DEVELOPMENT AND EVALUATION OF A VACUUM FRYING SYSTEM FOR BANANA CHIPS (*Musa spp.*)

by

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(2014-28-103)

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2017

DECLARATION

I hereby declare that this thesis entitled **"Development and evaluation of a vacuum frying system for banana chips** *(Musa spp.)***"** 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 of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis entitled **"Development and evaluation of a vacuum frying system for banana chips** *(Musa spp.)***"** is a *bonafide* record of research work done independently by Ms. Ranasalva. N under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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SYMBOLS AND ABBREVATIONS

%	:	Per cent
&	:	And
/	:	Per
@	:	At the rate of
<	:	Less than
β	:	Beta
+	:	Plus
$\pm$	:	Plus or minus
ΔE	:	Colour difference
μl	:	Micro litre
$\mu g/kg$	:	Micro gram per kilo gram
a^*	:	Greenness or redness
a_w	:	Water activity
$^\circ B$	:	Degree Brix
b^*	:	Blueness or yellowness
cP	:	Centipoise
$^\circ C$	:	Degree Celsius
$CaCl_2$	:	Calcium chloride
cm^{-1}	:	Per centimetre
d.b	:	Dry basis
etc	:	Etcetera
et al.	:	And others

Fig	:	Figure
g	:	Gram
gL^{-1}	:	Gram per litre
gcm^{-3}	:	Gram per cubic centimetre
h	:	Hour
hp	:	Horse power
i.e.,	:	That is
kPa	:	Kilo Pascal
kJg^{-1}	:	Kilo Joule per gram
kg	:	Kilo gram
kgh^{-1}	:	Kilo gram per hour
kW	:	Kilo Watt
kgcm^{-2}	:	Kilo gram per centimetre square
L	:	Litre
L*	:	Lightness or darkness
lpm	:	Litre per minute
Min	:	Minute
mm	:	Milli metre
mm of Hg	:	Millimetre of mercury
mms^{-1}	:	Milli metre per second
m Pa s	:	Milli Pascal second
meqO$_2$kg^{-1}	:	Milli equivalent oxygen per kilo gram
m^{3}hr^{-1}	:	Metre cube per hour

mg KOHg^{-1}	:	Potassium Hydroxide in milligrams per gram
N	:	Newton
N$_2$	:	Nitrogen
Nsm^{-2}	:	Newton second per square metre
p	:	Probability
pps	:	Parts per second
R^2	:	Regression coefficient
rpm	:	Revolution per minute
s	:	Seconds
w.b	:	Wet basis
X$_1$	:	Frying temperature
X$_2$	:	Frying pressure
X$_3$	:	Frying time
Viz	:	Namely
AACC	:	American association of cereal chemists
ANOVA	:	Analysis of variance
AOAC	:	Association of official analytical chemists
Approx.	:	Approximately
AnV	:	p-Anisidine value
Atm-raw	:	Atmospheric fried raw banana chips
Atm-ripe	:	Atmospheric fried ripened banana chips
BMI	:	Body mass index
CCRD	:	Central composite rotatable design

DAD	:	Diode array detector
EX	:	Excellent
FFA	:	Free fatty acid
FR	:	Fair
FMF	:	Fuzzy membership function
GD	:	Good
HMI	:	Human machine interface
HPMC	:	Hydroxypropylmethylcellulose
HPLC	:	High performance liquid chromatography
ICMR	:	Indian Council of Medical Research
IV	:	Iodine value
JMFM	:	Judgment membership function matrix
JS	:	Judgment subset
KCAET	:	Kelappaji College of Agricultural and Engineering Technology
KAU	:	Kerala Agricultural University
LDPE	:	Low density poly ethylene
Matlab	:	Multi-Paradigm numerical computing environment and fourth-generation programming language
MC	:	Methyl cellulose
MD	:	Medium
NFMF	:	Normalized Fuzzy membership Function

NHB	:	National Horticultural Board
NS	:	Not satisfactory
PID	:	Proportional integral derivative
PV	:	Peroxide value
RSM	:	Response surface methodology
SPI	:	Soy protein isolate
SS	:	Stainless steel
TA	:	Texture analyser
TOTOX value	:	Total oxidation value
TPC	:	Total polar compound
TSS	:	Total soluble solids
USA	:	United State of America
USB	:	Universal serial bus
VF-raw	:	Vacuum fried raw banana chips
VF-ripe	:	Vacuum fried ripened banana chips
WPI	:	Whey protein isolate
YI	:	Yellowness Index

Introduction

CHAPTER I

INTRODUCTION

India has the distinction of being the pioneer in banana production in the world. The country's production area and production capacity of banana was 776 hectares of 29.7 million tonnes in 2016 with highest production in Tamil Nadu, Maharastra, Gujarat and Andra Pradesh (GOI, 2017). Kerala state of India is privileged to posses the largest consumers of banana in the country and an appetizing variety of banana products. It includes banana fritters (*palampori*), banana chips, sweet banana chips coated with jaggery, banana flour, banana *payasam*, *halwa*, *etc*. Moreover, the *Nendran* banana clone '*Chengalikodan*' of Kerala has been recently accorded with geographical indication status in the year 2015 (Mini, 2015).

Banana, '*The Apple of paradise',* is a climacteric fruit that produces ethylene after harvest, ripen rapidly and is highly prone to storage loss (Uma and Shanmugam, 2015). The post harvest loss of banana begins from harvesting, handling, and storage due to improper handling. The estimated post harvest loss in fruits and vegetables is 5 to 30 per cent of its total production. The loss was mainly due to improper post harvest handling. The estimated loss for banana was 10-12 per cent (GOI, 2017). The main reason for the loss was its improper post harvest handling and its specific storage temperature of 12-14°C which demanded a separate cold storage chamber that incurs additional cost. Nevertheless, bananas with its richness in nutrients like vitamin B, potassium, phosphorus, *etc* and its affordability adorn a unique platform amongst other fruits.

A pragmatic solution for reducing the post harvest loss in *Nendran* banana is the adoption of suitable processing strategies. Banana chips are the flagship product among its processed products and are known as '*The taste of Kerala'*. They are an inevitable component of marriages and traditional celebrations of Kerala. The traditional banana chips after encountering threat from its western snack counterpart has now regained its share in snack market with emerging brands like Tierra, A1 chips, banana slices, *etc*.

Snack food market registered colossal growth among food processing industries in India. Deep fat fried products have a key share in snack food production sector. Frying, particularly deep fat frying crafts the product to be appealing in terms of colour, aroma, texture and taste. The absence of suitable replacement for the taste of deep fat fried products has increased the consumer demand for these products. Nevertheless, high intake of the same is associated with several health issues like obesity, cancer, cardiovascular disease, diabetes, *etc* due to intensive absorption of oil (Albert and Mittal, 2002). Besides, degradation of oil quality during deep fat frying also poses a potential threat to consumer's health. In spite of all the health issues, consumers continue to relish deep fat fried snack products.

The presence of high oil content is often not essential for product quality and is disadvantageous to consumers and producers in terms of profit margin based on reusable cycle (Oginni *et al.,* 2014). The development of superior grade fried products with minimum oil and of good quality is of great interest to food industry and consumers. The health concern of the modern consumers has placed on demand, the need for low fat, healthy and tasty snack product. This prompted researchers to investigate and come up with means to reduce the oil content of fried snack products.

Traditionally, fried products are produced by deep fat frying method. In this method edible fat is heated above the boiling point of water and serves as the heat transferring medium. During this process fat migrate into the food, providing nutrients and flavour (Tarmizi and Niranjan, 2011). The oil content of deep fried product show high percentage than any other processing method. The other prevailing non fat frying process like air frying, utilises air as the heating medium. But, the taste of air fried product could not compete with that of deep fat fried product. Vacuum frying is a promising alternative frying technology to improve the quality of fried products (Song *et al*., 2007).

Vacuum frying technology obliterates all the detrimental effects of atmospheric frying on both oil and fried product. During vacuum frying, the

sample is heated under a negative pressure that lowers the boiling and smoking points of water and oil (Troncoso *et al*., 2009). This effect reflects positively on the quality of oil and fried product. The unbound water in the fried food could be rapidly removed when oil temperature reach the boiling point of water. Moreover, absence of air during frying inhibit lipid oxidation and enzymatic browning, thus preserving the colour and nutrients of samples. Studies have also showed that the formation of acrylamide a potential carcinogenic agent could be reduced to a negligible amount by adopting vacuum frying technology.

Vacuum frying is a progressing and propitious technology for the production of low fat fried products with better quality (Dueik and Bouchon, 2011). Several studies in this regard have been carried out with various foods like fruits, vegetables, chicken and fish. The pressure, temperature and time of vacuum frying need to be optimised for different products based on the product and oil properties. Oil used in vacuum frying could be reused several times without affecting its quality (Garayo and Moreira, 2002). Vacuum fried products pose acceptable organoleptic properties without any major change in the nutritional quality.

Adoption of pre-treatments on fried products like coating with hydrocolloids, battering, blanching cum drying, *etc* could considerably reduce the oil content (Albertos *et al.,* 2016). The de-oiling mechanism like post centrifugation was also employed to reduce the oil content of fried product.

Reduction of oil content alone does not safeguard the health of consumers. The frying oil which is the cooking medium must be of good quality without any free radicals. Thus the choice of oil is yet another challenge to prepare deep fat fried products. Blending of rice bran oil with corn oil was the recommended choice for the production of quality fried products (Fan *et al*., 2013).

Frying under vacuum reduce the oil retention which offer less oily taste without compromising natural colour, flavour and nutrients of the products. There exists a research gap in the adoption of vacuum frying process protocol for

Nendran banana. Research is yet to be undertaken for optimising pre-treatments along with evaluation of blended oils for vacuum frying of this common fruit of Kerala. Hence the present research work was formulated with the following objectives

- To develop and evaluate a vacuum frying system suitable for production of ripe and unripe banana chips
- To optimise the pre-treatment and process parameters for vacuum fried banana chips
- To conduct shelf life studies of vacuum fried chips under modified atmosphere packaging

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with a comprehensive review associated with the development of vacuum frying system, quality of frying oil and properties of fried products. Summarising and compiling previous research results bestows an insight of work to be committed in the present study. With this perspective, the following were reviewed in detail

2.1 Banana and its products

2.2 Frying

2.3 Frying oil

2.4 Deep fat frying

2.5 Vacuum frying

2.6 Pre-treatments for frying

2.7 De-oiling of fried product

2.8 Changes in properties of frying oil

2.9 Properties of fried products

2.10 Sensory analysis

2.11 Packaging and storage studies

2.12 Statistical analysis

2.1 BANANA AND ITS PRODUCTS

The *Nendran* banana ranks first in the commercial market with high medicinal values (Das, 2010). *Nendran* bananas have a beneficial effect in reducing blood pressure, anemia, ulcer, heart burn and obesity (Sampath *et al.*, 2012). Gowri and Shanmugam (2015) surveyed the market potential of three banana varieties *viz., Nendran*, *Kathali* and *Poovan* in India and stated that *Nendran* variety have high scope in commercial market providing 71.1% profit to the cultivating farmers followed by *Kathali* (68.1%) and *Poovan* (65.3%).

Illeperuma and Jayathunge, (2001) developed a process protocol for osmo-air drying of over ripe banana to prepare *Kolikuttu*. The process parameters were optimised based on the sensory, nutritional and quality attributes of developed product. The optimised protocol was to soak the bananas in 70°B sugar syrup for 5 h followed by drying at 65°C for 8 h. This resulted in quality product with low water activity (0.59) and moisture content (3.5%).

The sustainability of volatile compounds in banana chips, prepared using different drying methods (hot air drying, vacuum microwave drying and freeze drying) were studied by Mui *et al.* (2002). The banana chips dried with 90% of air drying and 10% with vacuum microwave drying possessed high volatile compounds than other combinations of drying.

Bornare *et al.* (2014) demonstrated several value added products from banana which includes, chips from *Nendran* banana, banana candy prepared using jaggery, flour from raw banana, powder from ripe banana, juice, fruit bar, jam, jellies and wine from over ripe bananas. Similarly, the process protocol for value added products with raw banana flour like health mix and millet based ethnic mix were standardised based on the quality and sensory attributes (Sudheer *et al.*, 2014; Sudheer and Ranasalva, 2015).

Elkhalifa *et al.* (2014) studied the quality parameters of fried potato chips, fried banana chips and baked banana chips. The quality parameters and sensory preference was high for fried banana chips compared with baked banana chips and fried potato chips. But the oil content of baked banana chips was 63% less than the fried products. This study proved that fried banana products had good consumer preference. Sonia *et al.* (2015) developed a protocol for flavoured banana chips. Fresh and dry form of garlic, black pepper, curry leaves and coriander leaves each with concentration of 1 and 2% were tested for its quality and sensory analysis. On sensory and quality evaluation, 2% of dry garlic flavoured banana chips scored best results.

Vimitha *et al*. (2015) standardised the protocol for the production of *Nendran* banana intermediate moisture food using osmo-vac technology. The standardised process conditions were slicing (6 mm) of ripe banana, blanching (2 min) soaking in osmotic solution (60 - 65°B for 24 h) and drying in vacuum dryer (60°C for 9 h). The sensory evaluation and other quality analysis exhibited a good score for the banana intermediate moisture food prepared from standardised process.

James *et al.* (2016) optimised the production process of fried plantain product *dodo* by employing response surface methodology. The optimised frying temperature and time were 177.51°C and 2.10 min respectively. The product showed highest score of 7.5 out of 9 point hedonic scale in sensory analysis with moisture content (14.56% *w.b*), oil content (1.42%) and hardness 2.4 N.

2.2 FRYING

Frying is a multifarious and essential operation in the field of food industry (Hubbard and Farkas, 2000). It is an ancient cooking method which involves engrossing food in oil or fat at high temperature. The fried product discerns unique texture and aroma than other cooking methods (Bouchon and Pyle, 2004). Orthoefer (1987) suggested that frying was a fast heating and uniform cooking method than other cooking processes. During frying, moisture present in the food product gets evaporated and oil from frying medium penetrates into food due to temperature gradient and the crust on surface of fried product was formed due to this mass transformation (Blumenthal, 1991). Food behaves as a colloid non porous, non homogenous anisotropic material on frying (Wu *et al.* 2010).

The usual frying temperature is 180°C or higher and at this temperature, both food and cooking oil underwent various physical and chemical changes (Firestone, 1993). Based on usage of oil for frying, they were categorised into deep fat frying, shallow frying and sautéing. Deep fat frying was the most preferred processing method of frying due to its reduced cooking time and unique

cooked flavour (Blumenthal and Stier, 1991). The shallow frying involved limited usage of oil where the product was not completely immersed in heating medium while deep fat frying involved complete immersion of food product into oil. In Sauteing, the base of cooking vessel was greased with oil and the cooking was carried out under low flame due to scorching (Warner, 2008).

2.3 FRYING OIL

Krishna *et al.* (2005) confirmed that chemically refined rice bran oil showed 7% low oil uptake than sunflower oil on deep fat frying of *bhujja*. It was also proved that the chemical change was significantly less in rice bran oil. They reported that the reduction in oil uptake was due to the presence of oryzanol content.

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

Feranil *et al.* (2011) stated that the use of coconut oil increased the good cholesterol and body mass index (BMI) of pre-menopausal women. However, Marinova *et al.* (2012) found that olive oil was more thermally stable than corn, soya bean and coconut oil on heating to a frying temperature of 185°C.

Debnath *et al.* (2012) demonstrated the quality changes of rice bran oil on frying cycles and revealed that the rice bran oil significantly resists TPC generation than palm oil. The TPC of rice bran oil increased from 3.2% to 23% after 25 times of frying while that of palm oil increased beyond 27%.The presence of oryzanol, a natural antioxidant, contributes to the low TPC in rice bran oil on frying. Leong *et al.* (2015) experimented on repeated frying of oils and their result supported the findings of Maryam *et al.* (2010). Palm oil had high oxidation and hydrolysis stability compared with soya bean, groundnut, coconut, sesame, rapeseed, sunflower and olive oil.

2.3.1 Blending of Oil

According to Indian Council of Medical Research, a balanced diet should contain 20% fat, out of which 8-10% energy should be from saturated and polyunsaturated fatty acids each and 10-12% energy from monounsaturated fatty acids (ICMR, 2010). Single refined oil had an ideal fatty acid profile composition, so blending of oil is an economic way of modifying the fatty acid composition and physicochemical characteristics of vegetable oils (Karthickumar *et al*., 2015). Several studies on blending of oil for the purpose of deep fat frying were done and are reviewed below.

The corn oil and olive oil was blended and compared with individual corn and olive oils for its qualities after deep fat frying (Arhontoula *et al.,* 2006). The iodine value of corn oil decreased rapidly than blended oil, while olive oil showed no significant change after 5 days of frying. The result of other oil stability parameters favoured olive oil with less degradation followed by blended oil and corn oil which were highly susceptible to degradation after 6 h of frying. Conversely, Zahir *et al.* (2014) found low oxidation degradation in corn oil when compared with mustard oil on repeated frying.

Similarly, thermal and oxidation stability of coconut oil blends were studied by Khan *et al.* (2008) during the production of potato chips. Among the three blends (blend I – coconut oil + sesame oil; II – coconut olein oil + sesame oil; III - coconut olein oil + palm olein oil) tested, the blend III yielded good sensory and physical quality of potato chips as well as exhibited good oxidation stability.

Mariscal and Bouchon (2008) used Fritomaster, a commercially available blended oil known for its high oxidation stability (partially hydrogenated oil: 25% sunflower oil and 75% soya bean oil) to vacuum fry apple slices. Alireza *et al.* (2010) also had reported that the palm oil blended with canola oil (1:1) exhibited good thermal and oxidation stability with high degree of unsaturation (87.7 g/100 g) than when blended with sesame oil (1:1) (65.32 g/100 g). The blend also

displayed negligible change in iodine value which was preferred for deep fat frying.

The palm oil was usually preferred for deep fat frying due to its good oxidation stability during frying (Shyu and Lucy, 2011). Further, Khan *et al.* (2011) carried out a sensory analysis of wheat based product fried with blends of coconut and sesame oil (A), coconut olein with sesame oil (B) and coconut olein with palm oil (C). The result suggested that blend C was preferred by consumers, since the intensity of coconut oil odour reduced significantly and also had high frying stability compared to other two oil blends.

A study carried out by Monika and Kiran (2013) on blend of rice bran oil with olive, groundnut, soybean, sunflower, mustard and palm oil proved that rice bran oil and palm oil blend (80:20) exhibited minimum degradation and chemical reactions on repeated frying. Another study on blend of rice bran oil with sunflower oil was done by Mishra and Sharma (2014). The result showed that blended oil had low colour degradation with less peroxide formation than pure rice bran oil. Also, the results suggested that, frying of moist potato produced more peroxides (8.65 meqO_2kg^{-1}) than that with dried potatoes (4.02 meqO_2kg^{-1}) in the blended oil.

Tiwari *et al.* (2014) blended palm and sesame oil in different ratios to improve the thermal stability of oil during deep fat frying at 180°C for 12 h. The results of their study confirmed that oils blended in ratio 52: 48 palm: sesame oil had high thermal stability with increase in iodine value from 111.32 to 82.45 and decrease in peroxide value from 8.43 to 6.32 meqO_2kg^{-1}.

Siddique *et al.* (2015) investigated palm oil blend (sunflower, soya bean and canola oil) and its quality changes on repeated frying of fish at 200°C. On fourier transform infrared (FTIR) spectroscopy analysis, similar absorption band between 2900 - 3006 per centimetre was noted for both pure and blended oils before subjected to frying which indicated similar structure for the fresh oil blends. After frying was carried out, the blend with high palm oil ratio was found

stable on *cis-trans* bond changes and blend with sunflower and canola oil got saturated.

2.4 DEEP FAT FRYING

Deep fat frying process involved heat and mass transfer and exhibited extensive physical and chemical changes on fried product (Sahin and Sumnu, 2009). Vitrac, *et al*. (2002) examined the changes in deep fat fried product, *viz*., gelatinisation of starch, denaturation of protein and development of aromatic compounds through Maillard reactions and increase in oil content of food through oil absorption. The quality attributes like flavour, texture and nutrient composition were changed on deep fat frying (Zhang *et al.,* 2012).

The absorption of oil during deep fat frying could be better understood by knowing its heat and mass transfer mechanism. The quality parameters of fried product like oil content, moisture loss and other attributes were highly influenced by its heat and mass transfer (Sahin and Sumnu, 2009). Farkas *et al.* (1996) reported that before attaining complete frying, the product experienced two phases with four stages in each phase of frying. The non - boiling phase which included first and final stage (initial heating and bubble end point) and the boiling phase which included second and third stage (surface boiling and falling rate stage).

There are two distinct modes of heat transfer during deep fat frying: convection (between food and heating medium) and conduction (within the food). It was reported that rate of heat transfer through convection was governed by heat transfer coefficient while conduction depended on thermal conductivity coefficient. Natural convection took place between submerged food surfaces in oil which was the initial heating stage in frying. Due to turbulence in the frying oil at temperature above the boiling point of water, heat transfer shifted from natural to forced convection in the second boiling stage. In the third falling rate stage, transfer of heat was initiated through conduction within the inner part of food. The final stage which is non bubbling stage was associated with thickening of crust surface which decreases the heat transfer resulting in absence of bubbles on the

surface of food. This final stage indicates completion of frying (Farkas and Hubbard, 2000).

The rate of heat transfer during frying, highly rely on heat transfer and thermal conductivity coefficient of product to be fried (Moreira *et al.,* 1995). Alvis *et al.* (2009) stated that food was completely exposed to uniform heat treatment through frying medium during deep fat frying which provided unique flavor and aroma to the product.

Ahromrit and Nema (2010) used Fickian diffusion theory (Dincer, 1996) and investigated the heat and mass transfer properties of pumpkin, sweet potato and taro during frying. The results of their study indicated that diffusion theory was simple to determine the heat and mass transfer properties.

The mass transfer during frying was governed by Fick's law of diffusion. The mechanisms proposed for the mass transfer were vapour and moisture diffusion, hydrodynamic and capillary flow and surface evaporation, which were complicate to be modelled mathematically (Wang and Sun, 2003).

The results of experiments conducted by Costa *et al.,* (1999), Sahin *et al.* (1999) and Budzaki and Seruga (2004) on heat and mass transfer coefficient during frying elucidated that heat and mass were proportional to temperature. The Fig. 2.1. explains the changes within the food product on deep fat frying.

Mosavian and Karizaki (2012) elucidated that the mass transfer parameters like effective moisture diffusivity and mass transfer coefficient were directly proportional to frying temperature and reverse for mass transfer Biot number in rice crackers.

2.5 VACUUM FRYING

Vacuum frying was an alternative frying technique where frying was done under reduced pressure (Troncoso *et al*., 2009). This frying condition rendered to produce superior quality of fried product with low oil content and retained the colour (Song *et al*., 2007).

Atmospheric conditions

Frying oil oxidation

High temperature

Frying oil thermal degradation

CRUST

Beneficial compounds degradation

Oil uptake

Key structural

Components changes

CORE

Starch dehydration

Moisture loss

Water vapourisation

Frying oil hydrolysis
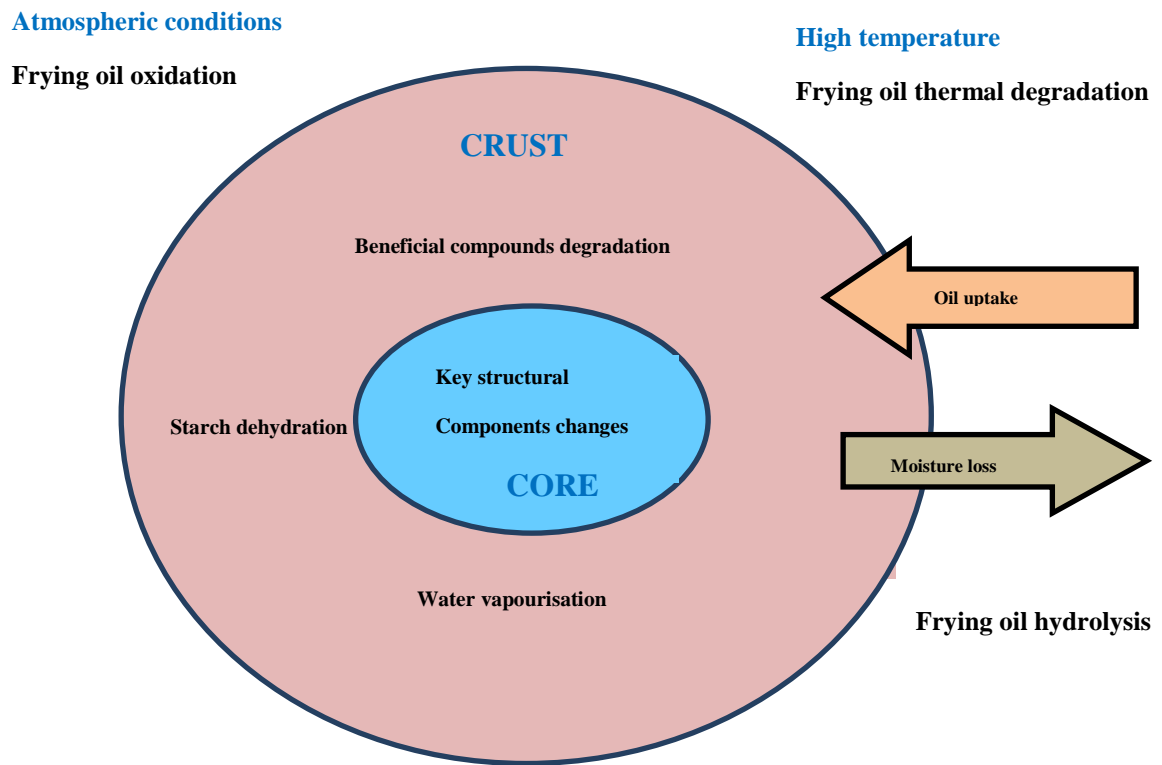
Fig. 2.1 Changes during atmospheric deep fat frying

(Esan *et al*., 2013)

Granda *et al*. (2004) identified vacuum frying as a novel application to reduce acrylamide formation in potato chips. Perez-Tinoco *et al*. (2008) reported that the quality of pineapple chips in terms of retention of its colour, nutritional attributes and antioxidant capacity was better under vacuum frying than atmospheric frying. The optimised frying temperature and time was 112°C for 7 mins. Vacuum fried pineapple chips had an oil content of 20% (*d.b*) and moisture content of 4%, with reduced colour loss.

