present, due to consumer's awareness, there is a lot of demand for healthy and tasty snack products with less oil content which provide good health. In this context, investigation on processing technologies focus on producing high quality fried products with less oil content and good textural property. The technology of vacuum frying is a best option for the production of novel snacks which fulfil the consumers demand and meet nutritious requirements. Vacuum frying is a novel technology, in which the food is heated under lower temperature and pressure(<6kPa). Vacuum frying lowers the water activity, oil content, retains the color and preserve nutrients in the fried product. The batch type vacuum frying system consists of two chambers *viz.,* frying chamber (3kg capacity) and oil storage chamber (30-35L capacity). The refined palm oil was used for vacuum frying and the de-oiling was done at 1000 rpm for 10 min. After every batch of vacuum frying, the oil was collected for quality analysis. Prior to the research, the physico-chemical properties of raw carrot (Ooty-1) was determined. The pre-treatments *viz.,* blanching, blanching cum drying, blanching cum freezing, freezing and gum coating were optimized based on the quality of vacuum fried carrot chips. The freezing pre-treatment obtained the best results among other pre-treatments in terms of less oil content (14.48 %), water activity (0.214), moisture content (2.67%), hardness (1.282 N) and red color retention of a* value (22.85). The standardization of process parameters were done using RSM (CCRD) based on the quality characteristics of VF-carrot chips. The process parameters selected in this study were frying temperature (100,110 and 120^{0}C), frying pressure (11,13 and 15 kPa) and frying time (16,18 and 20 min). The optimum operating conditions of vacuum frying *viz.,* frying temperature, vacuum pressure and frying time were found to be 100°C, 11 kPa and 16 min respectively. At optimum operating conditions of 100°C, 11 kPa and 16 min, the quality parameters were oil content (11.31%), bulk density(0.873 g/cm^3), true density(1.714 g/cm^3), moisture content(3.28%), water activity (0.384), hardness (1.31 N),thickness expansion (60.42%), L*(43.48), a*(14.36) b*(28.12) and energy content(1021 KJ/100g). Packaging and storage studies were conducted for the treatments which had high sensory score. The laminated aluminium flexible pouch with N_2 gas filling was found to be the best packaging technique to enhance the shelf life of VF carrot chips to a storage period of 4 months. The oil quality parameters *viz.,* total polar compounds (TPC), viscosity, peroxide, free fatty acids (FFA) etc were within the allowable limits even after 40 batches of vacuum frying. The total production cost of 1kg of vacuum fried carrot chips was found to be Rs. 355/-.