Dueik et al. (2010) stated that reduction of micro structural changes during vacuum was a major advantage of the technology. Andrés-Bello et al. (2010) compared vacuum frying (90, 100 and 110°C) and atmospheric frying (165°C) of gilthead sea bream fillets for its oil uptake, colour and shrinkage. Vacuum frying of gilthead sea bream fillets revealed better results in all quality attribute. Dueik and Bouchon (2011) portrayed vacuum frying as an ideal frying method for frying carrot, potato and apple chips without significant degradation in nutritive quality when compared to atmospheric frying. In vacuum fried carrot chips 90% of total carotenoids and in apple chips 95% of ascorbic acid (AA) were retained.

Suxuan and Kerr (2012) indicated that vacuum frying and baking methods were the only two healthy cooking methods to produce low fat crispy snack products from corn. Ravli et al. (2013) compared quality attributes of two stage (TS) (atmospheric frying for 1 min followed with vacuum frying for 3 min) and single stage (SS) frying (vacuum frying) of sweet potato chips. The TS frying showed better texture and appearance with 15% low oil content than SS frying.

Jorge *et al.* (2012) performed an experiment to understand the evolution of heat transfer coefficient at different vacuum frying processing conditions. The effect of frying temperature and pressure was enumerated using the bubbling efficiency parameter. The results denoted that convective heat transfer coefficient increases with increase in frying temperature (100 -140°C).

Garayo and Moreira (2002) described the three stages of mass transfer mechanism during vacuum frying *viz.,* Frying, pressurisation and cooling. During frying stage, the frying sample formed a crust by losing its surface moisture to the frying medium. The boiling point of water was less than 100°C under vacuum pressure (56.0°C for 16.661 kPa, 45.4°C for 9.888 kPa and 24.6°C for 3.115 kPa). Absorption of oil by the product was absent during frying stage. The second pressurisation stage started when the sample was vented to remove it from oil. At this stage, the pressure gradient created trigger to facilitate the penetration of surrounding gas and surface oil into the pore space of sample until it reached atmospheric pressure. The diffusion of gas rapidly into the empty pore space of fried product prior to surface oil assured low oil content in this stage. The third

cooling stage occurred when the fried samples were taken out of the fryer. The remaining adhered oil on the surface diffused into the sample during cooling stage.

2.5.1 Vacuum Frying System

Garayo and Moreira (2002) developed a vacuum frying system (Fig. 2.2.) and potato chips fried in the developed system possessed better nutritional quality than conventionally fried product. An electric pressure cooker with capacity 24 l was customised to serve as vacuum frying chamber. The chamber was provided with pressure gauge and transducer to measure temperature, and a lift rod to hold the frying chamber. A dual seal vacuum pump was connected to the frying chamber. A condenser was fitted between frying chamber and vacuum pump to avoid mixing water vapour from frying chamber and vacuum pump oil.

Dueik *et al.* (2010) experimented vacuum frying of carrot chips using a steel chamber (316 L) with lid and chamber connected to a two stage vacuum pump capacity (1.92 mm of Hg) at which boiling point of water is 38°C. The developed system was reported to be effective in frying when evaluated with carrot chips. Andrés-Bello *et al.* (2010) used GASTROVAC® equipment (Fig. 2.3.) for the vacuum frying experiments on gilthead sea bream fillets and compared with atmospheric frying. The equipment setup consisted of a pressure cooker with a basket, membrane vacuum pump and temperature control system. Both the vacuum fried carrot chips and gilthead sea bream fillets showed significant retention of nutritive attributes than atmospheric frying.

Nuttapong and Thatchapol (2015) experimented on vacuum frying of banana in the vacuum frying system represented in Fig. 2.4. The system comprised of a storage tank for storing oil after completion of frying. The heat was supplied through gas cylinder with external flame to heat the oil used for frying. The results showed vacuum fried banana chips had with low oil absorption than atmospheric fried ones.
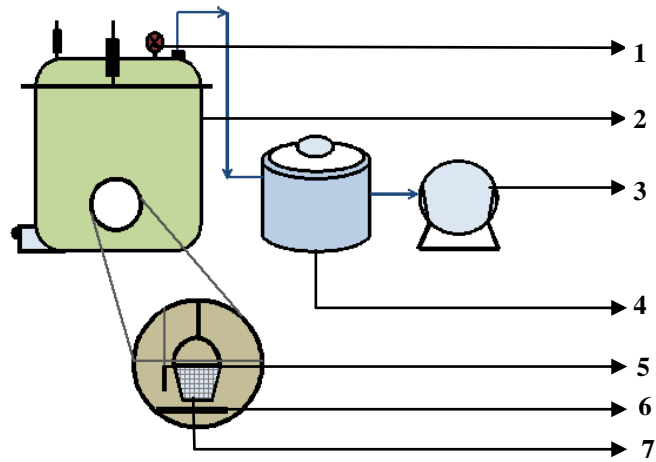
1.Pressure gauge   2.Frying chamber   3.Vacuum pump   4.Condenser

5.Temperature probe   6.Heating element   7.Frying basket

Fig. 2.2 Vacuum frying system experimented with potato chips

Garayo and Moreira (2002)
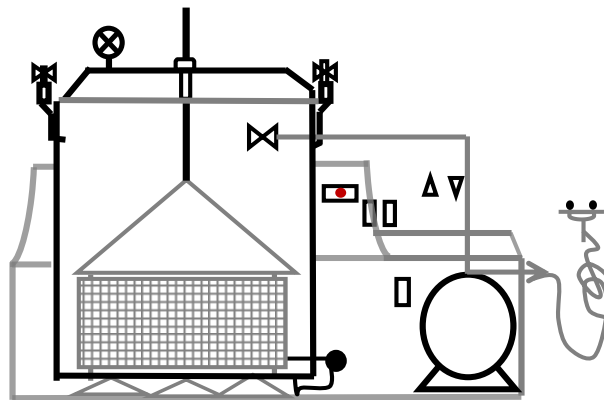
(1) Frying chamber   (2) Frying basket   (3) Vacuum pump

(4) Heating element

Fig. 2.3 Vacuum-frying system used for frying of gilthead sea bream fillets

Andrés-Bello *et al.* (2010)
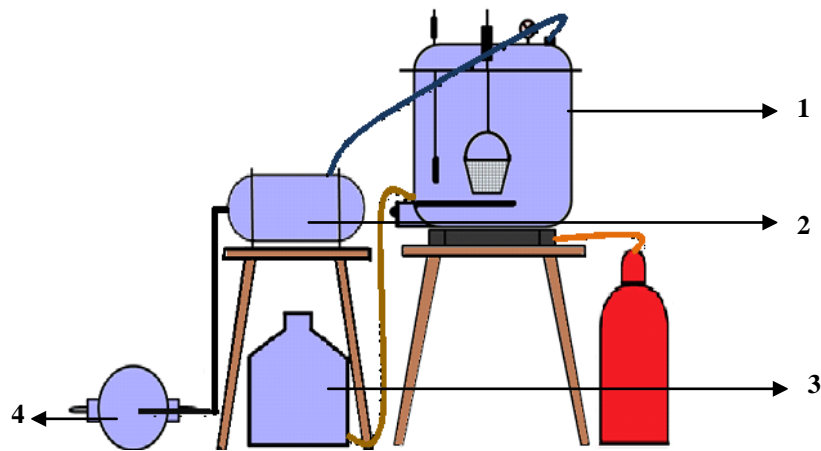
1. Vacuum fryer   3. Oil storage tank
2. Condenser   4. Vacuum pump

Fig. 2.4 Vacuum frying system with gas cylinder

Nuttapong and Thatchapol (2015)

2.5.2 Process Parameters for Vacuum Frying

The frying temperature, pressure and time were the major parameters optimised based on the fried product quality. A study conducted by Garayo and Moreira (2002) on vacuum frying of potato chips showed that high frying temperature (144°C) combined with low pressure of 3.11 kPa favoured faster rate of moisture removal. The optimised frying conditions to attain an effective plateau of moisture in fried product was 360 s frying time at 3.11 kPa and 600 s at 16.661 kPa with frying temperature of 144°C.

Fan *et al.* (2005) optimised frying conditions to obtain low oil content and high nutrient vacuum fried carrot chips. Frying temperature of 100 - 110°C, vacuum pressure of 0.010 - 0.020 MPa and a frying time of 15 min were the optimised processing parameters for vacuum fried carrot chips.

Jorge *et al.* (2009) studied the effect of vacuum break condition on post cooling of vacuum fried potatoes. It was observed that high vacuum break velocity and draining time resulted in low oil uptake.

Vacuum frying of carrot chips using sunflower oil at 98 and 118°C and atmospheric frying at 160 and 180°C with thermal driving force (DF) of 60 and 80°C was studied. Better quality of carrot chips with 90% of carotenoid retention were found in vacuum frying at 108°C frying temperature 1.92 mm of Hg pressure with the frying time (till the bubble end point) of 8 min (Dueik *et al.,*2010).

Andrés-Bello *et al.* (2010) reported that vacuum fried gilthead sea bream fillets, fried at 110°C and 25 kPa for 10 min exhibited low oil content than the fillets fried under other low temperatures of 90 and 100°C. Similarly, Pan *et al.* (2015) illustrated that the frying temperature significantly affected the oil absorption and moisture loss in vacuum fried breaded shrimp. The oil content increased with increase in temperature (90, 100 and 120°C) and the shrimp fried at 120°C and 20 kPa for 12 min showed highest oil content of 0.25 ± 0.019 g oil per gram dry solid.

It was evident from the experimental results of Mayyawadee and Gerhard (2011) that frying temperature (140°C) and time (10 s) favoured crispness with other organoleptic properties in fried cassava crackers. Diamante *et al.,* (2012) optimised the vacuum frying conditions for low oil absorption and low browning index with maltodextrin coating as 100°C frying temperature, 65 min frying time and 70% maltodextrin.

Sandhu *et al.* (2013) studied the changes in oil absorption pattern during frying of chicken nuggets concomitant with pressure gradients. The results confirmed that negative pressure created inside the fryer in last stage of frying and cooling stage provoked the oil absorption during frying. Amany *et al.* (2012) and Teruel *et al.* (2014) reported that pressure gradient created immediately after frying favoured oil absorption during vacuum frying. The surface oil present over fried product gets diffused into core of fried product which resulted an increase in oil content.

2.6 PRE-TREATMENTS FOR FRYING

Pre-treatments are done mainly to increase the quality and to reduce the oil absorption in the fried product.

2.6.1 Blanching cum Drying

Blanching is a process of partial heating of the product intended to inactivate the enzymes. It is executed commonly as a pre-treatment prior to thermal processing. Debnath *et al.* (2003) stated that drying created a firm surface matrix limiting the oil absorption during frying. Similarly, Pedreschi and Moyano (2005) stated that oil uptake of potato chips, pre – treated with blanching (85°C for 3.5 min) and drying and fried at 180°C for 10 min was low. The oil uptake was 45% less compared to untreated samples.

Apple slices pre-treated by drying were compared with vacuum and atmospheric frying by Mariscal and Bouchon (2008). The results of their study revealed that drying as a pre-treatment before vacuum frying had a synergic effect on the reduction (50%) of oil absorption in fried apple slices. Similarly, Da-Silva and Moreira (2008) compared vacuum and atmospheric fried sweet potato, green beans, mango and blue potato. Among the four produce, mangoes and green beans were pre-treated with 50% maltodextrin and subjected to osmotic dehydration prior to frying. Vacuum fried sweet potatoes and green beans showed 26% and 16% less oil content respectively, than atmospheric frying. While, vacuum frying of mango and blue potato resulted in significantly higher oil content than atmospheric frying.

Troncoso *et al.* (2009) performed deep fat frying of potatoes pre-treated with blanching and chemical treatment. The results revealed that potatoes treated with sulphite had better colour since it acted as an anti-browning agent. Arlai (2009) demonstrated that blanching retained bio-active compounds and enhanced the colour in vacuum fried okra.

Samatcha *et al.* (2010) conducted an experiment on fried popped rice with drying as pre-treatment. Steam cooked rice was dried at 65°C for 2, 3 and 4 h and

fried at 210°C for 5, 10 and 15 s. The results showed that the product dried for 2 h had lighter colour after frying and the sample dried for 3 h had good sensory acceptability.

2.6.2 Freezing

Vacuum fried carrot chips pre-treated with maltodextrin solution and freezing absorbed high oil during frying. The oil content was significantly higher (52%) for the frozen pre-treated product and low oil content (20%) was observed in maltodextrin treated sample (Shyu *et al.,* 2005). Fan *et al.* (2005) confirmed that freezing was an alternate pre-treatment to improve the quality of fried product.

Diamante *et al.* (2011) reported that no significant difference was observed in moisture content of fried kiwi fruit pre-treated with freezing along with soaking in 35% maltodextrin solution and without soaking.

Albertos *et al.* (2016) investigated on vacuum fried carrot slices pre-treated with high pressure processing and freezing. The carrot chips pre-treated with freezing favoured high oil absorption than untreated and high pressure processed samples. Carrot slices of 5 mm thickness was blast frozen at -20°C for 2 h and stored at the same temperature till processing. The frozen samples were fried at 106°C, 80 mm Hg for 9 min and the fried product exhibited significantly lower moisture content and high oil content compared with untreated sample.

2.6.3 Gum Coating

Hydrocolloids possess wide multifunctional application in food processing industry like emulsion stability, textural modification and regulation of moisture content. Nonetheless they also hold ability to form edible film on food surface and act as hurdle for oil absorption during frying. Suitable coating material was explored for oil reduction in deep fried cereal products. Eleven coating materials including gelatine, gellan gum, 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

(WPI) were considered under the study. Double layer coating was most effective in reducing oil absorption than single layer coating but retention of water was high in it. The water uptake and fat uptake ratio (SPI/WPI) revealed that mixed coating reduced the fat uptake by 99.8% with an index of 2.72, and SPI/MC coating reduced fat uptake by 83.5% with an index of 3.19 with better coating for low oil uptake (Albert and Mittal, 2002).

Khalil (1999) attempted to reduce the oil absorption in potato chips using hydrocolloids (with 1.5% carboxy methyl cellulose and 0.5% calcium chloride + 5% pectin) and achieved 54% and 43% reduction in oil content. Mellema, (2003) stated that thermal gelling in gum coating or its cross linking property facilitated low capillary pressure resulting up to 50% reduction in oil absorption.

Hydrocolloid cements the cell wall of banana and prevent oil uptake during deep fat frying. Conversely, moisture content was high in hydrocolloid coated chips than in control due to the water holding capacity of hydrocolloids. Furthermore, quality and bulk volume of the fried product was enhanced (Sahin *et al.,* 2005). Ngadi *et al.,* (2009) coated chicken nuggets (1 mm thickness) with mixture of wheat flour, guar gum, corn flour, wheat crumbs, salt and spices and kept in microwave for 300 s. The treated nuggets showed significantly low moisture with crisp texture than the un-treated chicken.

Singthong and Thongkaew (2009) studied the effect of different hydrocolloid (alginate, pectin and carboxy methyl cellulose) coating on matured banana (*Musa sapientum Linn*.) chips. Pectin was reported to reduce oil content by 23 g per 100 g besides higher sensory score on all attributes. Similarly, 27% reduction in oil absorption was achieved in hydrocolloid treated fried cassava products (Freitas *et al.,* 2009).

Sothornvit (2011) investigated edible coating combined with post frying centrifuge of vacuum fried banana chips (*cultivar Kluai Hom Thong*). Xanthan gum and guar gum coated banana chips without centrifugation resulted 17.22 and 25.17%, reduction in oil absorption. The combined gum coating and

centrifugation at 280 rpm reduced 33.71% oil content of the vacuum fried banana chips. The guar gum with its higher viscosity and film forming ability showed highest reduction in oil absorption compared with xanthan gum. Further, Kim *et al*. (2011) stated that the addition of gellan gum and guar gum as hydrocolloid coatings significantly reduced the heat transfer coefficients and oil uptake in potato strips during frying process.

Parimala and Sudha (2012) conducted a study on guar gum coated *puris* and reported that the fried *puris* had improved qualities in terms of moisture retention, oil absorption and texture with good shelf life. While, Barbut (2013) noted significantly less structural change in fried chicken (190ºC for 6 min) coated with batter and bread, than uncoated fried chicken.

Maity *et al.* (2015) effectively reduced oil absorption by 35.6% in vacuum fried gum arabic (1.5%) coated jackfruit. The other hydrocolloids *viz.,* pectin, carboxy methyl cellulose and sodium alginate were comparatively less effective in reducing oil absorption. Similarly, Naimeh *et al.* (2016) documented that the shrimp coated with basil seed gum showed 34.50% less oil uptake and 13.9% moisture loss than the uncoated shrimp fry.

Bouaziz *et al.* (2016) studied the quality of fried potato by treating it with almond gum. Individual slices by increasing concentration of almond gum from 0 to 20 gL^{-1} and dried at 55ºC for 2 h to remove the surface moisture and fried at atmospheric pressure between 160 to 190ºC. Results showed decreased oil content of fried potato chips by 34%.

2.7 DE-OILING OF FRIED PRODUCT

De-oiling is a crucial unit operation in case of all deep fat fried product. The pressure gradient during post frying decides the amplification or diminishing of the oil absorption and it also bank upon the surface oil and free moisture of the product (Garayo and Moreira, 2002). Da-Silva and Moreira (2008) suggested de-oiling as a compulsory process to be done immediately after vacuum frying to produce best quality fried product.

Moreira *et al.* (2009) determined high surface oil in the vacuum fried potato chips at the initial pressurisation stage on post frying. This increase in surface oil made the de-oiling process compulsory to remove it before pressurisation. Also, they examined low and high oil content of 14 and 86% in the internal core and surface of fried potato chips, respectively. About 80 - 90% of oil content reduction was achieved through de-oiling system before pressurisation.

Diamante *et al.* (2011) blotted vacuum fried kiwi fruit slices using dry paper towel and then centrifuged it at 750 rpm for 4 min to remove the surface oil. Fang *et al.* (2011) centrifuged vacuum fried purple yam chips at 450 rpm for 5 min to remove 50% surface oil. Amany *et al.* (2012) experimented on potato chips using a vacuum fryer with de-oiling mechanism at 750 rpm to remove surface oil of fried product. Ravli *et al.* (2013) elucidated that de-oiling (750 rpm for 40 s) was a decisive step after vacuum frying of sweet potato chips and concluded that de-oiling resulted in 60% reduction of oil content than traditional frying.

2.8 CHANGES IN PROPERTIES OF FRYING OIL

Frying oil undergoes several chemical changes during frying. They get hydrolysed with water, oxidized with oxygen and air, isomerise and polymerise short chain reactions to form free radicals (Choe and Min, 2007). Peroxide value (PV), free fatty acid (FFA) and total polar compounds (TPC) were the major indicative parameters of oil quality (Melton *et al.,* 1994).

2.8.1 Free Fatty Acid (FFA)

Free fatty acid content is a commonly used attribute to decide the oil quality, since it could be determined rapidly using reliable methods (Tarmizi and Ismail, 2008). Lin *et al.* (1998) increased the shelf life of fried oil by treating it with adsorbents and filters. They reused the treated oil for frying of chicken nuggets and extended its shelf life for upto 32 h of frying.

Sadoudi *et al.* (2014) elucidated that hydrolysis reaction with water and hydroperoxide decomposition at high temperature were the combining factors for the formation of FFA in oil. Amany *et al.* (2012) noted the reduction in FFA of

sunflower oil on vacuum frying used after six batches of frying. Further, a study done by Tarmizi *et al.* (2013) demonstrated that oils with low smoke point were highly prone to an increased FFA during frying. The result of the study confirmed that vacuum drainage performed after atmospheric frying exhibited two fold low FFA value (0.32%) than atmospheric drainage (0.59%).

2.8.2 Peroxide Value (PV)

Sunisa *et al.* (2011) observed higher PV (50.34 meqO_2kg^{-1}) at 170 and 180ºC frying temperature than at 190ºC (36.75 meqO_2kg^{-1}). This was due to instability of peroxide compounds at high temperature. Also, Amany *et al.* (2012) described that PV was considered as an oxidation index indicating the lipid oxidation of oil. Low frying temperature (100 -120ºC) in vacuum frying contributed to significantly low PV (39.50 meqO_2kg^{-1}) than atmospheric frying (45.13 meqO_2kg^{-1}).

Mudawi *et al.* (2014) investigated the quality parameters of corn and sunflower oil on frying and found that the PV of corn oil (1 to 13.9 meqO_2kg^{-1}) increased rapidly than sunflower oil (1 to 4.3 meqO_2kg^{-1}) at 5 h of frying. Garima *et al.* (2015) studied the changes in PV of cooking oils after 5 times of frying. Soya bean oil showed high PV after frying (0.7 to 10.89 meqO_2kg^{-1}) followed by sunflower (0.4 to 8.43 meqO_2kg^{-1}), coconut oil (0.38 to 6.63 meqO_2kg^{-1}), palm oil (1.03 to 6.01 meqO_2kg^{-1}) and ground nut oil (0.58 to 5.1 meqO_2kg^{-1}). From these results, palm oil was recommended for deep fat frying.

2.8.3 p-Anisidine Value (p-AnV)

p-Anisidine value is an indicator of secondary oxidised compounds especially aldehydes formed by breakdown of peroxides (Faranak *et al.*, 2010). Felix and Roman (2009) examined the changes in oil quality at different frying temperatures and it was indicated that p-AnV of canola oil fried at 170°C was 4.65 and increased three fold as the frying temperature was raised to 215°C.

p-Anisidine value is an important parameter which was closely related to oxidation of oil (Bou *et al.,* 2012). Prakash *et al.* (2016b) assessed the quality

changes of mustard oil that underwent 30 h of frying. The results indicated p-AnV increased rapidly with frying time and made the oil unfit for frying after 15 h of frying.

2.8.4 Total Oxidation Value (TOTOX value)

The total oxidation value is a combination of peroxide and p-Anisidine representing the oxidation status of oil. The increase in TOTOX value indicated the oil degradation (Prakash *et al*., 2015). Latha and Nasirullah (2014) confirmed the increase in TOTOX value in rice bran oil after several times of frying. The TOTOX value increased from 5.32 to 24.3 after 8 h of frying at 180°C. Similarly, Prakash *et al.* (2016b) noted a sharp increase in TOTOX value of mustard oil from 6.39 to 41.34 after 30 h of frying.

2.8.5 Iodine Value (IV)

Fan *et al.* (2013) compared the frying stability of rice bran and palm oil and reported decreasing trend of IV in both the oils. The reduction of IV in rice bran oil was 12%, while in palm oil it was 38%. Higher rate of reduction in IV value indicated higher proportion of unsaturation in the oil, which later disintegrates on frying. The results concluded that rice bran oil have greater stability on frying than palm oil.

2.8.6 Viscosity

Changes in viscosity of frying oil were mainly due to formation of polymers. Viscosity itself was not a deciding attribute for determining the quality of frying oil (Gertz, 2000). A study on changes in viscosity of palm and olive oil on atmospheric frying of potatoes at 180°C after 40 batches was done by Kalogianni *et al.* (2011). Significantly high value of viscosity was noted in palm oil (25.3 to 53.4 m Pa s) than olive oil (12.42 to 32.5 m Pa s). Also, Probir *et al.* (2012) observed an increase in viscosity from 56 to 84.48 m Pa s in soya bean oil after eight times of deep fat frying.

Comparable change was noted by Lioumbas *et al.* (2012) in palm and olive oil viscosity on vacuum frying. After 40 times of frying no significant change in viscosity was observed in olive oil. Tarmizi *et al.* (2013) demonstrated the difference in viscosity during frying performed under vacuum and atmospheric drainage respectively. The viscosity of oil increased from 45.92 to 53.5 and 55.64 m Pa s in vacuum and atmospheric drainage.

2.8.7 Colour Values

Gutierrez *et al.* (1988) claimed that the presence of non polar compounds and unsaturated carbonyl compounds darkened the frying oil when subjected to high frying temperature. Lalas (2009) noted similar findings of 20% increase in redness value (a^*) which indicated the darkening of oil at high temperature than yellowness value (b^*) at high temperature.

In the same way, Tarmizi *et al.* (2013) substantiated that the colour values of fried oil were relatively less in the oil drained at vacuum condition than atmospheric environment. Since drainage at vacuum condition employed 50% low temperature than atmospheric condition, a reduction of 46.7% darkness was noted in L^* value in vacuum drained fried oil than atmospheric drainage. Similar trend was noted in colour of rice bran oil where the L^* value was decreased and a^* and b^* value was increased after 40 h of frying (Aniołowska and Kita, 2015).

2.8.8 Total Polar Compounds (TPC)

Polar compounds signifies the presence of tocopherols, mono and di-glycerides, free fatty acids and other fat soluble compounds excluding triglycerides (Fritsch, 1981). Also, Lalas (2009) reported that TPC was the most reliable compound for measuring the quality of frying oil. In many countries including India, the acceptable polar compound is 25% by weight. This compound mainly includes five compounds *viz.,* polymers and dimmers of triglycerides, oxidised triglyceride monomers, diglycerides and free fatty acids (Farhoosh *et al.,* 2011).

Guillén and Uriarte (2012) noted an increase in TPC percentage with increase in frying temperature of extra virgin olive oil when heated at 190ºC. For every hour of heating, 0.533% increase in TPC was observed which reached to 25% at 33.71 h. Conversely, Amany *et al.* (2012) stated that the sunflower oil used for vacuum frying showed less than 25% TPC and 29.18% in atmospheric frying   after 24 h of storage.

2.9 PROPERTIES OF FRIED PRODUCTS

Moisture content, oil content, acrylamide content, density, porosity, shrinkage, colour and texture are the most important quality parameters in fried products. Studying the kinetics of the quality changes during frying is necessary to predict and improve the final quality of the product.

2.9.1 Oil Content

Garayo and Moreira (2002) produced vacuum-fried potato chips with decreased oil content (27% wet basis) compared to atmospheric-fried potato chips (40% wet basis). Bouchon *et al.* (2003) examined the relationship between oil absorption and surface of the product on deep fat frying. It was found that the formation of crust during frying was an important factor which affected oil absorption. It was also concluded that oil absorbed were in three different phases as structure oil, penetrated surface oil and surface oil. The surface oil was the highest percent found in fried product than oil absorbed in other two phases. Similarly, it was noted that aatmospheric fried apple slices absorbed 21% higher oil than vacuum fried apple slices at same thermal driving force of 50ºC (Mariscal and Bouchon, 2008).

Conversely, Troncoso *et al.* (2009) observed significantly high oil content in vacuum fried potato chips (48.45%) than atmospheric fried potato chips (35.32%). The cause for high oil content at vacuum frying was elucidated as two phases in vacuum frying. Unlike atmospheric frying, vacuum frying comprised of two phases - frying phase and pressurisation phase which favoured oil absorption. However, Dueik and Bouchon (2011) illustrated 50% less absorption in vacuum

fried apple, potato and carrot chips than atmospheric fried products. Also, 52% less oil content was reported by Amany *et al.* (2012) on vacuum fried potato chips at 120ºC at 5.311 kPa than atmospheric fried potato chips at 180ºC.

Aida *et al.* (2016) attempted to reduce the oil content of banana chips by pre-treating it with sugar coating. The highest reduction (0.66%) was observed in banana chips treated with 12% sugar concentration and fried at 180°C for 5 min.

2.9.2 Moisture Content

The moisture content of fried food is a determinant criteria of the shelf life of the product. Andrés-Bello *et al.* (2010) compared the moisture loss in gilthead sea bream fillets fried in vacuum and atmospheric condition. Vacuum fried samples showed 25-40% loss of moisture while atmospheric frying exhibited 70% reduction. This was due to higher process temperature (170°C) in atmospheric frying than vacuum frying (100°C).

The removal of moisture was influenced by temperature and time period of frying. Higher the temperature and longer the time, higher will be the moisture removal rate. This phenomenon was observed by Maity *et al.* (2014) on fried jack fruit bulbs under vacuum frying. The decrease in moisture content of jack fruit chips fried at 100ºC was 26% whereas the one fried at 80ºC was 11%.

2.9.3 Water Activity

The tolerance limit of water activity for any microbial growth in a dehydrated product is 0.6 a_w. Apart from microorganism, other chance of spoilage at below 0.6 a_w would be due to oxidation or any other chemical reactions (Adams and Moss, 1995).

A study conducted by Perez-Tinoco *et al.* (2008) on vacuum frying of pineapple chips conveyed that frying time has no effect on water activity reduction. It was also confirmed that the increase in frying temperature and decrease in frying pressure significantly decreased the water activity of fried

pineapple. Dueik *et al.* (2010) reported that the water activity of vacuum fried carrot chips was 0.44 a_w which was well below the tolerance limit.

2.9.4 Bulk Density and True Density

An increase in frying temperature promoted significant reduction in bulk and true density of fried rice and cassava crackers. Also, bulk density of vacuum fried sweet potatoes decreased between 40 - 50% with raw potato slices (Maneerote *et al.,* 2009, Mayyawadee and Gerhard, 2011). In contrast, Ravli *et al.* (2013) noted no significant effect of frying temperature on bulk and true density of vacuum fried sweet potatoes.

2.9.5 Thickness Expansion

Ravli *et al.* (2013) explained the changes in thickness of vacuum fried sweet potato chips at different frying temperature (120, 130 and 140ºC). The thickness reduced spontaneously at early period of frying and then increased slowly to reach a constant thickness expansion value. The thickness expansion values were between -55.63 and -58.56%.

2.9.6 Texture

The hardness of fried product is largely affected with frying time. The results of several researchers revealed no significant difference in texture between vacuum and atmospheric fried chips. However, pretreatments like coating with hydrocolloids created difference in texture of fried product. Sahin *et al.* (2005) observed that the chicken nuggets coated with guar, gum arabic showed higher hardness value than xanthan and hydroxypropylmethylcellulose (HPMC) coated samples. Similarly, Singthong and Thongkaew (2009) noted maximum hardness in banana chips pretreated with ($CaCl_2$ and hydrocolloids) than in the control. It was due to the concerted activity of hydrocolloids that forms a rigid gel network on surface of the banana slices to protect the cell structure. The pectin layer on the control sample disintegrated on the surface during frying reducing its hardness value on post frying.

Conversely, Dueik *et al.* (2010) experimented on vacuum fried carrot chips and concluded that the frying technology did not affect the textural values significantly. Both vacuum fried and atmospheric fried carrot chips showed similar range of texture values of 5.01 to 5.68 N. However, vacuum fried kiwi fruit soaked in maltodextrin and frozen exhibited significant variation in the textural property when compared to unsoaked and frozen fruits. The soaked samples showed higher hardness value (2.5 N) than unsoaked sample (1.9 N) (Diamante *et al.*, 2011).

2.9.7 Colour Values of Fried Products

Krokida *et al.* (2001) stated that the lightness of fried potatoes was an important criteria for consumer acceptance. Dueik *et al.* (2010) justified that lightness (L^*) of vacuum fried carrot chips showed negligible reduction in percentage of L^* value than atmospheric fried carrot chips. The L^* value before frying was 65.2 and after vacuum frying was 58.4. Their study also conveyed that, lower the L^* value, darker the fried product and degradation of carotenoid. Similar trend was reported by Andrés-Bello *et al.* (2010) in case of vacuum fried gilthead sea bream fillets that possessed significantly higher L^* value compared to atmospheric fried one, at 165ºC. The a^* value was 3.4 in atmospheric frying, while it was -12 in vacuum frying condition. The blue - yellow (b^*) value of atmospheric fried gilthead sea bream fillets were significantly higher than vacuum fried products. This indicated darker colour in atmospheric frying.

Dueik and Bouchon (2011) conducted an evaluation on colour values of vacuum fried carrot, apple and potatoes and concluded that the L^* value was consistently higher than atmospheric frying. The L^* value was 60.5, 56 and 33.1 in raw carrots, vacuum fried carrots (108°C) and atmospheric fried carrots (180°C), respectively. Similar trend was observed in case of a^* (redness) and b^* (yellowness) values.

2.9.8 Acrylamide Content

Acrylamide is one of the hazardous compounds formed when carbohydrate rich food products were subjected to frying, baking, grilling and roasting operations. Granda *et al*. (2004) reduced acrylamide content by 63% in vacuum fried potato chips by reducing the frying temperature from 140°C to 120°C. In 2005, Granda and Moreira studied the kinetics of acrylamide formation in traditional (150 -180°C) and vacuum (118 - 140°C) fried potato chips. It was noted that the acrylamide formation kinetics was entirely different in both frying techniques, which was mainly due to adoption of different temperatures in frying. In atmospheric frying, formation of acrylamide was increased constantly and reached to higher level. In contrast, the acrylamide formation was observed only at the initial stage and it does not exceed beyond that in vacuum frying technology.

Bekas *et al.* (2006) examined the acrylamide content of 32 commercial deep fat fried potato chips samples available in local market of Poland. The acrylamide content ranged between 380 μgkg^{-1} to 861 μgkg^{-1}, which was identified to be safe when consumed occasionally. Daniali *et al.* (2010) compared the acrylamide content in various deep fat fried banana snack products. It was found that the banana fitters had the highest acrylamide content of 7468.8 μgkg^{-1} than other snacks while sweet banana chips had 501.3 μgkg^{-1} and raw banana chips had 234.4 μgkg^{-1}.

Bassama *et al*. (2011) identified the relation between formation of acrylamide in plantains with respect to water activity and asparagine content present in it. Nine varieties of plantain flour were experimented for the acrylamide content at different temperatures from 140 to 180º C. The results revealed that increase in temperature and reduced water activity influenced the formation of acrylamide rigorously. Ana *et al.* (2013) optimised the frying process parameter to obtain minimum acrylamide from fried product using dynamic optimisation method. The results of the study confirmed 16.5% reduction in acrylamide content.

2.10 SENSORY ANALYSIS

Sensory analysis is a scientific method used to evoke, measure, analyse and interpret reactions to those characteristics of food materials as they are perceived by the sensor of sight, smell, taste, touch and hearing. It is a subjective method of analysis. In general, sensory quality of food is the consumer's reaction to the physical and chemical constituents of food in its prepared and formulated form. The sensory analysis results of vacuum fried carrot chips which were pre-treated with freezing and high pressure processing revealed that freezing ranked the highest in crispness and overall perception of sensory panels. The oil content of frozen sample was higher than the control sample, but the structural changes induced the sensory perceptive of panels (Albertos *et al.,* 2016). Moreover, the sensory score done through Hedonic scale revealed that vacuum fried products had the highest preference than atmospheric fried products. This statement was supported from the results of the studies of Da-Silva and Moreira (2008), Amany *et al.* (2012), Ravli *et al.* (2013) and Teruel *et al.* (2014) on sensory analysis of vacuum and atmospheric fried products.

2.10.1 Fuzzy Logic on Sensory Analysis

Fuzzy sets theory introduced by Zadeh in the year 1965, allowed uncertain phenomena to be treated mathematically. Fuzzy comprehensive model for ranking of foods and developing new food products was developed in 1991. Fuzzy logic is an important tool by which vague and imprecise data could be analysed and important conclusions regarding acceptance, rejection, ranking, strong and weak attributes of food could be drawn. Fuzzy sets could be used for analysis of sensory data instead of average scores to compare the samples attributes (Shinde and Pardeshi, 2014).

Jaya and Das (2003) conducted sensory evaluation of reconstituted mango drink and three other commercial branded mango drinks (Real, Slice and Frooti) using fuzzy logic. The mango drink of brand 'Slice' ranked first with 0.241 for taste, 'Real' brand with 0.227 for taste, reconstituted mango drink with 0.215 for

mouth feel and 'Frooti' with 0.205 for taste. Also, Lazim and Suriani (2009) compared the sensory attributes of three different coffee samples namely Indoc, Nesc and Incom using fuzzy logic. Based on evaluation of sensory attributes, highest score was obtained by Indoc followed by Nsec and Incom.

The beer samples (n=14) from Chinese market were analysed with comprehensive fuzzy model that was evaluated by 60 sensory panels (Liu *et al.*, 2012). The sensory indices for the beer samples were sourness, sweetness, bitterness, acerbity, goaty and overall acceptance. The sample with the highest preference on sensory attributes scored 3.97, while the sample with least preference scored 1.23. Mukhopadhyay *et al.* (2013) conducted sensory analysis for 5 samples of *chhana podo,* a traditional dairy product. The analysis was done on a five point Hedonic scale with 120 sensory panels. These sensory results were validated with its ranking of attributes using Fuzzy logic. Among these, the sample that ranked first had the following scores in each attributes *i.e.,* aroma (0.845), colour (0.835), mouth feel (0.802) and taste (0.792).

Chakraborty *et al.* (2013) aggregated the sensory scores of processed tea liquor sample using fuzzy logic model. The attributes ranking of a single sample which was in order of colour and brightness - Good > Strength – Medium > Briskness – Medium > Aroma – Fair.

Peng *et al.* (2014) analysed the sensory attributes of 21 samples of litchi wine prepared from different cultivars. The sensory analysis was made quantitative by employing fuzzy logic tool. The fuzzy logic provided numerical quantity for a linguistic variable. The added advantage of fuzzy analysis was that it ranked the sensory score of sample along with ranking of attributes. Among 21 samples labelled 1 to 21, sample 16 was the best with a total score of 94.5 out of 100 and sample 10 was the worst with a score of 78.01. The remaining 19 samples scored between the best and the worst.

Fuzzy logic tool executed through Matlab software version 7.6 was used to analyse the sensory attributes of four commercial jam samples (S_1, S_2, S_3 and S_4)

by Shinde and Pardeshi (2014). The S_4 sample was preferred by the consumers with highest ranking score of 0.7163 out of 1. Similar quantitative ranking of sensory attributes were carried out effectively in sugarcane based beverages (Prasad and Nath 2002), instant green tea powder and granules (Sinija and Mishra, 2011), kokum juice drink (Sahu and Kadeppagari, 2016), mango milk shake prepared from skim milk (Prakash *et al.,* 2016a) based on quantitative scores using fuzzy logic approach.

Sana et al. (2016) used fuzzy logic for ranking the sensory attributes of eight samples of beetroot candy. The sensory value of 15 panel members for the attributes viz., sweetness, taste, mouth feel and overall acceptance were analysed. They calculated the ranking of sensory attributes within the samples using scale factors in MS office Excel 2007. The ranking order was found as $S_8 > S_7 > S_6 > S_2 > S_5 > S_1 > S_3 > S_4$. The attributes of S8 sample was Taste > overall acceptance > sweetness = mouth feel.

2.11 PACKAGING AND STORAGE STUDIES

Illeperuma and Jayathunge (2001) used nitrogen flushing in aluminum pouches laminated with polyethylene for osmotic dehydrated bananas and extended its shelf life upto eight months of storage without affecting its sensory attributes. The vacuum fried carrot chips was found to have high storage stability at 25°C for six months when stored in 25 μm low density polyethylene package with 95% nitrogen flush (Fan *et al.,* 2005).

Diamante *et al.* (2012) stored vacuum-fried apricot using polyethylene terephthalate bags at room temperature for further analysis, while Nuttapong and Thatchapol (2015) stored vacuum fried banana chips in aluminum foil bags after cooling at room temperature. Esana *et al.* (2015) reported that sweet potatoes fried at 108°C for 9 min and vacuum packed in polyethylene bags had a shelf life of 30 days.

2.12 STATISTICAL ANALYSIS

The optimisation of process parameters for vacuum fried products was done by researchers using different statistical software. The response surface

method was used by Tarzi *et al.* (2011) and Maadyrad *et al.* (2011) for optimisation of vacuum fried mushroom and kiwi fruit. Shyu and Lucy (2011) suggested that central composite rotatable design under Design Expert version 7.0.0 was user friendly and effective for optimisation design of vacuum fried carrot chips. Esana *et al.* (2015) and Bouaziz *et al.* (2016) reported that Box - Benkan analysis performed using Design Expert version 6.0.2 was effective for the optimisation of process protocol of sweet potato chips and potato chips. However, selection of optimisation design was based on levels and factors of treatments.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

The present study on "Development of vacuum frying system for banana chips (*Musa paradisica*)" was carried out under the project, Centre of Excellence in Post-harvest Technology in the department of Food and Agricultural Process Engineering, KCAET, KAU, Tavanur, Kerala. This chapter elaborates the approach followed to accomplish the objectives of the study. The raw materials and its preparation methods for frying, selection of oil for blending, methodology for the development of vacuum frying machine and the experimental design to evaluate its process parameters, standard methods adopted to analyse the properties of fried product with its packaging and storage were studied.

3.1 RAW MATERIAL

The raw and ripened *Nendran* banana cultivar (*Nedunendran AAB*) was used for the study.

3.1.1 Procurement of Raw Material

The raw *Nendran* banana with its suitable maturity indices (disappearance of angularity in the fruit) and ripened *Nendran* banana with appropriate ripening indices (TSS 22 - 24ºB) for frying was procured from KCAET farm, Tavanur.

3.1.2 Sample Preparation for Frying

The procured ripened bananas were cleaned and peeled manually. These peeled bananas were sliced using banana slicer (Balakrishna Engineering, Coimbatore, India) with stainless steel blade (SS 304) of thickness ranging between 1 - 1.5 mm. The thicknesses of sliced bananas were measured using vernier caliper (RSK Digital Caliper, China). Similarly, in case of raw banana chips, the bananas were sliced without peeling. This would improve fibre content of fried product. The sliced raw bananas were pre-treated with turmeric powder for two minutes to improve the colour of fried product. The samples were kept in aluminum foil to avoid moisture transfer before further processing.

3.2 DEVELOPMENT OF VACUUM FRYING SYSTEM

A batch type vacuum frying system with 12 kgh^{-1} capacity was developed. Unlike commercially available vacuum fryers which have one compartment for both oil storage and frying process, the developed system consisted of two different chambers for oil storage and frying. The additional chamber for storage facilitated short frying process when compared with single chamber which takes three fold time more for frying.
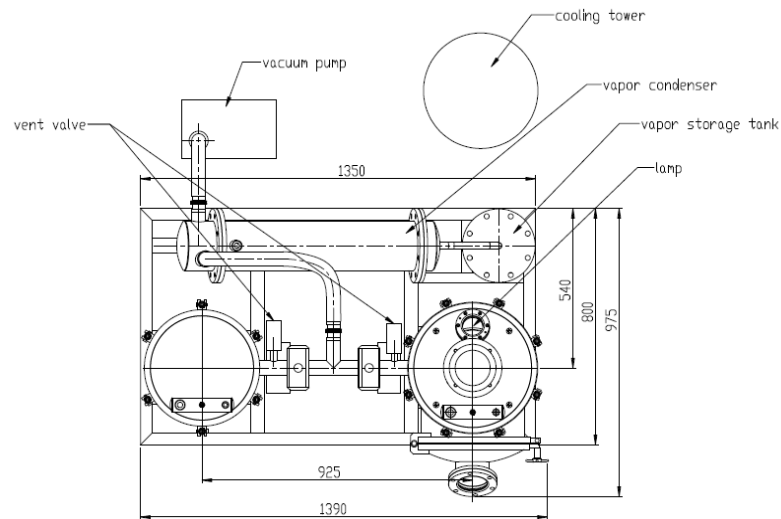
Plate. 3.1 Schematic diagram of top view of vacuum frying system

3.2.1 Frying System

Frying system comprised of two chambers *viz.,* oil storage chamber (diameter 356 mm and 835 mm length) and fryer chamber (diameter 406 mm and 984 mm length) made of stainless steel (SS 316). Plate.3.1. depicts the top view of developed vacuum frying system. Both the chambers were provided with heaters of 1.5 kW and 3 kW controlled by microprocessor, PID (Proportional Integral Derivative) controller. The frying chamber houses the de-oiling system that was fastened with frying basket holder.

3.2.2 De-oiling System

De-oiling system consisted of a 0.5 hp motor (make: Prime motors, India) with 6 pole, 1000 rpm (revolutions per minute). The motor was mounted at the top of frying chamber connected to frying basket holder at the other end. The frying basket holder was fastened with screw mechanism to contain the frying basket during frying and de-oiling. Frying basket of diameter 273 mm and depth of 143 mm was made of stainless steel (SS 316) with bottom curved (30º) provided with closure (Plate. 3.2). The curved bottom of frying basket aided in easy draining of oil after frying.

3.2.3 Pressure System

The pressure system was constructed with pressure transmitter (make: SETRA, India) of measuring range 0 to 250 kPa which was controlled by a control valve. The pressure was maintained using 3 hp water ring vacuum pump (make: Sabar, India) of 30 m^3h^{-1} capacity. Compound dial gauge with measurement ranged between -1 and 4 $kgcm^{-2}$ was used to read the pressure change in both the chambers. The 2-D diagram (Plate. 3.3) represents the front view of vacuum frying system with dimensions. Two separate pneumatically operated spherical disc butterfly valves (make: AIRA, India) were attached with each chamber to create vacuum inside the chambers. Pressure difference was created through vent valves (make: AIRA, India) using nitrogen gas between the chambers to transfer oil. The Plate. 3.4 and 3.5 illustrates the 3-D view and delveloped vacuum frying system. The nitrogen gas was used in order to maintain the oil quality, since creation of pressure gradient using air enhances the chance of oxidative rancidity in the oil. The oil was transferred from the storage tank to frying tank and vice versa through SS ball valves.
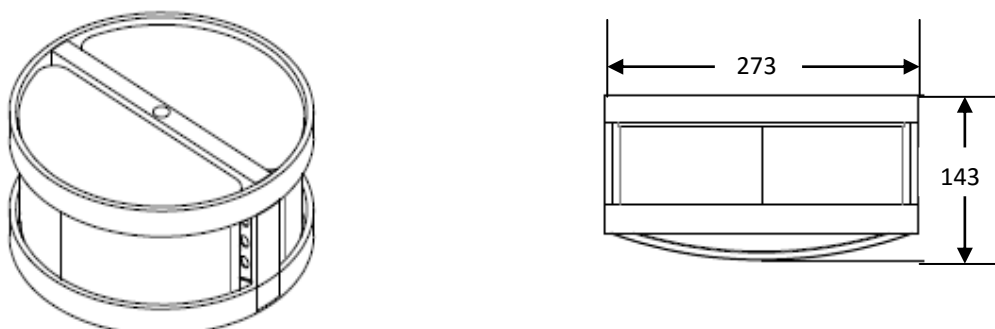
(a)   **(b)**

Plate. 3.2 Frying basket (a) Isometric view (b) Side view
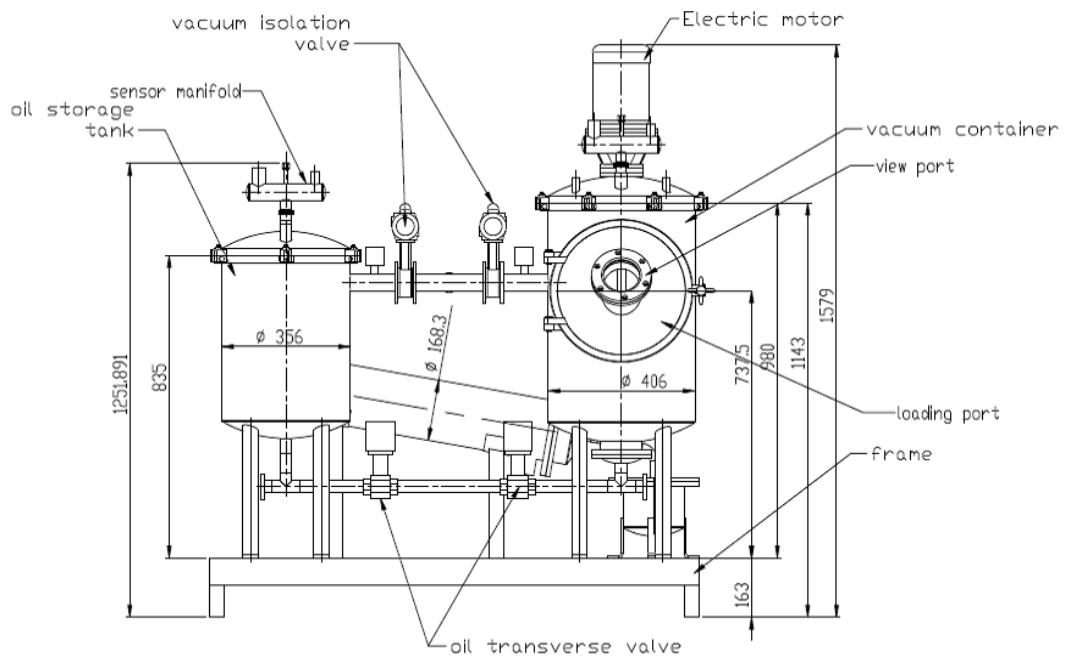
Plate. 3.3 Schematic diagram of front view of vacuum frying system

3.2.4 Cooling System

Cooling system included cooling tower of 10 L capacity attached with 1 hp water pump (make: Protech, India) with head flow of 5 to 10 lpm (litre per minute). Vapour removed during frying was condensed using shell and tube heat exchanger (dimension: 165 x 800 mm long and diameter: 12 x 800 mm length - 22 No.). The vapour was collected through a closed basin fitted with ball valve.

3.2.5 Control System

The control system of vacuum frying equipment was communicated through OMRON PLC with HMI (Human Machine Interface). The data logging using USB port was provided in the control panel to record temperature and pressure change during the operation. The developed vacuum frying system is depicted in Plate. 3.5. Additional facilities used for the operation of vacuum frying system was a compressor (make: Ingersoll Rand, India) with air pressure of 600 kPa provided with a pneumatic manifold that could withstand 100 kPa pressure. The total power required to operate the vacuum frying system is tabulated in Table (3.1).

Table. 3.1 Power requirement for vacuum frying system

S. No	Component	Power (kW)
1.	Vacuum pump	2.2
2.	Dry motor	0.37
3.	Cooling motor	0.37
4.	Heater (3 No.)	7 – 5
5.	Compressor	1
6.	Water pump	0.37
7.	Power of controls	0.25
Total power = 12.5 kW		
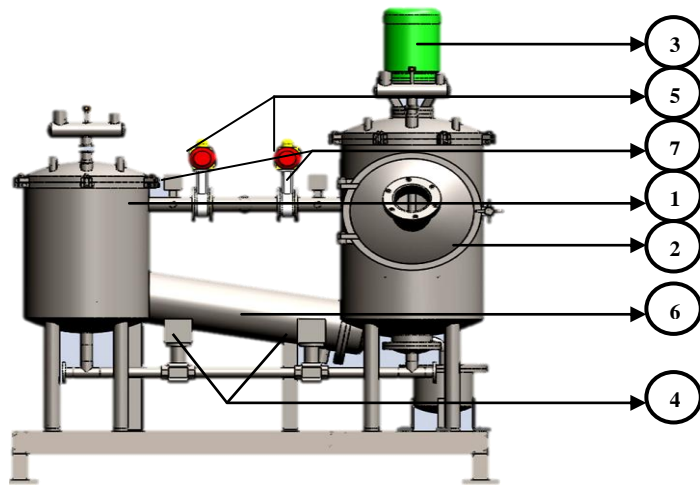
1. Oil stor

4. Oil flow control   5. Vacuum valve   6. Condenser

7. Nitrogen flow valve

Plate. 3.4 Three dimensional view of vacuum frying system

1.

4. Oil storage chamber   5. Cooling tower   6. Control panel

7. Vacuum valve   8. Condenser   9. Oil flow valve

10. Frying chamber

Plate. 3.5 Developed vacuum frying system for banana chips

3.3 VACUUM FRYING PROCESS

The vacuum frying process could be divided into four stages: depressurisation, frying and de-oiling, pressurisation, and cooling (Garayo and Moreira, 2002) (Table. 3.2). The steps involved for vacuum frying process in the developed vacuum fryer is illustrated below.

3.3.1 Sample Loading

The prepared banana samples were weighed initially and loaded into previously washed frying baskets. The two frying baskets were loaded with equal quantity (approx. 950 - 1000 g each) of samples in order to have a balance during frying and de-oiling. The loaded frying baskets were kept inside frying chamber using basket holder and chamber was closed tightly. The frying oil (29 - 30 L) was filled into storage chamber by opening the top lid of storage chamber. This frying oil was preheated before 10 -15 min of frying. Sample loading is followed by four phases of vacuum frying as mentioned below.

3.3.2 Depressurisation Phase

This phase is basically a creation of low pressure inside the storage and frying chambers. Low pressure (6 - 10 kPa) was created by opening the vacuum valve connected with storage and frying chambers. Simultaneously, the frying chamber was heated to the desired frying temperature.

3.3.3 Frying and De-oiling Phase

Frying was performed when vacuum frying chamber attained the set temperature and pressure. The following changes in pressure occurred between the storage and frying chambers during this phase. The vent valve of storage chamber was opened to increase the pressure by using nitrogen gas and oil inlet valve was also opened. Due to pressure gradient created between storage chamber (high pressure) and frying chamber (low pressure) oil gets transferred in to frying chamber through oil inlet valve. The vent valve and oil inlet were then closed. The

loaded banana slices were immersed in oil for a set frying time. During frying process, the frying basket was rotated at a speed of 20 - 30 rpm using de-oiling motor attached in it. After completion of frying, the pressure gradient was created to transfer the oil from frying chamber to storage chamber. The vent valve of frying chamber and oil inlet valve was opened favouring the creation of pressure gradient (storage chamber with low pressure and frying chamber with high pressure) oil to transfer from frying chamber to storage chamber. The vent valve and oil inlet valve were then closed. The pressure was reduced again inside the frying chamber prior to de-oiling. The de-oiling motor was then set to higher rpm (> 800 rpm) for desired time. The removal of surface oil from fried banana chips was effected through a centrifugation process.

3.3.4 Pressurisation and Cooling Phase

The vacuum was then released in frying chamber using vent valve and the product was unloaded, allowed to cool till it reaches room temperature. The vacuum fried banana chips were packed using active packaging with nitrogen (N_2) flush and stored at room temperature for further analysis.

Table. 3.2 Stages of vacuum frying

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

| Phase 4 | Cooling | Product temperature was brought down to room temperature before packaging and storage |

The performance evaluation of vacuum frying with raw and ripened *Nendran* banana with selected blend of frying oil and optimisation of de-oiling process, pre-treatments and process parameters were done through four different experiments, *viz.,* Experiment I – Selection of oil for frying, Experiment II – De-oiling for vacuum frying of banana chips, Experiment III – Selection of suitable pre-treatments and Experiment IV – optimisation of process parameters of vacuum frying.

EXPERIMENT I

3.4 FRYING OIL

The frying oils used for the study *viz.,* coconut oil (brand: NILA, Kerala), rice bran oil (brand: PAVIZHAM, Kerala), palm oil (brand: PALMSON, Kerala), corn oil (brand: AVITTA, Tamil Nadu) were purchased commercially, the rice bran and palm oil blend (80:20), was also evaluated. The selected five oils were screened by sensory evaluation and the screened frying oils were used for further experiments (Khan *et al.*, 2011; Monika and Kiran, 2013).

3.4.1 Selection of Frying Oil

The selected frying oils were used for vacuum frying of both raw and ripened banana chips in the developed vacuum frying system (elaborated in section 3.2). The experimental design for vacuum frying of banana with different frying oils is illustrated in Table. 3.3. and process flowchart is given in Fig.3.1.

Table. 3.3 Experimental design of vacuum frying of banana chips with different frying oil

Independent variables	Dependent variables
• O_1 - Coconut oil • O_2 - Rice bran oil • O_3 - Palm oil • O_4 - Corn oil	• Product properties (oil content, colour values and sensory analysis) • Oil properties (free fatty acid (FFA), (total polar compounds (TPC), peroxide value (PV), p-anisidine

• O$_5$ - Rice bran : Palm oil	value (AnV), total oxidation value (TOTOX), iodine value (IV), free fatty acid value (FFA), viscosity and colour values)

       The frying parameters were fixed based on trial and error method. The vacuum fried samples were tested for sensory analysis and oil absorption. The frying oil was tested for its various quality parameters. Blending of frying oil was decided based on the analysis result. The four treatments were statistically analysed using ANOVA general factorial method (Design expert software version 7.0.0). The analysis method for various quality parameters of oil and fried product are discussed in section 3.9.
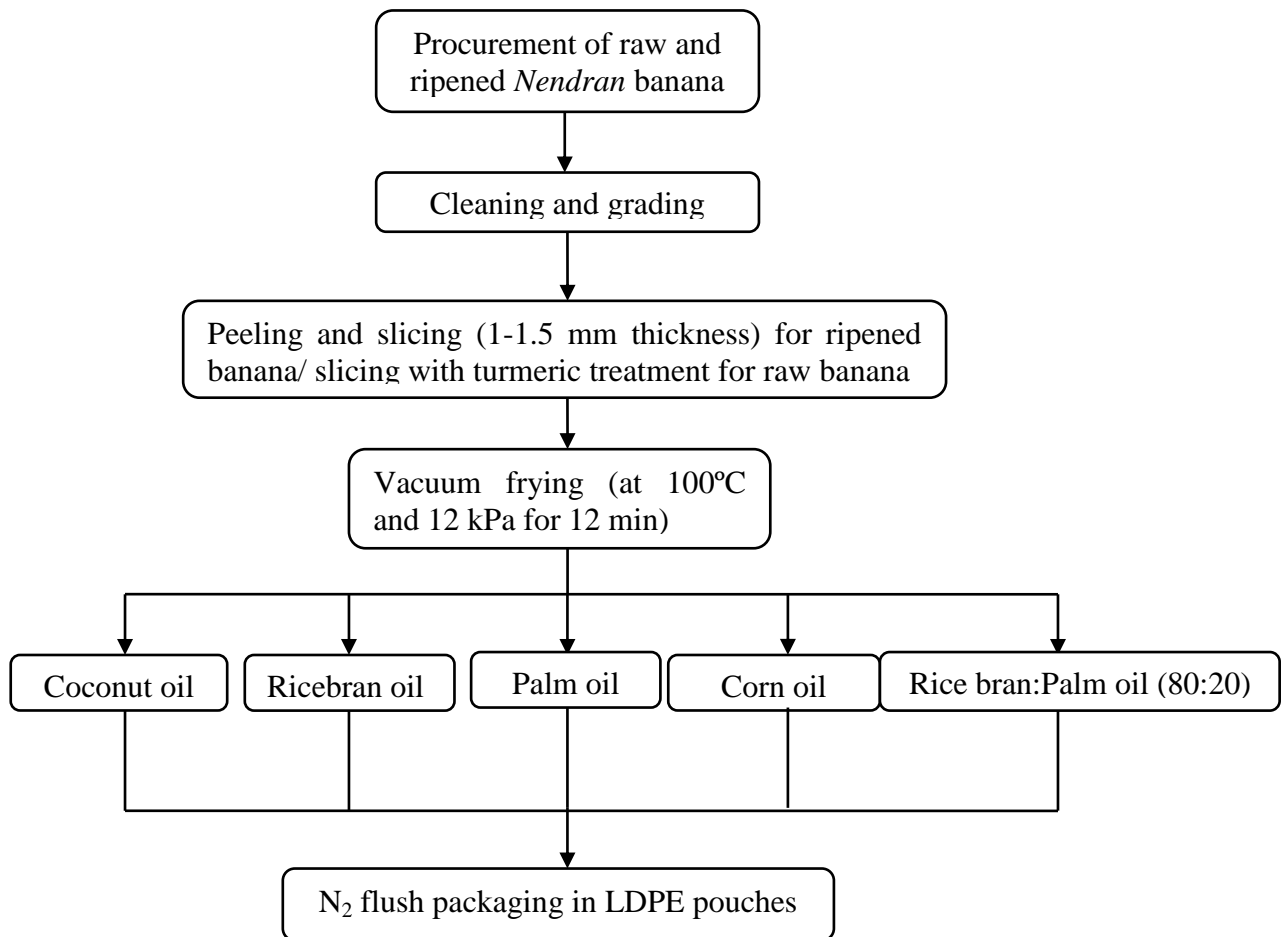
Fig. 3.1 Process flowchart for vacuum frying of banana chips with different frying oil

EXPERIMENT II

3.5 DE-OILING FOR VACUUM FRYING OF BANANA CHIPS

De-oiling of vacuum fried raw and ripened bananas was conducted after frying using centrifugation at high speed for a desirable time. The Fig. 3.2 represents the process flowchart for vacuum frying with different de-oiling parameters. Different centrifugation speed and time to remove the surface oil of vacuum fried banana chips were evaluated (Table. 3.4).

Table. 3.4 Experimental design of vacuum frying of banana chips with different centrifugation parameters

Independent variables	Dependent variables
Centrifugation speed (400, 600, 800 and 1000 rpm) and centrifugation time (0, 3, 5, 7 and 9 min)	Product properties (oil content, moisture content, water activity, bulk density, true density, thickness variation, colour values, texture and sensory analysis

The twenty treatment combinations were statistically analysed using ANOVA general factorial method and optimised for centrifugation parameters (speed and time) for de-oiling.

EXPERIMENT III

3.6 PRE-TREATMENTS FOR VACUUM FRYING OF BANANA CHIPS

Different pre-treatments were carried out for vacuum frying of both raw and ripened banana slices to reduce the oil absorption during frying. The pre-treatments selected were blanching cum drying, guar gum coating and freezing. The experimental design for vacuum frying of banana chips with different pre-treatments are presented in the Table. 3.5. and process flowchart is illustrated in Fig. 3.3.

```
┌─────────────────────────────┐
│   Procurement of raw and     │
│   ripened *Nendran* banana   │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│     Cleaning and grading     │
└─────────────────────────────┘
              │
              ▼
┌──────────────────────────────────────────────┐
│ Peeling and slicing (1 -1.5 mm thickness) for  │
│ ripened banana/ slicing with turmeric treatment │
│ for raw banana                                  │
└──────────────────────────────────────────────┘
              │
              ▼
┌──────────────────────────────────────────────┐
│ Vacuum frying with optimised oil at 100ºC and  │
│ 12 kPa for 12 min                               │
└──────────────────────────────────────────────┘
              │
              ▼
┌──────────────────────────────────────────────┐
│ De-oiling with centrifugation speed (400, 600, │
│ 800 and 1000 rpm) for various time (0, 3, 5, 7 │
│ and 9 min)                                      │
└──────────────────────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐
│ N₂ flush packaging in LDPE   │
│ pouches                      │
└─────────────────────────────┘
```
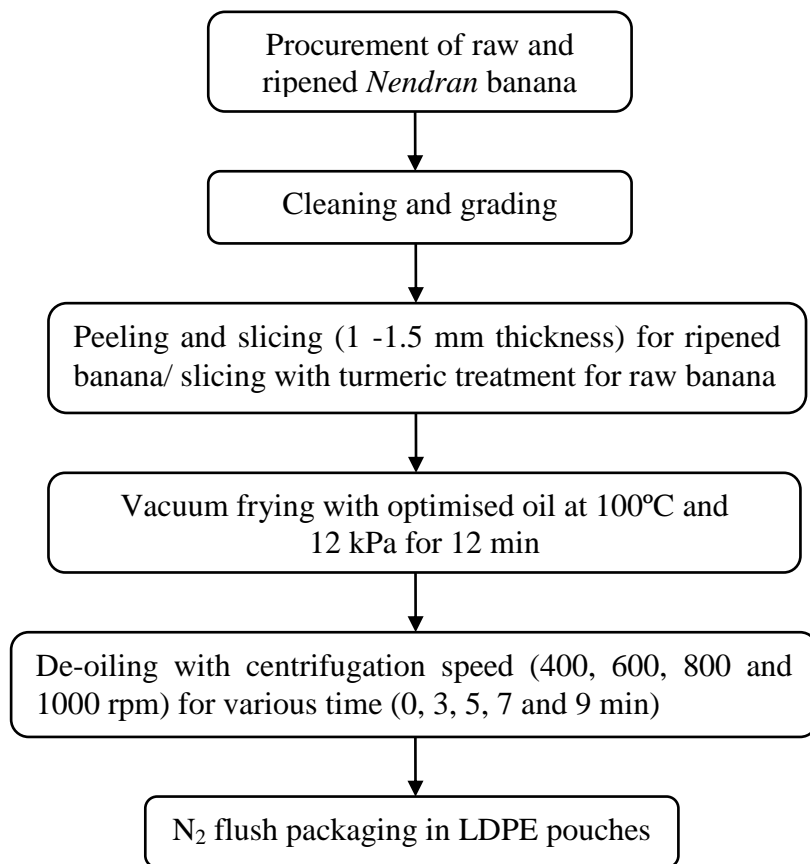
Fig. 3.2 Process flowchart for vacuum frying of banana chips with different centrifugation speed and time (de-oiling)

3.5.1 Blanching cum Drying and Freezing

The sliced banana samples with 1 mm thickness were water blanched for 2 min (Troncoso *et al*., 2009) and dried at 65ºC for 3 h (Samatcha *et al*., 2010) and fried. Freezing was achieved by deep freezing for overnight (12 h) (Fan *et al.,* 2005).

3.5.2 Coating of Guar Gum

The guar gum coating was prepared by dissolving 1.5% of guar gum in distilled water at 90ºC for 30 min (Sothornvit, 2011). The application of gum on sliced banana was done by dipping and the thickness of coating was controlled by duration of dipping; the percentage weight gain was calculated by weighing the

gum before and after coating. The ratio of coating solution to banana slices was 10:1and the slices were dipped for 5 minutes in the gum solution.

Table. 3.5 Experimental design of vacuum frying of banana chips with different pre-treatments

Independent variables	Dependent variables
• Blanching cum drying • Freezing • Gum coating • Control (untreated) • Atm-fried chips	Product properties (oil content, moisture content, water activity, bulk density, true density, thickness variation, colour values, texture and sensory analysis

```
┌─────────────────────────┐
│ Procurement of raw and  │
│ ripened Nendran banana  │
└─────────────────────────┘
            │
            ▼
┌─────────────────────────┐
│  Cleaning and grading   │
└─────────────────────────┘
            │
            ▼
┌───────────────────────────────────────────┐
│ Peeling and slicing (1-1.5 mm thickness)   │
│ for ripe banana/ slicing with turmeric     │
│ treatment for raw banana                   │
└───────────────────────────────────────────┘
```

Blanching cum drying (2 min water blanching and drying at 65ºC for 3 h)

Freezing for 12 h

Dipping in 1.5% guar gum for 5 min

Vacuum frying in optimised oil (at 100ºC and 12 kPa for 12 min)

N₂ flush packaging in LDPE pouches
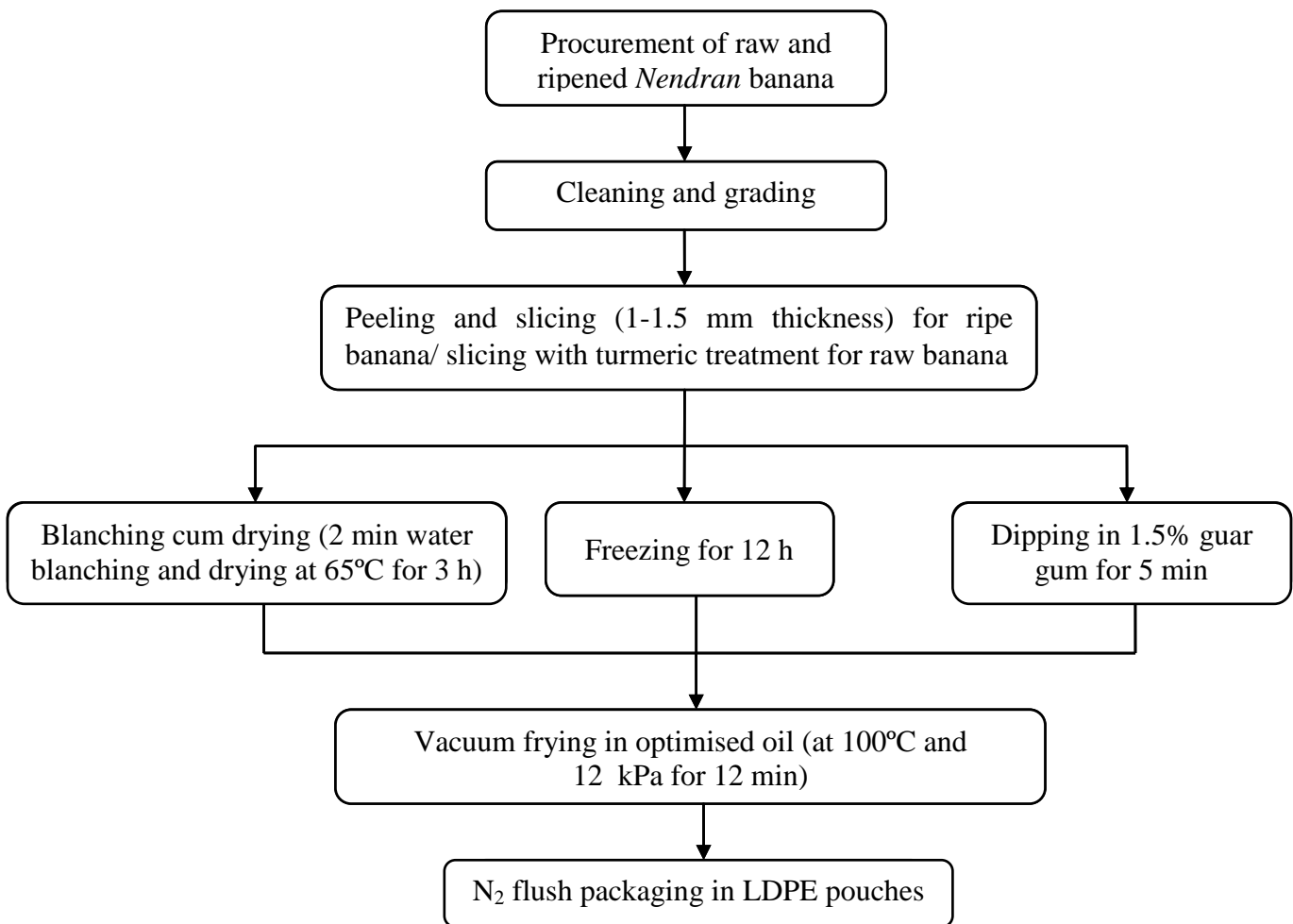
Fig. 3.3 Process flowchart for vacuum frying of banana chips with different pre-treatments

Vacuum frying of pre-treated raw and ripened bananas slices was performed with optimised blend of frying oil. De-oiling of vacuum fried chips was conducted with optimised de-oiling parameters obtained from previous experiment. The fried samples were tested for its quality parameters. These four treatments were statistically analyzed using ANOVA general factorial method (Design expert software version 7.0.0) and optimisation of pre-treatment was done. The standard methods adopted for quality analysis of fried product are discussed in section 3.8.

The experimental design for optimising the process parameters were conducted after optimising oil blend, de-oiling parameters and pre-treatments of vacuum frying of raw and ripened banana chips.

EXPERIMENT IV

3.7 EXPERIMENTAL DESIGN

In order to conduct the experiment in a systematic and efficient manner the experimental work was optimised by response surface methodology. Response surface methodology (RSM) was adopted as it emphasised the modelling and analysis of the problem in which response of interest was influenced by several variables, and the objective was to optimise this response (Montgomery, 2001). The main advantage of RSM was to reduce number of experimental runs needed to provide sufficient information for statistically acceptable results. A four-level, three-factor central composite rotatable design was employed (Myers, 2001). The independent variables and design of experiments selected are discussed in this section.

3.7.1 Selection of Independent Variables

X_1: Frying temperature (90-120°C) - 90, 100, 110 and 120ºC

X_2: Frying pressure (10- 25 kPa)   - 10, 15, 20 and 25 kPa

X_3: Frying time (10-16 min)   - 10, 12, 14 and 16 min

3.7.2 Dependent Variables

The dependent variables for the process parameter optimisation is given in Table. 3.6

Table. 3.6 Dependent variables for optimisation of process parameter

Product quality	Oil quality
• Oil content, moisture content, water activity, bulk density, true density, thickness variation, colour values, texture values, energy value, acrylamide content and sensory analysis	• Total polar compounds (TPC), peroxide value (PV), p-anisidine value (AnV), iodine value (IV), free fatty acid value (FFA), total oxidation value (TOTOX), viscosity, colour values

The coded values for the respective independent variables of experimental design are tabulated (Table. 3.7). The Table. 3.8 details the number of experiments with its replications and combinations that are obtained by response surface analysis. The vacuum frying of banana experiment was conducted with combinations of process parameters represented in Table. 3.9. The best treatment was optimised based on quality of vacuum fried product.

Table. 3.7 Coded and actual values of independent variables for vacuum frying

Independent variables	Code variables	Levels in Coded Form				
		-2	-1	0	1	2
Frying temperature (ºC)	X_1	80	90	105	120	130
Pressure (kPa)	X_2	6	10	18	25	30
Frying time (min)	X_3	8	10	13	16	18

Table. 3.8 Experimental design in coded form for response surface analysis

Coded variables			Combinations	Replications	Number of Experiments
X_1	X_2	X_3			
±1	±1	±1	8	1	8
±2	0	0	2	1	2
0	±2	0	2	1	2
0	0	±2	2	1	2
0	0	0	1	6	6

Code '0' is for centre point of the parameter range investigated '±1' for factorial points, and '±2' for star points; X_1 - Frying temperature (°C), X_2 - Pressure (kPa), X_3 - Frying time (min)

Table. 3.9 Experimental design for optimisation of process parameter of vacuum fried banana chips

Run	Coded levels			Un coded levels		
S.No	X_1	X_2	X_3	Frying Temperature (°C)	Pressure (kPa)	Frying time (min)
1	2	0	0	130	18	13
2	0	0	0	105	18	13
3	-1	-1	1	90	10	16
4	-2	0	0	80	18	13
5	0	0	0	105	18	13

6	0	0	-2	105	18	8
7	0	-2	0	105	6	13
8	1	-1	1	120	10	16
9	-1	-1	-1	90	10	10
10	0	0	0	105	18	13
11	1	-1	1	120	10	10
12	0	0	0	105	18	13
13	0	2	0	105	30	13
14	1	1	-1	120	25	10
15	-1	1	-1	90	25	10
16	-1	1	1	90	25	13
17	0	0	2	105	18	18
18	0	0	0	105	18	13
19	0	0	0	105	18	13
20	1	1	1	120	25	16

3.8 QUALITY PARAMETERS OF FRIED PRODUCTS

3.8.1 Estimation of Oil Content

The oil content of vacuum fried banana chips was analysed using AOAC standard procedure (AOAC, 1990) with soxhlet apparatus (Pelican Equipments, Soc plus model: SOCS 06 ACS, India).

3.8.2 Moisture Content

Moisture content determination of vacuum fried banana chips was conducted using American Association of Cereal Chemists (AACC, 1986) method.

3.8.3 Carbohydrate

The estimation of carbohydrate was carried out by the AOAC standard procedure (AOAC, 2005).

3.8.4 Protein

The protein content of the vacuum fried banana chips was estimated using AOAC standard procedure (AOAC, 2005) micro Kjeldahl method with protein analyser (Pelican Equipments, model : KEL PLUS).

3.8.5 Energy Content

The energy content of the vacuum fried product was calculated using the standard equation provided by Ekanayake *et al*. (1999) which involves the protein, carbohydrate and fat.

3.8.6 Colour Values

The colour of vacuum fried banana chips was measured quantitatively using HunterLab Colourimeter – Color flex EZ diffuse model. It works on the principle of focusing the light and measures energy reflected from the sample across the entire visible spectrum. The colourimeter uses filters rely on "standard observer curves" that define the amount of red, green and blue colours. The primary lights required matching a series of colours across the visible spectrum and mathematical model used to describe the colours are called Hunter model. It provides reading in terms of L^*, a^* and b^*. Where, luminance (L^*) forms the vertical axis, which indicates whiteness (100) to darkness (0). Chromatic portion of solids is defined by: a^* (+) redness, a^* (-) greenness, b^* (+) yellowness and b^*(-) blueness.

The colour of the banana chips was measured by using CIELAB scale at 10˚ observer at D_{65} illuminant with 50 mm diameter measuring space. Before measuring the colour of samples, the instrument was standardised by placing black and white standard tiles. The chips were ground into powder to avoid reflection error during measurement and were filled into a transparent cup without any void space at the bottom. The deviation from colour of the samples with standard was also observed and recorded in the computer interface.

Total color difference (ΔE) between raw (L_0^*, a_0^*, b_0^*) and fried banana chips (L^*, a^*, b^*) was determined using the below equation (3.1) adopted by Troncoso *et al*. (2009)

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \qquad 3.1$$

3.8.6.1 Yellowness Index

The Hunter lab b^* was used for the depiction of yellowness of ripened banana chips. The yellowness index was calculated using the formula (equation 3.2) used by Francis and Clydesdale (1975)

$$YI_{FC} = \frac{142.86b^*}{L^*} \qquad 3.2$$

3.8.7 Texture Analysis

Crispness is a measure of force required to break the food sample which is expressed in Newton (N). Determination of crispness of vacuum fried banana chips was performed using a Texture Analyser (TA) (TA.XT texture analyser, Stable micro systems Ltd.).

Texture Analyser is a microprocessor controlled texture analysis system (TA HDI model), which can be interfaced to wide range of peripherals, including computers. It consisted of test bed, movable bar and control system (key board). The test bed and control system are linked to each other. Texture analyser measures force, distance and time and thus provides three-dimensional analysis.

The probe carrier present at top of TA contained a very sensitive load cell. Force was calibrated by fixing the load cell of 25 kg on the movable bar of the texture analyser. Calibrated weight was hung on the load cell using hanger, ensuring that the base was free without any attachments and enough clearance was maintained for the weights to hang freely and the probe was clear from all obstructions. The heavy-duty platform is the base from which many attachments were fitted to the texture analyser. It ensures the precision alignment of probes and product samples. A force time curve was recorded and analysed by Texture Exponent 32 software program (version 3.0).

The tests were conducted on individual chips at a time and the required values were obtained from the graph. During the testing process, the probe was allowed to move downwards to fracture/rupture the sample for a specified distance of 2 mm. Once the probe touched the sample, the maximum force required to rupture the chips was observed and compared between the samples. The crispness test for fried banana chips was conducted using standard method available in the TA library for tortilla chips.

TA-XT2 Settings

Mode	: Measure Force in Compression
Option	: Return to Start
Pre-Test Speed	: 1.0 mms^{-1}
Test Speed	: 1.0 mms^{-1}
Post-Test Speed	: 10.0 mms^{-1}
Strain	: 40 per cent
Trigger Type: Auto	: 5 g
Data Acquisition Rate	: 500 pps
Probe	: Crisp fracture rig (HOP/ CFS) with 25 kg load cell

The test was performed using the above TA settings. The result was obtained from the graph and tables in result window.

3.8.8 Bulk Density

Bulk density was computed using standard equation (Ravli *et al.,* 2013). Five chips samples were weighed and its bulk volume was measured using liquid displacement method cylinder using 10% ethanol (Nunes and Moreira, 2009).

3.8.9 True Density

True density of vacuum fried banana chips was calculated as per the method recommended by Deshpande and Poshadri (2011).

3.8.10 Thickness Expansion

The degree of thickness expansion was calculated with the equation used by (Ravli *et al.,* 2013).

3.8.11 Water Activity (a_w)

The water activity of banana chips was determined using water activity meter (model: Aqua lab, Decagon Devices Inc., Pullman (Wa), USA) (Perez-Tinoco *et al.,* 2008).

3.8.12 Acrylamide Content

The acrylamide content of the vacuum fried banana chips was determined using the modified high performance liquid chromatography (HPLC)–diode array detector (DAD) method (Shamla and Nisha, 2014).

3.9 QUALITY PARAMETERS OF FRYING OIL

3.9.1 Total Polar Compound (TPC)

This parameter was determined by Testo 270º (make: Italy) instrument. In Testo 270º instrument measures TPC based on the dielectric constant of oil and it was directly transformed into percentage weight of TPC (Guillén and Uriarte, 2012). The oil to be tested was preheated to 40ºC in a glass beaker. The probe with sensor of Testo 270º was inserted into the preheated sample. Care was taken to avoid the sensor touching bottom of the beaker. The digital display on the instrument displays the TPC in percentage.

3.9.2 Oxidation Stability

The peroxide value (PV) expressed in milliequivalents of active oxygen per kilogram (meq $O_2 \, kg^{-1}$), p-Anisidine value (AnV) expressed as anisidine units, Free fatty acid expressed as free oleic acid percentage and Iodine values (IV) are the important parameters that decide the oxidation stability of edible oil. All these four attributes were determined using rapid analysis equipment FoodLab (CDR FoodLab, Italy). The instrument is compliant with Association of Official Analytical Chemists **(AOAC) official method** (Kwon *et al.,* 2016).

The equipment performs the test through photometric reading of cuvettes with samples and test solution. The device contains 16 incubation cells to warm the sample or test solution with cuvettes and 4 cells to execute the test. The manufacture provided different kit of test solutions with label R1, R2. The sample size and test kits vary depending on the attribute. The entire test was done with following general procedure.

The test tubes containing reagent R1 were placed in one of the incubation cells and let to warm for at least 5 minutes. The cuvette was gently shaken for 2 - 3 times and kept in the cell marked with blue light and the read button was pressed to obtain readings for blank. Then the homogenised sample was drawn with the pipette tube 2 or 3 times and released it on the blotting paper before collecting for the test. Then 2.5 µl of sample was collected for free fatty acid value (FFA), 20 µl for p-Anisidine value (p-AV), 5 µl for peroxide value (PV) and iodine value (IV). The pipette tip was cleaned carefully with blotting paper, avoiding contact between the extremity of the tip and paper. Sample was then placed in the cuvette, keeping the tip immersed in reagent. The cuvette with sample was shaken gently for 2 - 3 times and placed in the cell marked with blue light. The read button was then pressed to execute the test.

In case of peroxide test, 10 µl of R2 solution was collected and added along with R1 and sample in the cuvette. The cuvette was then incubated for three minutes after gentle shaking of the contents. Later, the cuvette was placed in cell

marked with blue light and the read icon was pressed to obtain the photometric reading. The respective test results were displayed and recorded.

3.9.3 Total Oxidation Value (TOTOX Value)

The TOTOX value is the total oxidation value of oil which involves both peroxide and p-Anisidine value. The TOTOX value could be evaluated using the below given equation (3.3) recommended by (Shahidi and Wanasundara, 2002)

$$TOTOX = 2PV + AnV \qquad\qquad 3.3$$

3.9.4 Viscosity

The viscosity is the measure of resistance to flow and it varies with different oils and during frying. The viscosity is expressed in (mPa.s) and was measured in the study using Viscometer (model: Brookefiled DV E Viscometer, United States). The equipment consisted of a bubble stage to avoid experimental error due to dislodgement. The spindle (No.2) was fixed in screw present under viscometer to conduct the test. The oil sample (500 ml) was taken in a glass beaker and placed below the spindle and the spindle was lowered carefully without touching the sides or bottom of the beaker. The measurement was taken in auto range. The motor was then switched on and the spindle rpm was adjusted till 100% torque. The reading of viscometer was displayed in cP (centipoises). Similar procedure was followed for subsequent tests.

3.9.5 Colour Values

The colour values of oil before and after frying was analysed using Hunter Colour Lab. The details of the colourimeter and procedure to determine the colour values are given under section 3.8.3.

3.10. SENSORY ANALYSIS

An organoleptic evaluation of the product was done for colour, flavour, texture, taste and overall acceptability (Ranganna, 1977). All the samples were displayed to the ambient conditions. Nine-point Hedonic scale was used for

sensory evaluation and score card was given to bring out the inherent characteristics of vacuum fried product. The vacuum fried chips were evaluated for colour and appearance, texture (crispness), taste, flavour and overall acceptability in a distribution of cell on a 9-point Hedonic scale by a panel of 20 judges. The score card model is given in appendix A.

3.10.1 Fuzzy Logic

The sensory analysis done subjectively was ranked based on its attribute preference mathematically using fuzzy comprehensive model (Sana *et al.,* 2016). The sensory preference score given by 15 trained judges were taken and their linguistic judgment was converted to numerical ranking using fuzzy model. The attributes were assigned with respective values based on the preference given by sensory panels. Scores assigned for the vacuum fried banana chips were colour and appearance – 0.2, texture – 0.3, flavour - 0.1, taste – 0.2 and overall acceptability – 0.2. The sensory analysis using fuzzy logic involved formation of three sets.

I. Factor set (F_f)	- Quality attributes of vacuum fried chips (Colour and appearance, Texture, Taste, Flavour and Overall acceptability)
II. Evaluation set (E_f)	- Scale factors for quality attributes (Excellent (EX), Good (GD), Medium (MD), Fair (FR) and Not Satisfactory (NS))
III. Transformation set (T_f)	- Numerical values for the evaluation set (EX =1, GD = 0.9, MD = 0.7, FR = 0.4, NS = 0.1)

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

- **Fuzzy membership function (FMF) -** Value obtained by dividing the added individual scale factors with total number of judges

- **Normalized Fuzzy membership function (NFMF) -** It is the function obtained by multiplying FMF and scale factor allotted to respective membership function.

- **Normalized Fuzzy membership function matrix –** It is the matrix formulated by adding NFMF with its respective scale factors

- **Judgment membership function matrix (JMFM) –** This is the deciding matrix for ranking. It could be obtained by adding the column values of all matrix and divide with highest total column value

- **Judgment subset (JS) –** It is the final ranking of samples evaluated along with attributes preference of judges.

The model calculation along with sets and matrix table are given in detail in appendix B.

3.11 PACKAGING STUDIES

A suitable packaging material was selected based on preliminary studies. The 95% nitrogen flush packaging was recommended for fried products (Fan *et al.,* 2005). The packaging was done using nitrogen flush packaging machine (model: QS 400 V, Sevana packaging solutions, Kerala). Vacuum fried banana chips weighing 200 g were packed in a standard size standup pouch of LDPE 400 gauge thickness. The packed samples were stored in room temperature for storage studies.

3.12 STORAGE STUDIES

The storage studies were conducted at ambient temperature, which ranged between 25±5ºC and at a relative humidity of 70±10%. The changes in the physical and biochemical qualities of optimised vacuum fried banana chips were analysed at regular intervals of 30 days. Studies were conducted up to 120 days of storage. All the experiments were carried out in triplicate and the mean values were taken for the analysis.

3.13 STATISTICAL ANALYSIS

A central composite rotatable design (CCRD) using three factors at four levels (coded levels −2, 0, and 2) was used for optimisation of a responses (quality attributes of banana chips) for different experimental combinations were related to the coded variables (X_1, X_2 and X_3) by a second degree polynomial equation (3.4) predicted for optimisation of dependent variables (Y) is

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + + \beta_{11} A_2 + \beta_{22} B_2 + \beta_{33} C_2 +$$

$$+ \beta_{12} A.B + \beta_{13} A.C + \beta_{23} B.C + \beta_{24} B.D + \beta_{34} C.D + \varepsilon \qquad\qquad 3.4$$

where,

β_0 (constant),

β_1, β_2, β_3 (coefficients for linear effects)

β_{12}, β_{13}, β_{14} β_{23} (coefficients for interaction effects)

β_{11}, β_{22}, β_{33} (coefficients for quadratic effects) and

ε (random error).

The response surfaces and contour plots for these models were plotted as a function of two variables, while keeping the other variable at the optimum level CCRD consisted of 20 experiments under different conditions. Five replicates in the central point were included in order to estimate the experimental error. Factors and its levels were selected taking into account previous literature on this topic where vacuum fried products were used. The independent variables levels were coded for experimental 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, 2001).

3.13.1 Analysis of Data

A complete second order quadratic model was employed 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, Adjusted R^2, Adequate Precision and Fisher's F-test (Montgomery, 2001).

Adjusted R^2 is a measure of variation around the mean explained by the model, adjusted for the number of terms in the model. The adjusted R^2 decreases as the number of terms in the model increases if those additional terms do not add value to the model. Adequate precision compare the range of predicted values at design points to the average prediction error. The adjusted R^2 values were calculated using the equation 3.5,

$$\text{Adjusted } R^2 = 1 - \{\frac{SS_{residual}/df_{residual}}{(SS_{model}+SS_{residual})/(df_{model}+df_{residual})}\} \qquad 3.5$$

The significance of all terms in the polynomial was judged statistically by computing F-value at probability (p) of 0.1 to 0.01. A complete second order quadratic model was employed to fit the data and adequacy of the model was tested considering R^2 (coefficient of multiple determination, a measure of variation around the mean explained by the model), adjusted R^2 (a measure of the amount of variation around the mean explained by the model, adjusted for the number of terms in the model), predicted R^2 (a measure of how good the model predicts a response value) and Fischer F-test. Coefficient of determination, R^2 is defined as the ratio of explained variation to the total variation and is measure of degree of fit (Haber and Runyon, 1977). The smaller the value of R^2, lesser will be the relevance of dependent variables in the model that explains the behavior 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.

3.14 COST ECONOMICS

The cost economics was done for the optimised vacuum fried product for commercialisation of the product. The cost was determined with reasonable assumptions wherever necessary using standard method. The cost analysis is given in appendix C.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results and discussion of experiments involved in present investigation for the optimisation of oil suitable for vacuum frying, centrifugation parameters for de-oiling, pre-treatment for vacuum frying and processing parameters of vacuum fryer to produce superior quality vacuum fried raw and ripened banana chips using the developed vacuum frying system.

EXPERIMENT I

This experiment was conducted to analyse the suitability of coconut (O_1), rice bran (O_2), palm (O_3) and corn (O_4) oils and a blend of rice bran and

palm oil in the ratio 80:20 (O_5), for frying, based on its quality changes during vacuum frying and the quality of vacuum fried product.

4.1 QUALITY PARAMETERS OF FRYING OIL

The quality parameters of different oils during vacuum frying *viz.,* free fatty acid (FFA), peroxide value (PV), p-Anisidine value (p-AnV), total oxidation value (TOTOX value), iodine value (IV), total polar compound (TPC), viscosity and colour values are discussed below.

4.1.1 Free Fatty Acid (FFA)

Free fatty acid (FFA) value of the frying oil was analysed by the method elaborated in section 3.9.2. The initial FFA of palm oil was 0.06 mg KOHg^{-1} which was comparatively lower than other four oils, while coconut oil was found with higher FFA value with 26 mg KOHg^{-1}. The Fig. 4.1 depicts the changes in FFA value of five oils on vacuum frying. All the five oils showed significant ($p<0.0001$) increase in FFA value after two batches of vacuum frying though it was comparatively less than atmospheric frying. This was due to adoption of lower frying temperature and pressure in vacuum frying than atmospheric frying. Similar trend of increase in FFA value of cooking oils was observed by Garima *et al.* (2015). The FFA value of coconut oil was increased from 26 to 37 mg KOHg^{-1} which was higher than that of other oils. The FFA value of palm, rice bran, corn and blended oils, increased from 0.06, 0.84, 0.12, 0.74 and to 1.26, 0.98, 0.16 and 0.86 mg KOHg^{-1}, respectively during vacuum frying. Similar trend of increase was observed on vacuum frying of potato chips using palm oil by Amany *et al.* (2012). The FFA values of the five oils are represented in Fig. 4.1. It was observed that, though initial FFA value of rice bran oil was 0.84 mg KOHg^{-1} which was higher than corn and palm oils, the percentage increase after frying was less compared with other oils. This had proved the oxidation stability of rice bran oil than other oil due to the presence of oryzynol. Similar behaviour of stability in increase in FFA of rice bran oil was observed by Latha and Nasirullah (2014). The blended oil showed initial higher FFA value compared to palm oil, since it contain only 20% palm oil in the blend

but the increase of FFA after two batches of frying was less than both rice bran and palm oil. The higher per cent of rice bran oil in the blend contributed to the slight increase of FFA value during frying. The obtained trend was supported by the statement of Alireza *et al.* (2010) who observed that the blended oils have higher stability than the single frying oil on deep fat frying. 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.

4.1.2 Peroxide Value (PV)

The peroxide value (PV) of the five oils used increased significantly ($p<0.0001$) after two batches of vacuum frying. This increase during vacuum frying was significantly lower than during atmospheric frying due to reduced frying temperature and pressure. The Fig. 4.2 illustrates the changes in PV of frying oils used in the experiment before and after frying. The PV of corn oil increased from 0.156 to 0.244 meq.O_2kg^{-1} after two cycles of vacuum frying. A significantly higher PV was noted in atmospheric frying of potatoes at 140°C by Zahir *et al*. (2014). The increase in PV of palm, rice bran and blended oils was rom 0.21 to 0.32, 0.32 to 0.64 and 0.26 to 0.48 meq.O_2kg^{-1}, respectively was significantly low. This might be due to the presence of high percentage of
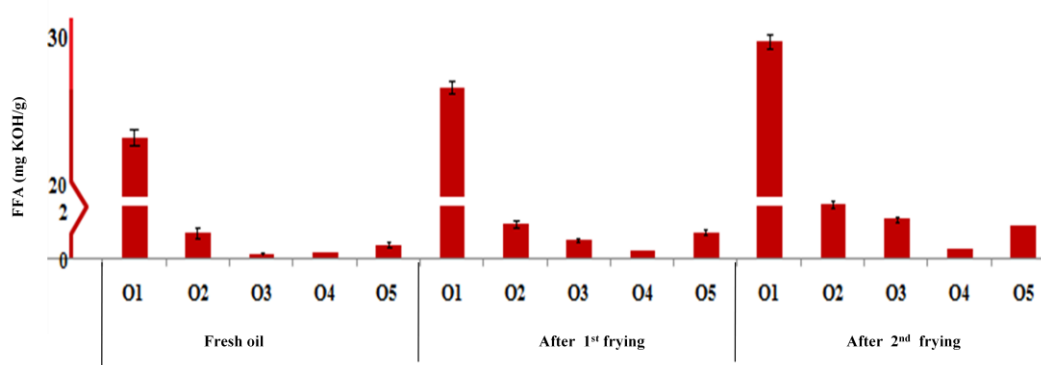
Fig. 4.1 Changes in free fatty acid values of oil on vacuum frying
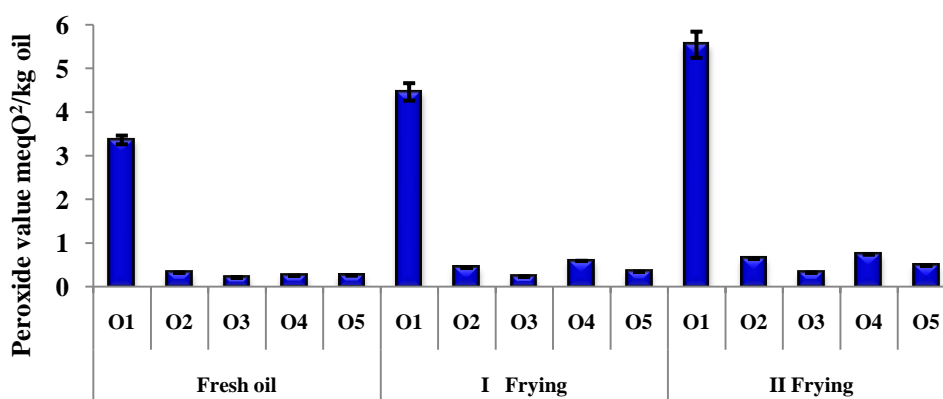
(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Plate. No. 4.1. Vacuum fried raw and ripened banana chips in different oils

(a) VF-raw   (b) Atm-raw   (c) Coconut oil   (d) Rice bran oil

(e) Palm oil   (f) Corn oil   (g) Blended oil   (h) Atm-ripe

unsaturation in both palm and rice bran oils. Similar trend of increase in PV of palm oil used for vacuum frying of potato chips was observed by Amany *et al.* (2012). The PV of coconut oil was increased from 3.36 to 5.54 meq.O_2kg^{-1} which was comparatively higher than other four cooking oils. The obtained results were in agreement with the study conducted on chemical properties of cooking oil on deep fat frying by Garima *et al.* (2015).

4.1.3 p-Anisidine Value (AnV)

The p - Anisidine value (AnV) was another parameter that indicated the secondary oxidation. The AnV of the cooking oils used in the experiment increased significantly ($p < 0.0001$) than its initial values. This indicated the secondary oxidation on vacuum frying. The Fig. 4.3 clearly depicts the increase in AnV of the oil during vacuum frying. The coconut oil exhibited maximum increase in AnV value from its initial value (5.7 to 9.3) which indicated its low oxidation stability on heating. Prakash *et al.* (2016b) identified similar rapid increase in AnV in mustard oil which proved to be unfit for thermal process. The palm and corn oils possessed low initial AnV of 0.6 and 2.4, respectively and it was found to increase significantly to 1.53 and 5.43, respectively after vacuum frying. The initial AnV of rice bran oil was 5.2 which was on par with coconut oil. But the AnV of rice bran oil increased to 5.8 which proved its oxidation stability on heating. Similar trend of oxidation stability in rice bran oil on atmospheric frying was found from the experimental results of Mishra and Sharma (2014). The AnV of blended oil increased from 3.9 to 4.5, after two batches of vacuum frying, the rate of increase was less than atmospheric frying. This was due to the reduced frying temperature and also the absence of atmospheric oxygen during vacuum frying, prevented the secondary oxidation. Also, the oxidation stability of blended oil was higher than pure oil due to its combined properties of stability towards oxidation (Mariscal and Bouchon, 2008).

4.1.4 Total Oxidation Value (TOTOX value)

The TOTOX value of frying oils which was calculated with the peroxide and p-Anisidine value increased significantly ($p < 0.0001$) after vacuum frying.

The Fig. 4.4 clearly describes the increase in TOTOX value on vacuum frying. The rate of increase was comparatively lower than that during atmospheric frying. This was due to the fact that in atmospheric frying higher frying temperature (160 - 180°C) was employed, while in vacuum frying the frying oil was subjected to low temperature (80 - 100°C). The initial TOTOX value of coconut oil was higher compared to other four oils *viz.,* rice bran (5.84), palm (1.02), corn (3.35) blended oils (4.42). The increase in TOTOX value was due to the formation of oxides in the frying oil on heating. The TOTOX value of rice bran and blended oil increased from 5.84 to 8.64 and from 4.42 to 5.46, repsectively after two batches of vacuum frying. However, Latha and Nasirullah (2014) had observed a high TOTOX value of 24.3 in rice bran oil at elevated temperature of 180°C. The low TOTOX value of rice bran and blended oil in the present investigation could be attributed to the lower frying temperature of 100°C. The TOTOX value of fried palm oil was low (4.17) compared to other four oils (coconut oil - 21.4, rice bran oil - 8.64 corn oil - 6.83 and blended oil - 5.46). This indicated that palm oil underwent significantly low oxidation compared to other four oils and was highly suitable for vacuum frying. Similar result was recorded by Shyu and Lucy (2011) who also observed that palm oil possessed good oxidation stability.

4.1.5 Iodine Value (IV)

Iodine value (IV) was determined using the method explained in the section 3.9.2. Higher the IV, higher will be the degree of unsaturation which was preferred in frying oil (Tiwari *et al.*, 2014). The IV of five frying oils used in the experiment decreased significantly ($p < 0.0001$) and the Fig. 4.5 clearly depicts the increase in IV of the five oils on vacuum frying. The corn oil has highest IV of 105 followed by rice bran oil (98.4), blended oil (86.45), palm oil (56.2) and coconut oil (9.5). This indicated the high degree of saturation in coconut oil. After
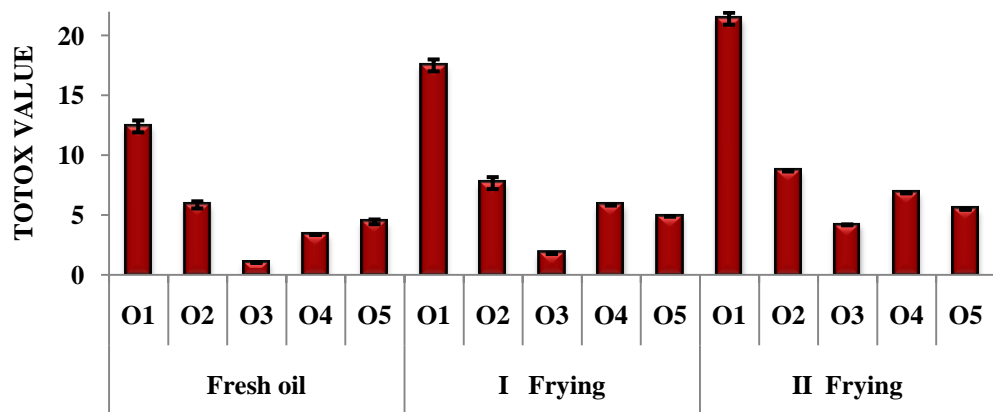
Fig. 4.4 Changes in total oxidation values of oils on vacuum frying
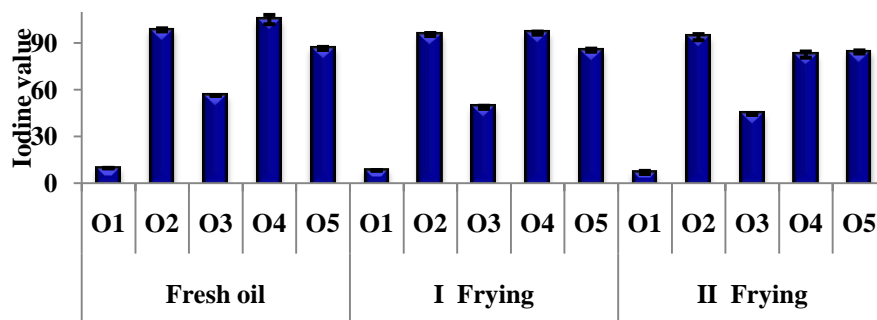
Fig. 4.5 Changes in iodine values of oils on vacuum frying
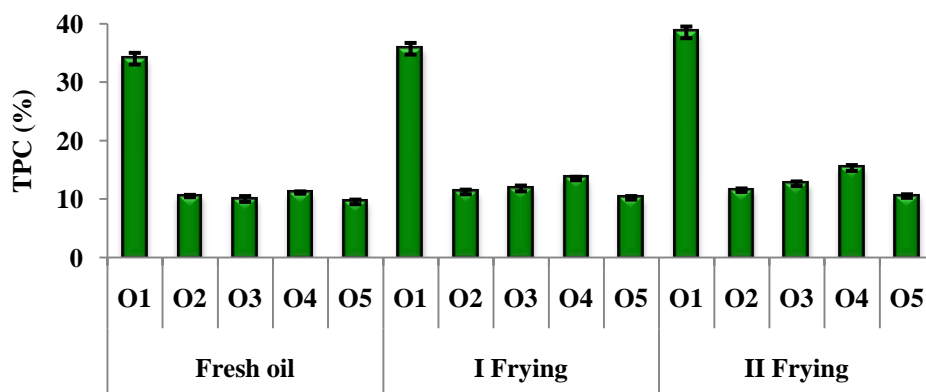
Fig. 4.6 Changes in total polar compound value of oils on vacuum frying

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two batches of vacuum frying, the IV of coconut oil significantly reduced to 6.74 while reduction in IV of rice bran oil (93.5) was comparatively lower than blended oil (84.3) corn (82.5) and palm oil (44.2). The IV of blended oil was higher than palm and lower than rice bran oil, this might be due to higher concentration of rice bran oil in the blend. The significantly lower reduction in IV of rice bran oil confirmed its oxidation stability. Similar result was reported by Fan *et al.,* (2013) who noted low IV for palm oil (50.9) and high IV for rice bran oil (94.5).

4.1.6 Total Polar Compounds (TPC)

The TPC of both fresh and fried oil was measured using the method referred in section 3.9.1. The TPC of all the five oils significantly increased after frying and are represented in Fig. 4.6. The rice bran, palm, corn and blended oils were selected for the experiment based on its fatty acid profile and its thermal and oxidation stability on frying (Alireza *et al.*, 2010; Monika and Kiran, 2013). The TPC value of rice bran, palm, corn and blended oils were 10, 10.5, 11 and 9.5% respectively. The initial TPC value of coconut oil was 34% which exceeded the recommended range for deep fat frying; neverthless, vacuum frying experiment was conducted with coconut oil due to its commercial as well as traditional use for deep fat frying in Kerala state. The TPC value of blended oil, rice bran, palm, corn and coconut oils increased to 10.5, 11.5, 12.6, 15.53 and 38.67%, respectively during vacuum frying. The allowable limit for TPC was 25% for all edible oils (Farhoosh *et al.,* 2011). The statistical analysis of variance indicated significant (<0.0001) difference among five oils. The result obtained for rice bran and blended oils was in agreement with the findings of Mishra and Sharma (2014). They observed increase in TPC of rice bran oil and its blend was due to the presence oryzanol that made the oil suitable for frying. The increase in TPC value of palm oil in the present study was contrary to the findings of Aniołowska and Kita (2015). They observed a significant increase in TPC of palm oil from 10.5 to 24.84% after 15.9 h of frying at 180°C. This might be due to exposure of oil to higher temperature while, in the present experiment oil temperature was

maintained at 110°C. Corn and coconut oils showed higher rate of increase in TPC value than rice bran, palm and blended oils.

4.1.7 Viscosity

The viscosity of the frying oils used in the experiments increased significantly ($p < 0.0001$) upon exposure to high temperature. The Fig. 4.7 illustrates the increase in viscosity of the frying oils after vacuum frying. Gertz (2000) evaluated the quality changes of frying oil and stated that the viscosity was an important indicator of oil quality. The initial viscosity of palm   oil was high (0.79 Nsm^{-2}) followed by that in blended oil, rice bran, coconut and corn oils with viscosity of 0.53, 0.32, 0.2 and 0.1 Nsm^{-2}, respectively. The high viscosity of palm oil was due to presence of polymers which was studied and reported by Kalogianni *et al.* (2011). The viscosity of corn oil increased from 0.1 to 0.16 Nsm^{-2}, which was less than the other four oils. Similar trend of increase in viscosity was reported on repeated frying of corn oil by Da-Silva and Moreira (2008). The increase in viscosity of rice bran and blended oils were insignificant compared to other three oils, due its stability by reducing the formation of polar compounds that increase the viscosity. It was observed that the increase in viscosity of the oils post vacuum frying was much less than with atmospheric frying. This might be due to the difference in frying temperature and pressure. Tarmizi *et al.* (2013) reported similar trend of change in rice bran oil viscosity between vacuum and atmospheric frying condition.

4.1.8 Colour Values

The changes in L^*, a^* and b^* values of the five cooking oils are represented in the graph (Fig. 4.8). The initial L^* values of coconut oil (27.23) was higher than the rice bran (15.45), blended (15.32), palm (12.18) and corn oils (12.67). Higher the L^* value, lighter was the colour of oil. This might be due to the presence of low polar compounds in coconut oil. Gutierrez *et al.* (1988) supports the above statement that the presence of non polar compounds darkens the colour of frying oil. On vacuum frying, the L^* value of oils were reduced significantly. This
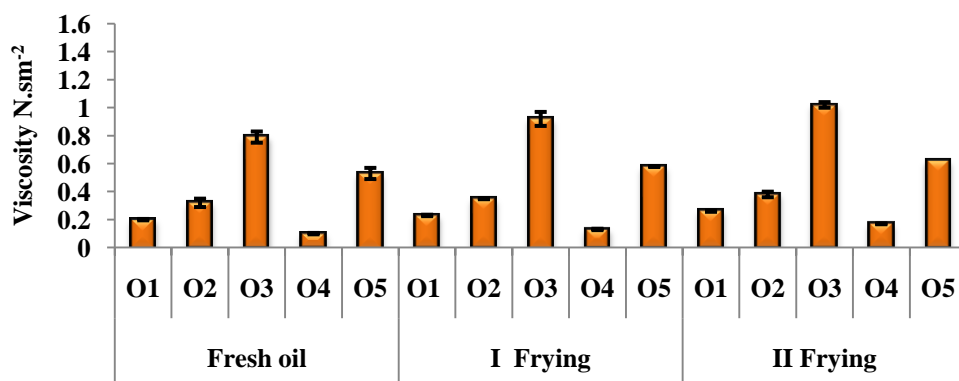
Fig. 4.7 Changes in viscosity of oils on vacuum frying
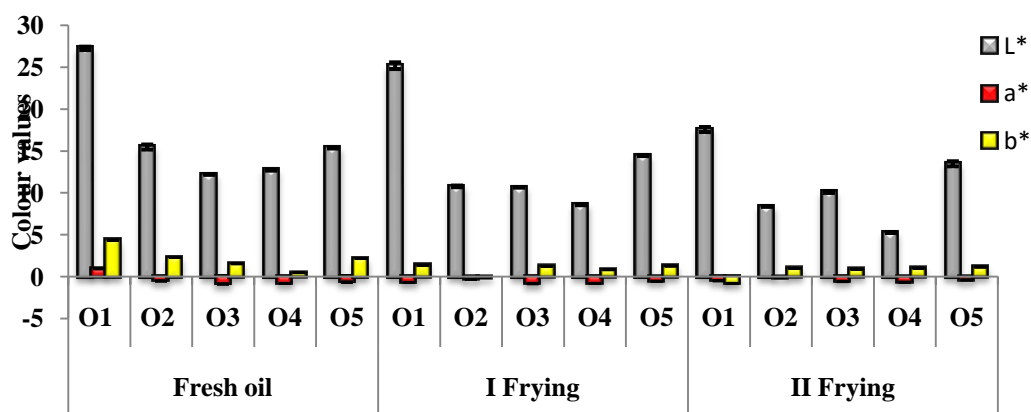
Fig. 4.8 Changes in colour values of oils on vacuum frying
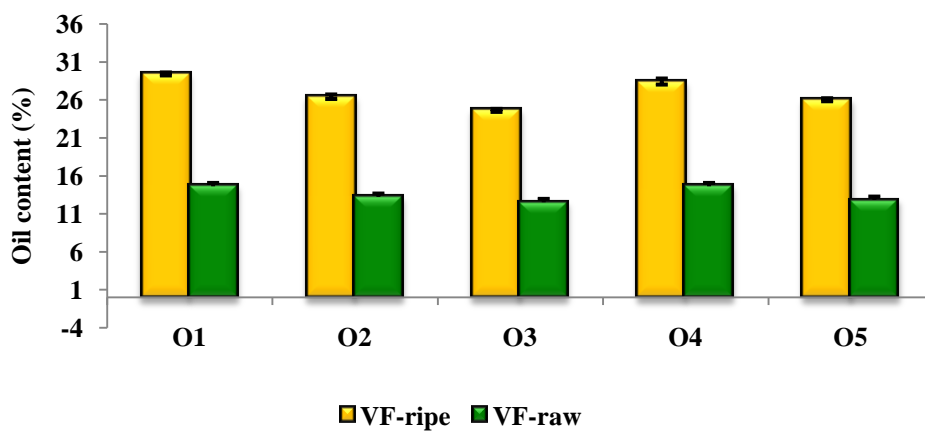
Fig. 4.9 Oil content of vacuum fried banana chips using different oils

darkening of oil colour reflected the total colour difference values (ΔE) of the oil and it ranged between -3.36 to -10.66. The reduction in L^* value could be attributed to the formation of various compounds like carbohydrates, sulphur, phosphates, *etc*. Mishra and Sharma (2014) also had observed a decrease in colour values of rice bran oil during deep fat frying.

The a^* value represent the redness, while the b^* value represent yellowness of the oil. Both the a^* and b^* values decreased significantly ($p<0.0001$) indicating the darkening of oil after vacuum frying. The initial a^* and b^* value of rice bran oil was -0.55 and 2.29, respectively which was reduced to -0.16 and 0.96. A similar decreasing trend was also observed for coconut, palm, corn and blended oils. These observations concur with the findings of Aniołowska and Kita (2015) for rice bran oil.

4.2 QUALITY PARAMETERS OF VACUUM FRIED BANANA CHIPS

The experiment I was conducted to optimise the oils for vacuum frying to be used for further study. The Plate. 4.1 represents VF-ripe fried with different frying oils. The critical quality parameters of fried product like oil content, colour values and sensory evaluation that depends on oil properties were measured for vacuum fried raw banana chips (VF-raw) and vacuum fried ripened banana chips (VF-ripe).

4.2.1 Oil Content of Vacuum Fried Banana Chips

The oil content of vacuum fried banana chips showed no significant difference with atmospheric fried banana chips since no de-oiling or pre-treatments were employed in experiment I. The oil content of VF-raw ranged between 12.5 to 14.9% *(w.b)* while that of VF-ripe was between 24.4 and 29.4 % *(w.b)*. The increased oil content in VF-ripe compared with VF-raw was due to the difference in sugar and moisture content between raw and ripened fruit that facilitate high oil absorption on frying in ripened bananas. The oil content of VF-ripe and VF-raw fried with different oils are represented (Fig. 4.9 and appendix-D2). The variation in oil content within the VF-raw and

VF-ripe were mainly attributed to difference in frying oil viscosity. The maximum oil content of 14.9 and 29.4 % *(w.b).* were found in the VF-raw and VF-ripe fried in coconut oil, respectively. The rate of oil penetration in fried product was higher in low viscous frying oil. The obtained result was in agreement with the observations of Vitrac *et al.* (2002) on vacuum fried cassava chips. Corn oil being the next low viscous oil, contributed to the oil content of fried product next to coconut oil, with 14.6 and 28.4% *(w.b)* in VF-raw and VF-ripe, respectively. The low oil content of 12.5 and 24.6% *(w.b)* was observed in VF-raw and VF-ripe, respectively fried in palm oil. The chips fried with coconut and corn oils showed significantly high oil content than in chips fried in rice bran and palm oil. Mehta and Swinburn (2001) stated that higher the saturation level of oil, higher will be the oil absorption. This agrees with the obtained result where the coconut oil possessed highest level of saturation which showed high oil absorption.

4.2.2 Colour Values of Vacuum Fried Banana Chips

The colour values L^*, a^* and b^* with its total colour difference was observed for the VF-raw and VF-ripe and are represented in appendix-D2 and Fig. 4.10. The results indicated significant ($p < 0.001$) difference of L^*, a^* and b^* values between the chips fried using different oils. The VF-raw and VF-ripe fried in coconut oil had high L^* value of 58.65 and 64.58, respectively, compared with other oils. This might be due to the lighter colour of oil. The chips fried using corn oil showed significantly darker colour with low L^* value of 46.24 and 49.43 in both VF-raw and VF-ripe. This might be due to the colour pigments that facilitate the darkening of fried product. The L^* value of the chips fried in rice bran, palm and blended oils were 57.01, 56.4 and 56.78, respectively. Krokida *et al.* (2001) reported similar behaviour of colour variation in deep fat fried potato chips in corn oil.

The a^* and b^* values of VF-raw and VF-ripe revealed significant changes ($p < 0.0001$) when fried with different oils. The chips fried in corn oil exhibited high a^* values of 7 and 14.15 in VF-raw and VF-ripe, respectively. The
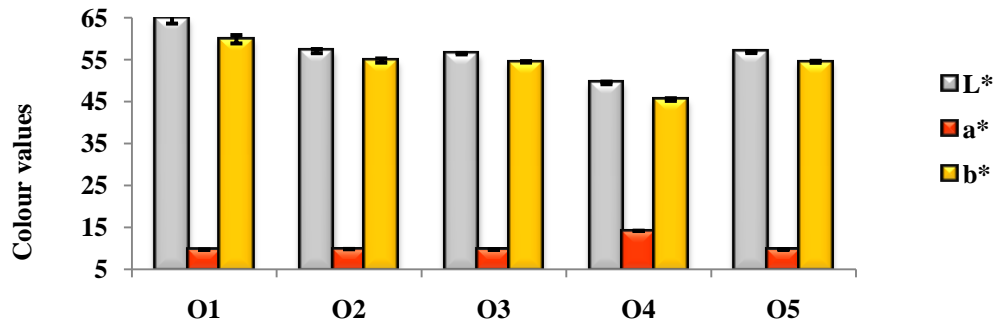
Fig. 4.10 Colour values of VF-ripe using different oils
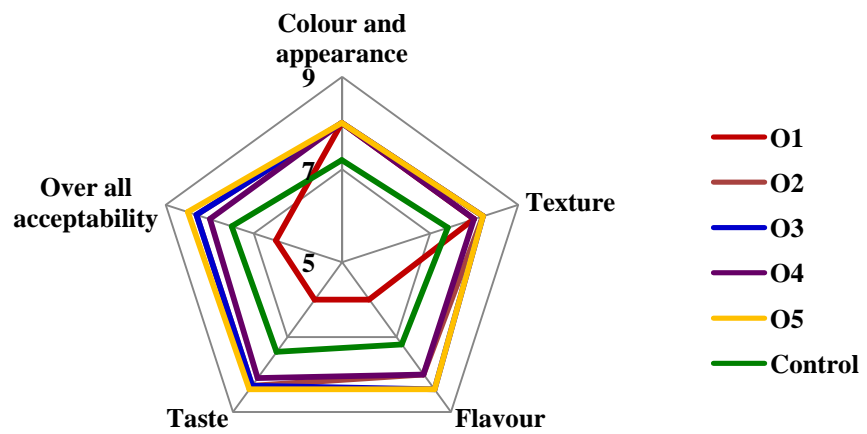
Fig. 4.11 Sensory analysis of VF-ripe using different oils

100

low b[*] values of 35.7 and 45.46 in VF-raw and VF-ripe, respectively. This indicated the production of dark colour chips with low yellowness index 127.38 in VF-ripe fried in corn oil. As discussed earlier, the chips fried in coconut oil had light colour with low a[*] value and high b[*] value of 6.11 and 37.02 VF-raw and 9.66 and 59.84 in VF-ripe, respectively. The a[*] and b[*] values in coconut oil indicated reduced redness and increased yellowness in both the VF-raw and VF-ripe. The yellowness index of VF-ripe fried in coconut oil was high 132.37, followed that fried with palm oil (131.4), blended oil (131.2) and with rice bran oil (130.3). The obtained result was in agreement with the study conducted on vacuum frying of potato, carrot and apple chips by Dueik and Bouchon (2011). The yellowness index and the total colour difference values were represented in the Appendix D2.

The statistical analysis and ANOVA table for all the quality parameters of the oil and fried product that are discussed in the section 4.1 and 4.2. are represented in Appendix D2.

4.2.3 Sensory Evaluation

The sensory analysis was done using Hedonic scale and the sensory attributes were also quantified and ranked using comprehensive fuzzy logic model. Similar results were obtained from both Hedonic scale and fuzzy model. The Fig. 4.11 is the graphical representation of Hedonic scale of VF-ripe. The sensory score of VF-raw varied from 4 to 6 on overall acceptability while the control sample which was atmospheric fried showed highest overall acceptability of 8. In case of VF-ripe, the overall acceptability ranged between 6 and 8.5. The vacuum fried ripened banana chips was preferred than the atmospheric fried control sample and it was reverse in case of raw bananas. From the graph it was clear that the overall acceptability of VF-raw and VF-ripe fried in coconut oil significantly low compared with chips fried in other four oils and the atmospheric fried chips. Another noteworthy observation was that, though 80% of the sensory panellists were from Kerala state, who uses coconut oil in all their culinary purpose regularly. The taste and flavour of VF-ripe coconut oil scored

predominantly less due to its high flavour intensity, while the other sensory attributes of texture and colour was on par with that fried in other oils. Similar trend of result was observed by Khan *et al.,* (2011) where the sensory analysis of *pooris* that were fried with equal blend of coconut oil and palm oil was not acceptable due to the intense flavour of coconut oil.

The fuzzy logic ranking order of sensory attributes of VF-ripe is represented in the Table. 4.1. The fuzzy comprehensive model ranking of VF-ripe was O2 = O3 = O5 > O4 > control > O1. The VF-ripe fried in palm, rice bran and blended oils showed equal preference and which was followed by corn oil, atmospheric fried product and coconut oil. The fuzzy logic comprehensive calculation for sensory analysis and ranking table of VF-raw are given in appendix D2 and D3.

Table. 4.1. Fuzzy ranking of vacuum fried ripened banana chips fried in different oils

Treatments	Ranking of attributes
O_1	C&A >Taste> Flavour > Texture = OA
O_2	OA = Taste = Flavour > C&A > texture
O_3	OA = Taste > Flavour > C&A > Flavour
O_4	C&A = Texture >Taste > Flavour > OA
O_5	C&A = Texture = OA > Flavour = Taste
Control	Texture > Taste > Flavour > OA = C&A

OA - Overall acceptability; C&A – Colour and appearance

From the results of experiment I, the VF-raw and VF-ripe fried in blended oil, rice bran and palm oils showed good score in sensory evaluation. Also, the properties of blended, rice bran and palm oils exhibited stability and suitability for frying compared with corn and coconut oils. Though rice bran oil possessed high thermal and oxidation stability, it had drawbacks like higher AnV and low iodine

value which could be overcome by blending with palm oil to formulate a blended oil in the ratio eighty:twenty. Hence, the blended oil was selected to carry out further experiments. Monika and Kiran (2013) had reported a similar blend ratio of rice bran and palm oil which was stable on repeated frying.

EXPERIMENT II

The experiment II was conducted to optimise the centrifugation parameters (speed and time) to achieve de-oiled vacuum fried banana chips. The VF-raw and VF-ripe were centrifuged at varying speed of (400, 600, 800 and 1000 rpm) and time (0, 3, 5, 7 and 9 min). A total of 20 treatments each were given for raw bananas (D1 to D20) ripened bananas (RD1 to RD20). The raw and ripened banana chips fried using conventional atmospheric frying was taken as control sample. The details of treatments are attached in appendix E.

4.3 EFFECT OF CENTRIFUGATION ON QUALITY ATTRIBUTES OF VACUUM FRIED BANANA CHIPS

The changes in quality attributes *viz.,* oil content, moisture content, water activity, bulk density, true density, thickness variation, texture, colour and sensory analysis during centrifugation for de - oiling of vacuum fried banana chips are discussed below.

4.3.1 Oil Content

The centrifugation of vacuum fried banana chips was done at a vacuum of 12 kPa immediately after frying. It was noted that the de-oiling efficiency during centrifugation was explicitly influenced by its speed and duration. From the Fig. 4.12 it could be elucidated that with increase in centrifugation speed the oil content of VF-ripe reduced significantly ($p < 0.0001$). A similar trend was observed for VF-raw and its tabulated values are given in Table.E2.1 (appendix-E2). Minimum oil content of 8.3% and 13.35% was observed in VF-raw and VF-ripe, respectively at post centrifugation speed of 1000 rpm for 5 min. This reduction of oil content was due to the removal of surface oil during centrifugation. Prolonging

the centrifugation duration to 7 and 9 min did not have significant effect on oil content reduction.

The maximum reduction of 74.1% and 71.4% was observed in VF-raw and VF-ripe, respectively at post centrifugation speed of 1000 rpm for 5 min than the atmospheric fried raw and ripened banana chips. The oil content ranged from 16.64 to 11.94% in VF-raw at low centrifugation speed of 400 rpm and with increasing centrifugation time from 3 to 9 min. The centrifugation speed of 600 and 800 rpm exhibited still more significant reduction in oil content. The work of Maity *et al*. (2014) supports the obtained trend of oil reduction, where vacuum fried jack fruit centrifuged at 500 rpm for 8 min showed maximum reduction in oil content than control sample. Similar reduction pattern in oil content was observed in apple chips fried under vacuum by Shyu *et al.* (2005). It was confirmed that de-oiling with centrifugation speed of 280 rpm showed 33.5% reduction whereas at 140 rpm 17.31% reduction was observed (Moreira *et al.,* 2009). No literatures were cited for the usage of 1000 rpm of centrifugation for de-oiling. So, this significant reduction of oil associated with an increase in centrifugation speed and time was probably due to comprehensive removal of surface oil through the pores. During centrifugation the high density oil is removed through the ridges and pores of fried product through capillary action. This lead to the skimming of oil in centrifuged products.

4.3.2 Moisture Content and Water Activity (a$_w$)

The measurement of moisture content determines the effectiveness of dehydration through frying at particular temperature and time. The initial period to attain the boiling temperature plateau is very short under vacuum frying (Garayo and Moreira, 2002). This phenomenon enables efficient evaporation of moisture from the product due to reduced pressure than other frying process. The Fig. (4.13.) and (4.14.) depicts moisture content and water activity of the vacuum fried ripened banana chips. It was noted that the centrifugation parameters did not significantly affect the moisture content and water activity of
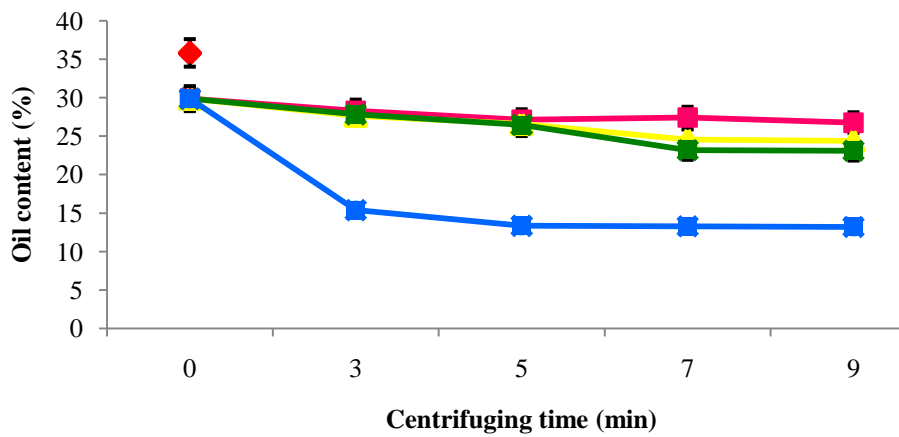
Fig. 4.12. Changes in oil content of VF-ripe on centrifugation

Fig. 4.13. Changes in moisture content of VF-ripe on centrifugation

■Control ■400 rpm □600 rpm ■800 rpm ■1000 rpm
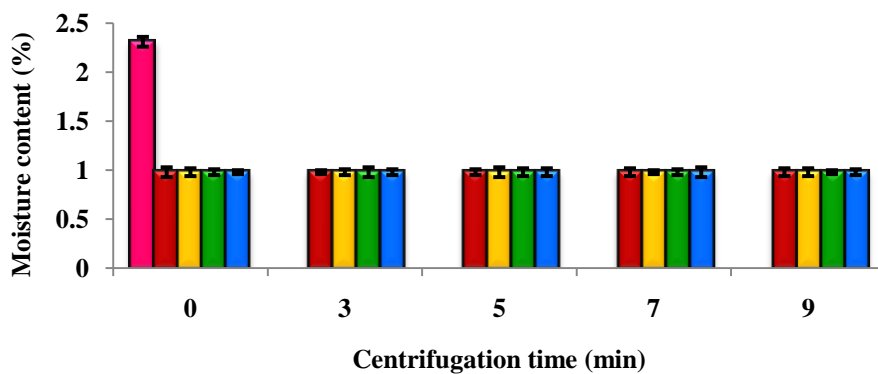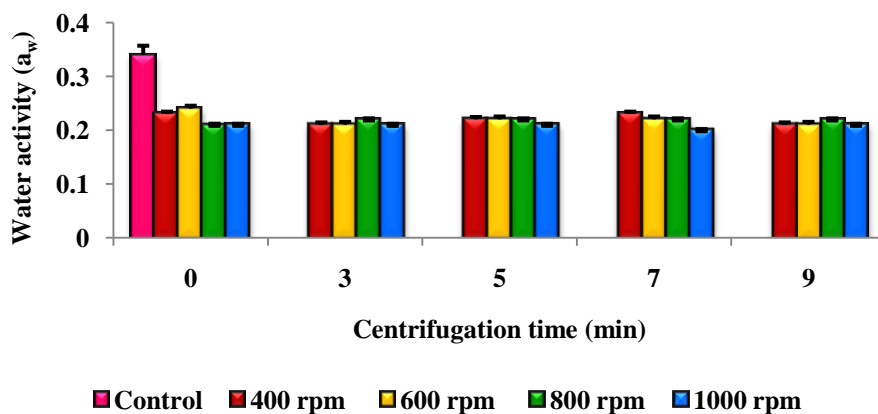
Fig. 4.14. Changes in water activity of VF-ripe on centrifugation

both VF-raw and VF-ripe. The moisture content and water activity of the VF-raw are represented in Table. E2.1. The moisture content of VF-raw and VF-ripe was observed as 0.96 and 0.98%, respectively. Tarzi *et al.* (2011) also had reported that moisture content of vacuum fried mushroom chips ranged between 0.05 and 14.35% at different frying temperature. In the present study, since the process was carried out at constant temperature and pressure, with varying centrifugation speed and duration, no variation in moisture content and water activity was observed.

The water activity of both VF-raw and VF-ripe ranged from 0.234 to 0.257, respectively. The reduction in moisture content was associated with removal of moisture content. Similar a_w value was observed by Sothornvit (2011) on edible gum coated vacuum fried banana chips. The determined moisture content and a_w were sufficient enough to resist the microbial growth.

4.3.3 Bulk and True Density

The bulk density of both VF-raw and VF-ripe decreased linearly with increase in centrifugation speed and duration when compared to control sample (Table. E2.1, Appendix-E2 and Fig. 4.15). The result showed a high bulk density value of 0.892 and 0.926 gcm^{-3} in VF-raw and VF-ripe, respectively at 400 rpm for 3 min of centrifugation. The least bulk density value of 0.413 and 0.432 gcm^{-3} in VF-raw and VF-ripe, respectively, was observed after centrifugation at 1000 rpm for 9 min. Similar trend of decrease in bulk density in de-oiled vacuum fried potato chips was observed by Moreira *et al.* (2009). This significant (p<0.0001) variation of bulk density of de-oiled vacuum fried banana chips was the effect of changes in oil content of the fried product.

The true density decreased significantly (p<0.0001) with increase in centrifugation speed. The tabulated true density values of VF-raw is given in appendix E2 and that of VF-ripe is illustrated in the Fig.4.16. A low true density value of 1.76 and 1.93 gcm^{-3} was observed in VF-raw and VF-ripe,

respectively after centrifugation at 1000 rpm for 5 min. However, no significant variation was found with varying time of centrifugation at 1000 rpm. The high true density value ranged between 2.46 and 2.69 gcm^{-3} in VF-raw, when centrifuged at lower rpm of 400, 600 and 800 rpm. The true density value of VF-ripe ranged between 2.19 to 2.75 gcm^{-3}, respectively under centrifugation speed below 1000 rpm. The trend of decrease in true and bulk density with increase in centrifugation speed was observed. This concomitant behaviour of vacuum fried banana chips could be linked to oil content of the product. The result was in accordance with previous findings of de-oiled potato chips at different temperatures 120, 130 and 140°C by Carla and Moreira (2011). A higher temperature and longer time of frying increased oil absorption which in turn increased the bulk and true density of vacuum fried potato chips.

4.3.4 Thickness Expansion

The centrifugation speed or time had no significant effect on thickness expansion. The thickness expansion of VF-ripe is represented in the graph Fig.4.17 and VF-raw is given in appendix – E2. The thickness expansion of atmospheric fried raw and ripened banana chips showed slightly higher percentage of -83.9% and -92.5%, respectively. While VF-raw and VF-ripe exhibited thickness expansion of -65.3% and -74.2%, respectively. This difference in thickness expansion between atmospheric and vacuum fried product was due to difference in frying conditions, the low pressure in vacuum frying prevented the expansion. Similarly, Garayo and Moreira (2002) noted less expansion in vacuum fried potato chips compared with atmospheric fried ones.

4.3.5 Colour Values

The colour value is the important physical property for the consumer preference for any food product. The ripened banana contains higher sugar content naturally than the raw bananas and therefore its colour was darkened due to Maillard reaction. The colour values of VF-raw and VF-ripe increased significantly (p<0.0001) with centrifugation speed and time. Moreover, they were
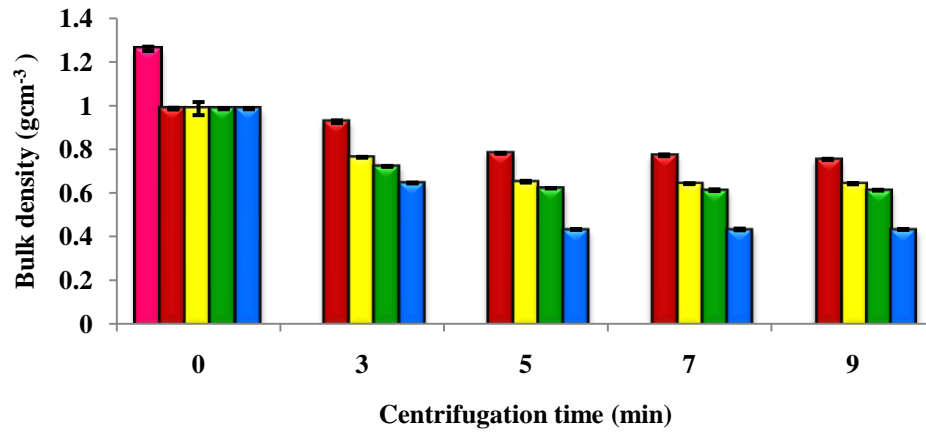
Fig. 4.15 Changes in bulk density of VF-ripe on centrifugation
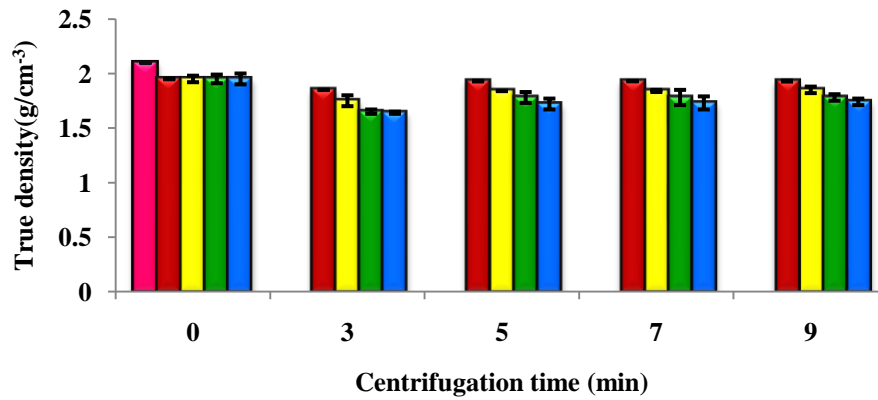
Fig. 4.16 Changes in true density of VF-ripe on centrifugation
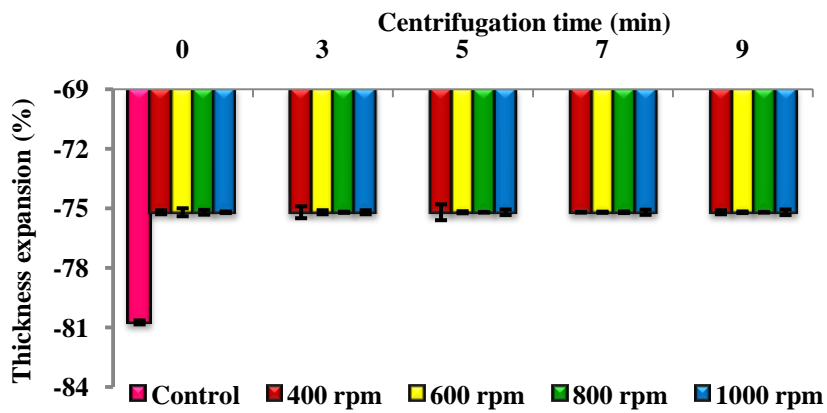
Fig. 4.17 Changes in thickness expansion of VF-ripe on centrifugation

significantly higher than that of atmospheric fried chips. This increased colour values were associated with difference in oil content and frying conditions. The colour of vacuum fried potato chips exposed higher L^*, a^* and b^* values than atmospheric fried potato chips, indicating dark colour and Maillard reaction in atmospheric frying than vacuum frying (Troncoso *et al.*, 2009). It was understood that the vacuum fried products were free from colour degradation due to low pressure and temperature of frying.

The L^* value of atmospheric fried raw and ripened banana chips were 56. 57 and 41.35, respectively which was lower than the vacuum fried chips. This indicated dark coloured product in atmospheric frying. The colour values L^*, a^* and b^* of VF-ripe are represented in Fig. 4.18, 4.19 and 4.20, respectively. Maximum L^* values of 63.21, 63.42 and 63.4 was observed in VF-ripe that were centrifuged at 1000 rpm for 5, 7 and 9 min, respectively. The product with higher L^* value after de - oiling through centrifugation could be adjudged as better quality. The b^* value of VF-ripe predominantly increased from 34.32 to 58.81, where as a^* value decrease from 11.84 to 7.47 which indicated reduced redness. This increase in b^* value representing high yellowness in vacuum fried ripened banana chips was observed irrespective of centrifuging speed and duration. The change in colour could be related with removal of oil content, which masks the lightness and yellowness of the fried product. The high yellowness index of 132.2, 132.4 and 132.65 was obtained in VF-ripe centrifuged at 1000 rpm for 5, 7 and 9 min, respectively (Fig. 4.21). The results were in accordance to the findings on de-oiled vacuum fried jack fruit chips which had higher lightness and yellowness compared to control samples (Maity *et al.*, 2014). Dueik *et al.* (2010) experimented on vacuum fried carrot chips and documented a similar trend of variation in colour values.

The VF-raw showed similar trend of significant increased ($p<0.0001$) in lightness on centrifugation when compared with atmospheric fried chips. The colour values of VF-raw are tabulated and given in appendix-E2. The maximum L^* value of 60.5 was observed in VF-raw centrifuged at 1000 rpm for 9 min,
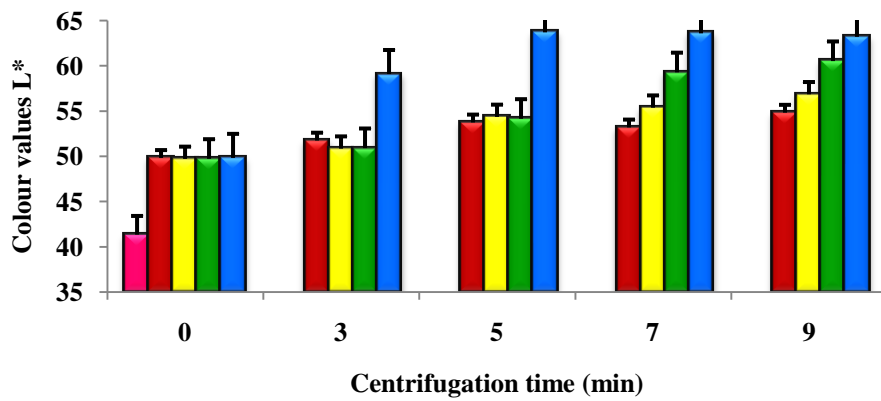
Fig. 4.18 Changes in colour values L* of VF-ripe on centrifugation
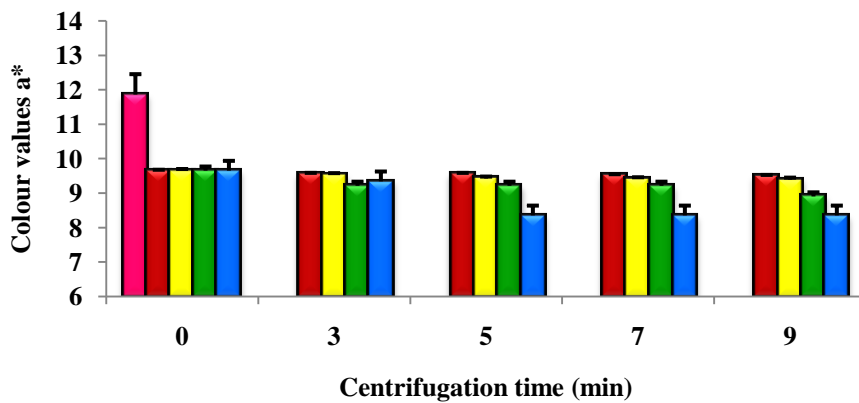
Fig. 4.19 Changes in colour values a* of VF-ripe on centrifugation

■ Control ■ 400 rpm □ 600 rpm ■ 800 rpm ■ 1000 rpm
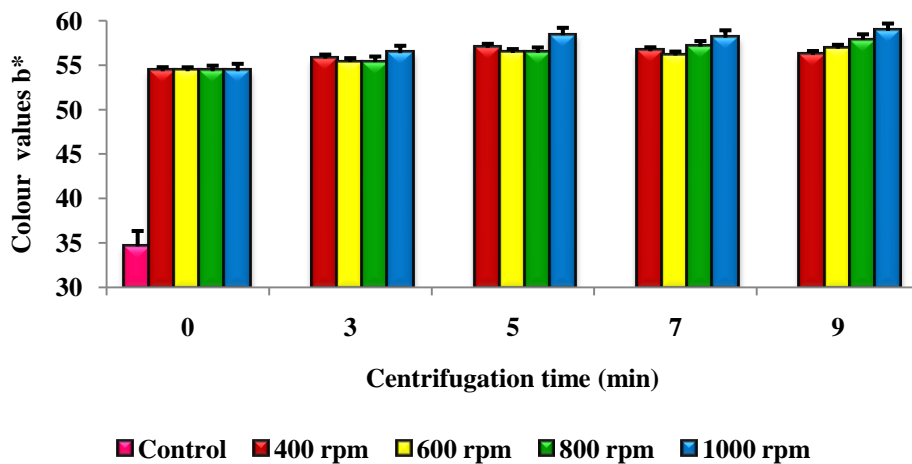
Fig. 4.20 Changes in colour values b* of VF-ripe on centrifugation

while minimum L^* value of 56.57 was observed for atmospheric fried chips. The higher L^* value indicated that vacuum fried chips were lighter in colour. The low oil content and reduced frying temperatures in vacuum frying were the prime factors responsible for this significant colour change. Conversely, a^* and b^* values of VF-raw were reduced significantly than atmospheric fried raw banana chips. The higher a^* and b^* values of 8.01 and 41.35, respectively was noted in atmospheric fried raw banana chips. The de-oiled VF-raw exhibited low a^* and b^* values of 5.7 and 35.6, respectively. Similar trend of lightness value was reported by Andrés-Bello *et al.* (2010) in vacuum fried gilthead sea bream fillets that possessed significantly higher L^* (Lightness) and lower a^* and b^* values compared to atmospheric fried products at 165ºC.

4.3.6 Textural Changes

Texture quality is a key factor of any food product as crispness plays a prime role in consumer acceptability. The cracking force or hardness value was an indicator of degree of crispness. Higher value of crispness could be interpreted as a good sign of consumer acceptability of fried product.

The texture pattern observed in banana chips was jagged force deformation. Similar pattern was recorded by Mayyawadee and Gerhard (2011) on vacuum fried cassava crackers. The cassava fries with high oil and moisture content showed less crispness than the samples with low oil and moisture content. The model graph Fig. E5.1 of texture analysis is given in appendix E5. The compression force increased linearly until the first fracture of banana chips and drops after reaching a peak force which was considered as hardness value. The compression force gradually increased till second fracture. This pattern of texture was expressed as jagged force deformation. In the present investigation, the samples which were de-oiled at higher centrifugation speed of 1000 rpm showed significantly ($p<0.0001$) low hardness value compared with samples centrifuged at low speed of 400 rpm. This was due to the retention of oil at lower centrifugation speed. The Fig. 4.22. below portrays change in hardness value of
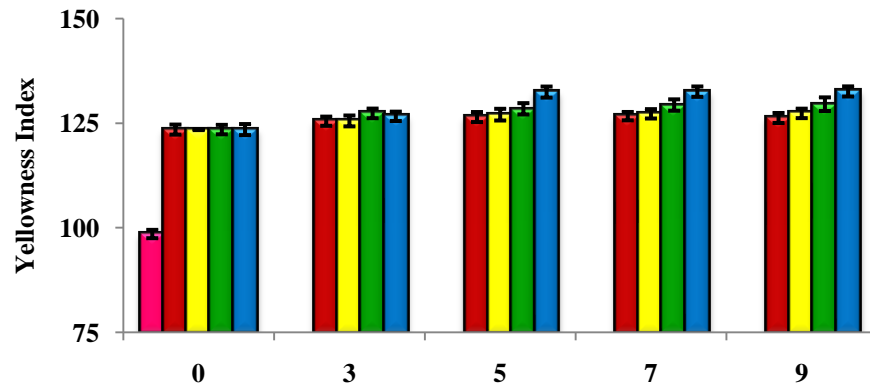
Fig. 4.21 Changes in yellowness index of VF-ripe on centrifugation
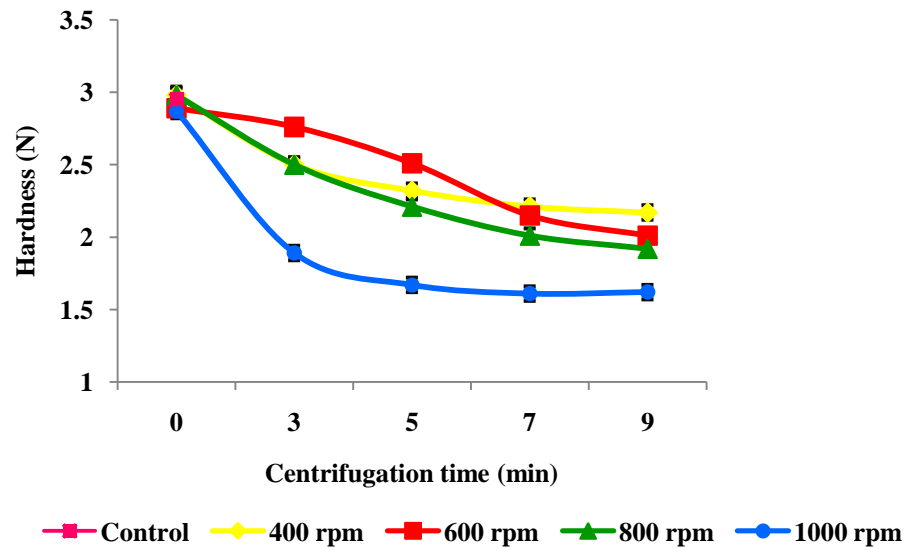
Fig. 4.22 Changes in hardness of VF-ripe on centrifugation

VF-ripe. The low hardness value of 1.62 N, observed in the VF-ripe that was centrifuged at 1000 rpm for 5, 7 and 9 min, reflected increased crispness for centrifuged product. The result could be correlated with the fact that oil content of banana chips centrifuged at 1000 rpm showed no change in its value beyond 5 min of centrifugation. Higher hardness value of 2.98 N was found with control sample, and subtle decrease in hardness value was noted with increase in centrifuging speed. The texture values of VF-raw are represented in Table. E2.1 (appendix-E2). Similar significant ($p < 0.0001$) reduction in hardness value was also observed. The higher hardness value of 1.98 N and lower hardness value of 1.43 N was observed in atmospheric fried raw banana chips and VF-raw centrifuged at 1000 rpm speed for 5 min, respectively.

It was illustrated that the degree of crispness varied with change in centrifuging speed and time. At higher centrifuging speed and time, crispness increased and *vice versa*. This result agrees with Sothornvit (2011) who reported that higher centrifuge speed of de-oiling resulted in less hardness value. Singthong and Thongkaew (2009) indicated that cell wall weakening occurred as a consequence of cell rupture and breakdown of pectin compounds present on the surface of banana which contributed to the textural change.

Table. 4.2 Mean sensory score of de-oiled vacuum fried ripened banana chips

Treatments	Colour & appearance	Texture	Flavour	Taste	Overall acceptability
RD1	8.3	8.7	8.4	8.3	8.2
RD2	8.5	8.5	8.4	8.5	8.5
RD3	8.4	8.3	8.5	8.4	8.3
RD4	8.3	8.4	8.2	8.3	8.4
RD5	8.5	8.3	8.6	8.5	8.5
RD6	8.2	8.5	8.3	8.2	8.3

RD7	8.5	8.3	8.2	8.5	8.4
RD8	8.4	8.4	8.3	8.4	8.5
RD9	8.2	8.5	8.4	8.2	8.3
RD10	8.1	8.6	8.3	8.1	8.2
RD11	8.4	8.3	8.5	8.4	8.4
RD12	8.3	8.6	8.3	8.5	8.2
RD13	8.6	8.2	8.4	8.6	8.5
RD14	8.2	8.4	8.5	8.2	8.2
RD15	8.3	8.5	8.6	8.3	8.3
RD16	8.3	8.2	8.4	8.3	8.3
RD17	8.5	8.6	8.4	8.5	8.5
RD18	8.3	8.5	8.2	8.3	8.3
RD19	8.2	8.5	8.5	8.2	8.2
RD20	8.4	8.2	8.3	8.6	8.3
Control	7.2	7.4	7.2	7.4	7.5

4.3.7 Sensory Evaluation

The Hedonic scale sensory score values for the specified sensory attributes of VF-raw is represented in appendix - E2, (Table. E2.2). It was evident from the Table. 4.2. that despite the different centrifugation speed and duration, no significant changes were observed in colour and texture score, though instrumental measurement exhibited changes with centrifugation parameter. The sensory score was significantly high in vacuum fried ripened banana chips than the atmospheric fried ripened banana chips. The overall acceptability score of VF-ripe 8.5 was observed in de-oiled, while it was 7.5 for atmospheric fried ripened

banana chips. This proved the consumer preference for vacuum fried ripened chips over atmospheric fried ripened chips. Findings of Sothornvit (2011) on gum coated high speed centrifuged banana chips concurred with those obtained for sensory attributes in present study. The VF-raw exhibited very low overall acceptability of 3.5 while control sample scored 8.4, which highlighted extremely low consumer acceptability for vacuum fried raw banana chips. The fuzzy logic ranking for the sensory of VF-raw and VF-ripe are depicted in the Table. E2.3 and E2.4 (Appendix - E2). All the samples ranked equally for vacuum fried centrifuged ripened banana chips and was higher than the control sample. However, it was converse in case of vacuum fried raw banana chips.

It was observed from the results of experiment II, that the centrifugation of vacuum fried banana chips significantly reduced the oil content of the fried chips. The centrifugation speed of 1000 rpm for 5 min showed remarkable reduction of 74.1 and 71.4% oil content in VF-raw and VF-ripe, respectively compared to atmospheric fried banana chips. The centrifugation did not show significant effect on moisture content, water activity and thickness expansion in both VF-raw and VF-ripe. The bulk density, true density and hardness decreased with increase in centrifugation speed. The colour values L^* and b^* increased, while a^* value decreased with increase in centrifugation speed and time. No significant changes were noted within the sensory score of vacuum fried ripened banana chips on centrifugation. While, the consumer acceptability was high for the vacuum fried ripened banana chips than the atmospheric fried chips. The sensory result was contradictory in case of raw vacuum fried bananas. The consumer acceptability of vacuum fried raw banana chips was below satisfactory and the atmospheric fried raw banana chips showed good consumer satisfaction.

EXPERIMENT III

The optimisation of pre-treatments to produce high quality vacuum fried banana chips was carried out in experiment III. The blanching cum drying, gum coating and freezing were the pre-treatments done on raw and ripened bananas which were then vacuum fried at 100°C and 12 kPa for 12 min. The untreated

VF-raw and VF-ripe were taken as the control. The Plate. 4.2 represents the VF-ripe with different pre-treatments. The individual quality parameters of the pre-treated and control samples were compared with corresponding atmospheric fried raw and ripened banana chips. The details of the treatments are given in appendix - F1 (Table. F1.1).

RT1

RT2

RT3

Control

Atm-ripe

Plate. 4.2 Pre-treated vacuum fried ripened banana chips

4.4 EFFECT OF PRE-TREATMENTS ON QUALITY OF VACUUM FRIED BANANA CHIPS

The changes on quality attributes of vacuum fried raw and ripened bananas that were provided with different pre-treatments are discussed below.

4.4.1 Oil Content

The pre-treatments significantly ($p < 0.0001$) affected the oil content of vacuum fried banana chips and the oil content was significantly lower than the atmospheric fried chips. The oil content of pre-treated VF-raw and VF-ripe are represented in appendix - F1 and Fig. 4.23. Highest oil content was observed in VF-raw and VF-ripe pre-treated with freezing which were 34.52 and 38.2%, respectively. The rapid formation of microstructure pores during the evaporation of ice crystals on frying facilitated high oil absorption. The results obtained were in agreement with Albertos *et al*. (2016), who observed increased oil absorption in vacuum fried carrot chips pre-treated with freezing. The lowest oil content of 7.54 and 10.21% was obtained in the VF-raw and VF-ripe, respectively, that were pre-treated with blanching cum drying. This reduced oil content was directly related to moisture loss of dried banana slices, that facilitated low oil absorption on frying. Gamble *et al.* (1987) revealed similar result on deep fat frying of tubers that were dried before frying. The oil content of gum coated VF-raw and VF-ripe was 8.25 and 13.14%, respectively. The reduction in oil content attained through gum coating pre-treatment was slightly higher than de-oiled chips without pre-treatment. The reduction in oil uptake in gum coated samples was achieved by the moisture retention, the coated gum form a layer on the surface that resisted the to and fro mass transfer in the product (Freitas *et al.,* 2009). Similar result was reported on deep fat fried shrimp pre-treated with basil gum coating (Naimeh *et al., 2016*).

4.4.2 Moisture Content and Water Activity (a$_w$)

Moisture content and water activity of the VF-raw and VF-ripe varied ($p < 0.0001$) significantly with pre-treatments. The moisture content of the VF-ripe

represented graphically in Fig. 4.24. and that of VF-raw is given in appendix - F1. The highest moisture content of 2.34 and 2.56% in VF-raw and VF-ripe, respectively, was noted in gum coated pre-treatment. The banana slices pre-treated with gum coating inhibited the moisture evaporation by forming a film over the surface, leading to high moisture content in vacuum fried banana chips. The result was in confirmation with the study of Pawar *et al.* (2014) on hydrocolloids treated *kachori* on deep fat frying. Lowest moisture content of 0.53 and 0.76%, respectively was observed in VF-raw and VF-ripe, pre-treated with blanching cum drying. The initial moisture removal of banana slices through drying contributed to low moisture content in the vacuum fried banana chips. Similar trend of low moisture content was observed in deep fat fried potato chips that were dried prior to frying by Pedreschi and Moyano (2005). The moisture content of control VF-raw and VF-ripe was 0.69 and 0.98%, respectively, while the frozen pre-treated was 0.68 and 0.98%, respectively. The control and frozen pre-treated treatments exhibited highest moisture removal. This was due to rapid removal of moisture on vacuum frying of frozen samples with high temperature gradient. Shyu *et al.* (2005) presented similar trend of moisture reduction in vacuum fried carrots chips pre-treated with freezing. The moisture content of Atm-raw and Atm-ripe was 2.12 and 2.31, respectively, which was higher than untreated VF-raw and VF-ripe, and less than corresponding gum coated pre-treatments.

The water activity of VF-raw and VF-ripe revealed significant variation ($p<0.0001$) with pre-treatments. The Fig. 4.25 depicts the graphical representation of water activity values of VF-ripe and the water activity values of VF-raw are tabulated in appendix - F1. The a_w values ranged between 0.21 and 0.23 in VF-raw and between 0.21 to 0.34 in VF-ripe, respectively. The a_w values obtained were adjudged to be well below the tolerance limit and within the safe level. The obtained results were supported by the study conducted on vacuum fried carrot chips by Dueik *et al.* (2010). Since deep fat frying cooking method was the fastest dehydration process, the vacuum frying as well as atmospheric frying exhibited safe level of moisture and a_w for storage.
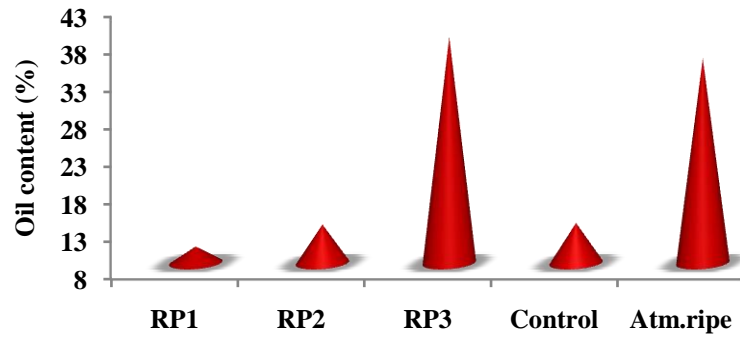
Fig. 4.23 Oil content of pre-treated vacuum fried ripened banana chips
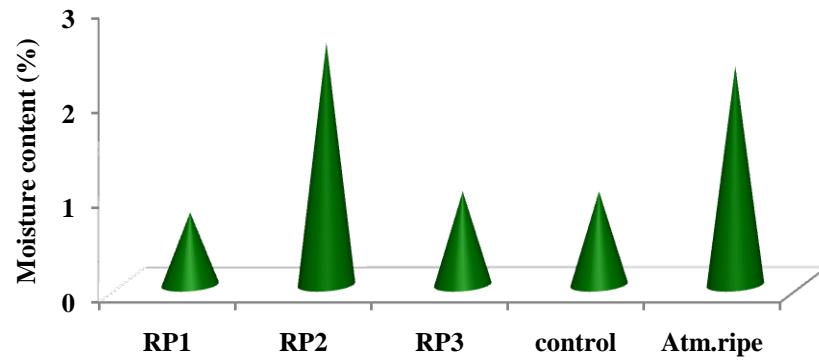
Fig. 4.24 Moisture content of pre-treated vacuum fried ripened banana chips
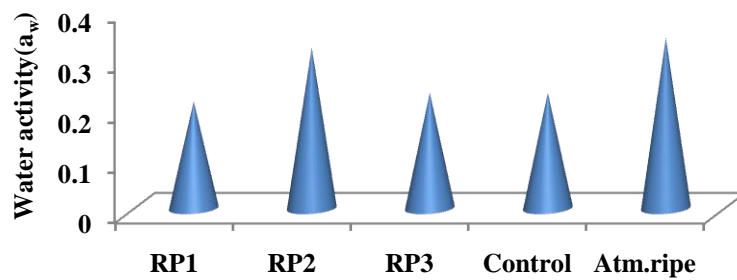
Fig. 4.25 Water activity of pre-treated vacuum fried ripened banana chips

4.4.3 Bulk and True Density

The bulk density and true density showed statistically significant difference (p<0.0001) on adoption of pre-treatments for the vacuum fried banana chips. The Fig. 4.26 and 4.27 illustrates the bulk and true density of VF-ripe. Lower bulk density of 0.325 and 0.347 gcm^{-3} was observed in the frozen pre-treatment of VF-raw and VF-ripe, respectively. Though the oil content was high in frozen pre-treatment which increases the bulk weight of the chips, thickness expansion was two times higher than the atmospheric fried chips. This might be attributed to lower bulk density in VF-raw and VF-ripe chips pre-treated with freezing. The obtained lower density values on freezing pre-treatment was in agreement with the result reported by Albertos *et al*. (2016) on vacuum fried carrot chips pre-treated with freezing. The gum coated pre-treated chips exhibited comparatively higher bulk density (0.912 and 0.924 gcm^{-3}) and true density (1.64 and 1.85 gcm^{-3}) in VF-raw and VF-ripe, respectively, than other pre-treatments, which might be due to comparatively high moisture content and low thickness expansion than other treatments. The bulk and true densities of control sample exhibited slight variation with values of corresponding gum coated pre-treatment. Sahin *et al.* (2005) reported similar behaviour of bulk and true density on hydrocolloid coated deep fat fried banana snack. The VF-raw and   VF-ripe that was pre-treated with blanching cum drying showed bulk density of 0.454 and 0.562 gcm^{-3}, respectively, and the true density of 1.23 and 1.36 gcm^{-3}, respectively. The reduced bulk and true density values in blanching cum drying than gum coated pre-treatment were due its low oil and moisture content. The density of Atm-raw and Atm-ripe were found to be higher than in control and in products subjected to blanching cum drying and gum coating pre-treatment. However, it was lower than density of chips pre-treated with freezing.

4.4.4 Thickness Expansion

The thickness expansion per cent varied significantly (p<0.0001) with pre-treatments for vacuum fried banana chips. The Fig. 4.28 clearly represents the
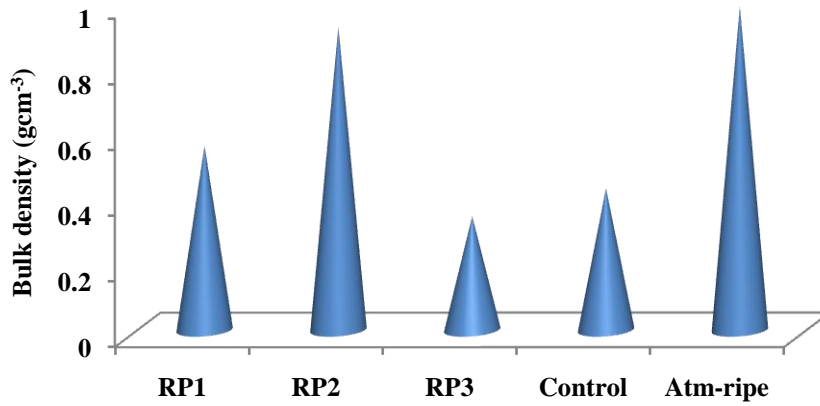
Fig. 4.26 Bulk density of pre-treated vacuum fried ripened banana chips
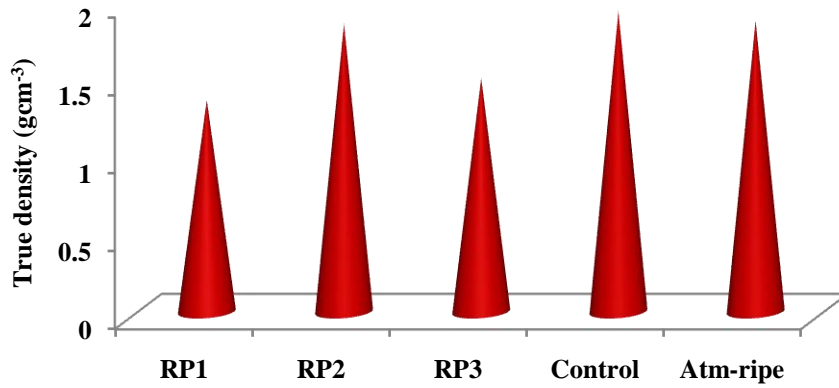
Fig. 4.27 True density of pre-treated vacuum fried ripened banana chips
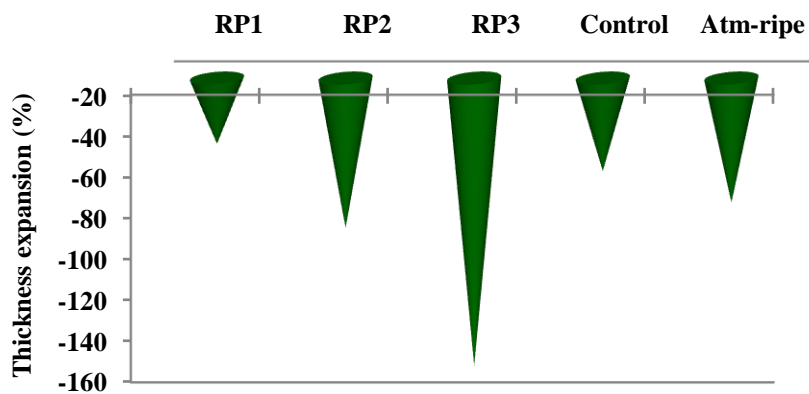
Fig. 4.28 Thickness expansion of pre-treated vacuum fried ripened banana chips

changes in thickness expansion in VF-ripe with different pre-treatments. The VF-raw and VF-ripe that were frozen prior to frying expanded maximum than the other pre-treated samples. The frozen samples when rapidly subjected to high frying temperature (100°C) expanded instantaneously due to high temperature and pressure gradient. Higher expansion of -94.2 and -160% were noted in VF-raw and VF-ripe, respectively, on frozen pre-treatment. The expansion of blanching cum drying and gum coating pre-treatments were lower than the corresponding freezing pre-treatment. Similar trend of thickness variation in deep fat fried sweet potato chips pre-treated with blanching and freezing was reported by Taiwo and Baik (2007). The expansion of gum coated pre-treated chips was -69.4 and -93.4%, respectively, which was higher than control. This was due to addition of another layer of film coating over the chips. However, the expansion of Atm-raw and Atm-ripe was also higher than the control, this was due to the difference in frying conditions of vacuum and atmospheric frying.

4.4.5 Colour Values

The colour attributes showed significant variation (p<0.0001) on pre-treatments of VF-raw and VF-ripe. The colour values of VF-ripe are illustrated in the Fig. 4.29. Maximum L^* value of 58.34 and 60.28, respectively, was observed in VF-raw and VF-ripe, pre-treated with freezing. The vacuum fried banana chips pre-treated with blanching cum drying showed minimum L^* value of 49.5 and 52.58 in VF-raw and VF-ripe, respectively. This indicated that freezing pre-treatment produced significantly light coloured fried product. While, dark coloured product was obtained from blanching cum drying pre-treatment. This colour degradation in blanching cum drying pre-treatment was due to drying process that darkens the colour of the product. The observations of Fan *et al.* (2005) on lighter coloured vacuum fried carrot chips, pre-treated with freezing than that of drying, was similar to the result of present study.

The a^* and b^* values of vacuum fried banana chips exhibited significant variation (p<0.0001) with pre-treatments. The VF-ripe that were pre-treated with blanching cum drying showed highest a^* value of 11.46 and the gum coated one

revealed highest b* of 49.53. This indicated dark coloured product on blanching cum drying pre-treatment. The product obtained from gum coated pre-treatment was with high yellowness. Similar trend was observed in colour values of hydrocolloid coated vacuum fried jack fruit chips (Maity *et al.,* 2015). The ΔE value which indicates the overall colour difference ranged between -2.21 to -15.17 in VF-ripe. The pre-treatment with gum coating showed highest yellowness index of 130.2 followed by freezing pre-treatment with 110. 57 and blanching cum drying had that least yellowness index of 104. 27 in VF-ripe. The gum coating and freezing pre-treatments showed acceptable colour values compared with blanching cum drying. It was also observed that the colour values of control were on par with frozen and gum coat pre-treatment.

The colour values of vacuum fried raw banana chips are tabulated in the appendix-F1. The a* value which indicated the redness of the VF-raw ranged between 7.19 and 8.42 without any significant variation among pre-treatments. The b* value which represented the yellowness was high in the atmospheric fried raw banana chips (41.35) and low in pre-treated VF-raw. The colour variation on vacuum frying was comparatively less than the atmospheric fried raw banana chips. The pre-treatments did not show significant variation on ΔE value of the VF-raw. This was due to low frying temperature and pressure in vacuum frying, that favoured reduced colour change in fried product than atmospheric frying. Mariscal and Bouchon (2008) reported similar result on the colour analysis of vacuum fried apple chips compared with atmospheric fried one.

4.4.6 Textural Changes

The Fig. 4.30 represents the textural changes in the pre-treated vacuum fried ripened banana chips. A higher hardness value of 2.46 and 3.54 N, respectively in both raw and ripened vacuum fried banana chips pre-treated with blanching cum drying. The removal of moisture prior to frying made the product compact and hard (Debnath *et al.,* 2003). Taiwo and Baik (2007) confirmed
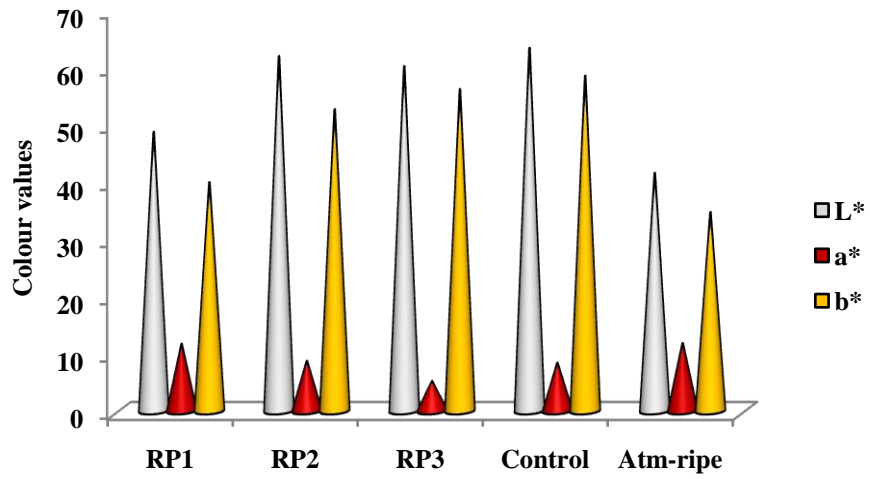
Fig. 4.29 Colour values of pre-treated vacuum fried ripened banana chips
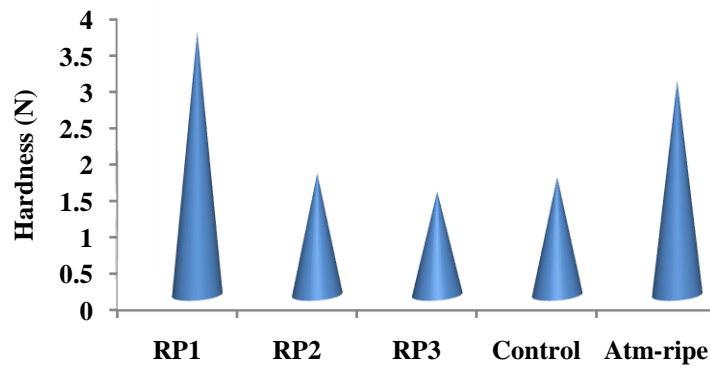
Fig. 4.30 Hardness of pre-treated vacuum fried ripened banana chips
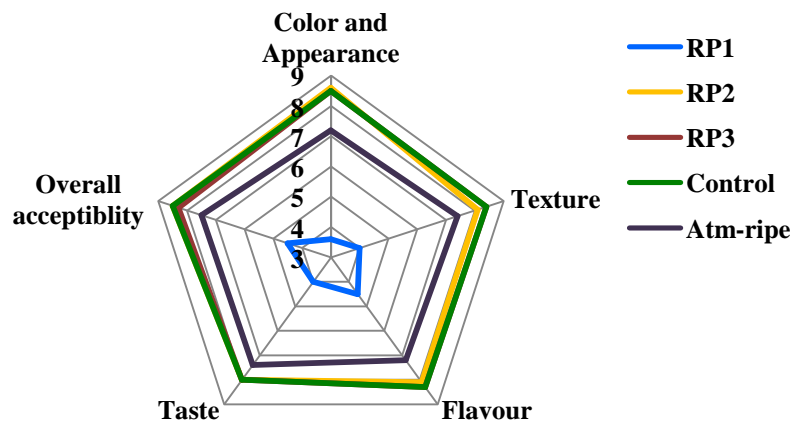
Fig. 4.31 Sensory evaluation of pre-treated vacuum fried ripened banana chips

higher degree of crispness in atmospheric fried sweet potato chips than that of vacuum fried chips pre-treated with drying. The VF-raw and VF-ripe pre-treated with freezing produced crispier chips with lowest hardness value of 1.2 and 1.42 N, respectively. The retention of moisture in the frozen banana slices increased the rate of mass transfer with high oil absorption that favoured crispness in the product. Similar improvement in texture of vacuum fried kiwi fruit, with frozen pre-treatment was reported by Diamante *et al.* (2011). The hardness value of gum coated vacuum fried banana chips had no significant difference with their corresponding control and atmospheric fried banana chips in case of both raw and ripened fruit. The result of Bouaziz *et al.* (2016) on almond gum coated deep fat fried potato chips revealed similar trend of textural change.

4.4.7 Sensory Evaluation

The sensory preference of pre-treated vacuum fried ripened banana chips was higher than the atmospheric fried chips, while it was reverse in case of raw banana chips. Fuzzy logic comprehensive model also showed similar observation. The sensory score of different pre-treated VF-ripe is given in Fig. 4.31. The gum coating pre-treated VF-ripe and control (ripe) scored the highest overall acceptability (8.5). The sensory attributes score of these were 7.5 for texture, and 8 for other three attributes *viz.,* colour and appearance, taste and flavour. This was followed by a sensory score of 8.2, for frozen pre-treatment VF-ripe. The overall sensory score for atmospheric fried ripened banana chips was recorded as 7.5. Poor score of 5 was noted in blanching cum drying pre-treated VF-ripe due to consumer's unacceptability. The fuzzy logic comprehensive model ranking among the treatments were (RP3 = RP2 = Control > Atm-ripe > RP1) the gum coated, frozen pre-treated and control VF-ripe sample ranked first followed by atmospheric frying and blanching cum drying pre-treatment. The ranking within the attributes among each treatment is represented in the Table. 4.3. The colour and appearance attribute ranked first among the sensory attributes due to its retention of yellow colour without darkening in the frozen and gum coating pre-treatments.

Table. 4.3 Fuzzy ranking of pre-treated vacuum fried ripened banana chips

Treatments	Ranking of sensory attributes
RP1	C&A > Texture > OA > Flavour = Taste
RP2	C&A > Texture = Flavour = Taste = OA
RP3	C&A = Texture = OA > Flavour = Taste
Control	C&A > OA = Flavour = Texture = Taste
Atm-ripe	Flavour > Texture > Taste = OA > C&A

OA - Overall acceptability; C&A – Colour and appearance

The sensory score for pre-treated vacuum fried raw banana chips was significantly low compared to VF-ripe and control chips. This was due to poor consumer acceptance of vacuum fried raw banana chips over atmospheric fried banana chips. The vacuum frying retained the natural colour and appearance, and the taste of the raw banana as such, which was not preferred by the consumers. The atmospheric fried raw banana chips with attractive yellow colour appearance, fried taste, and flavour was preferred by the sensory panellists.

The statistical ANOVA table of all the quality parameters of pre-treated VF-raw and VF-ripe is provided in appendix F3 and F4. All the quality parameter values of pre-treated vacuum fried raw banana chips are presented in the appendix-F1 (Table. F1.2). The quality attributes that were measured instrumentally *viz.,* oil content, moisture content, water activity, bulk density, true density, thickness expansion, and texture of pre-treated vacuum fried raw banana chips were illustrated to be significantly different with the atmospheric fried raw banana chips and are discussed in the above section. The sensory preference, which was the most decisive parameter of marketability of a developed product was unacceptable in case of VF-raw. This indicated that the raw banana chips was not suitable for vacuum frying with pre-treatments. The quality attributes of pre-treated vacuum fried ripened banana chips was on par with the untreated one. Moreover, the pre-treatment will incur additional expenditure without any extra benefits, experiment IV was carried out without any pre-treatment. So, the standardisation of process parameters for vacuum fried banana chips with optimised centrifugation of 1000 rpm for 5 min was carried out in experiment IV without any pre-treatment.

EXPERIMENT IV

The experiment IV was carried out for the standardisation of process parameters *viz.,* temperature, pressure and time of frying for the production of VF- raw and VF-ripe. The blended oil (rice bran: palm oil, 80:20) was used for conducting frying experiments and de-oiling was carried out at a centrifugation speed of 1000 rpm for 5 min in all treatments. Twenty treatments each were done for VF-raw and VF-ripe. The Plate. 4.3. represents the VF-ripe fried under different processing conditions. The atmospheric fried raw and ripened banana chips were considered as control sample for the sensory evaluation.

4.5 EFFECT OF PROCESS PARAMETERS ON QUALITY OF VACUUM FRIED BANANA CHIPS

The results were discussed based on the quality changes in different processing conditions (temperature, pressure and time) for VF-raw and VF-ripe.

4.5.1 Oil Content

The maximum oil content of 15.35 and 18.42%, respectively, were observed in VF-raw and VF-ripe, at the frying temperature of 130°C, pressure of 18 kPa and a frying time of 13 min. The minimum oil content of 4.36 and 7.35%, respectively were observed in VF-raw and VF-ripe, at the processing conditions of 80°C frying temperature, 18 kPa pressure and 13 min of frying. The Fig. 4.32 depicts the effect of processing parameters in oil absorption. The higher oil content at increased temperature, pressure and time were due to high moisture loss that facilitated high oil uptake. The reverse happened at reduced frying temperature, pressure and time. Similar effect of frying temperature, pressure and time were noted by Shyu and Lucy (2011) during optimisation process of vacuum fried carrot chips. The statistical models for each response were selected based on the regression coefficient values and effect of interaction terms with the process parameters. A linear model was fitted with the changes in oil content in different experimental conditions using multiple regression analysis. The values of R^2,

| RT1 | RT2 | RT3 | RT4 | RT5 | RT6 | RT7 |

| RT8 | RT9 | RT10 | RT11 | RT12 | RT13 | RT14 |

| RT15 | RT16 | RT17 | RT18 | RT19 | RT20 |

Plate. No. 4.3 VF-ripe fried under different processing conditions
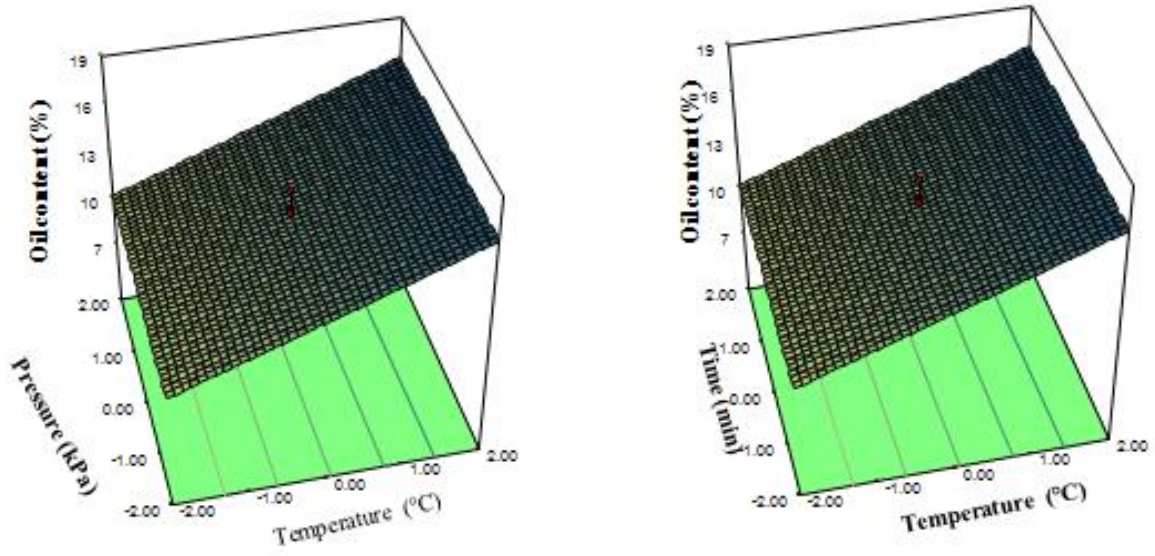
Fig. 4.32 Changes in oil content of VF-ripe with process parameters
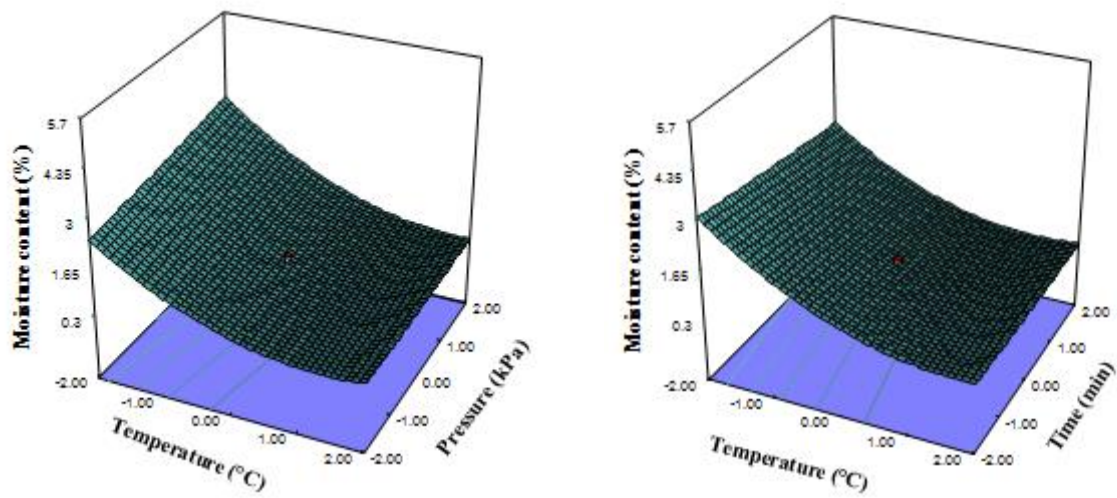
Fig. 4.33 Changes in moisture content of VF-ripe with process

revealed that the linear models were more suitable. The value of R^2 for the oil content of VF- raw and VF-ripe were 97% and 96.4%, respectively. Therefore, first order linear model was found to be sufficient to determine the effect of process parameters on oil content of VF-raw and VF-ripe.

$$OC = +13.33 + 3.15\,X_1 + 0.064\,X_2 + 0.62\,X_3 \quad R^2 = 0.964 \qquad \textbf{4.1}$$

where,   OC = oil content (%) ; X_1 = temperature (°C)

X_2 = pressure (kPa); X_3 = time (min)

It was evident from the Eq.4.1 that oil content depends on the frying temperature, pressure and time. The linear terms X_1, X_2 and X_3 exhibited positive effect on the oil content. The process parameters like frying temperature and time varied significantly (p<0.0001) and were directly proportional to oil content, while, the effect of frying pressure on oil content was insignificant. The oil content in VF-ripe fried at similar temperature (90°C) and time (16 min), with varying pressure of 10 and 25 kPa were 10.42 and 10.5%, respectively. Similar behaviour of pressure was noted in VF-raw. The result was concurrent with the findings of Rafael *et al.* (2012) who optimised the process parameters for vacuum fried mango snack with low oil content of 10.4% at 110°C temperature and 0.5 bar pressure for 1.5 min frying time.

4.5.2 Moisture Content and Water Activity (A_w)

The moisture content of the fried product was found to be inversely proportional to the temperature and time, while the pressure displayed direct relation. The maximum moisture content of 4.94 and 5.67%, respectively, were observed in VF-raw and VF-ripe at the frying conditions of 80°C, 18 kPa and 13 min. At high temperature of 130°C with similar pressure and time, minimum moisture content of 0.364 and 0.432 %, respectively, were obtained in VF-raw and VF-ripe. The changes in moisture content with process parameters

are represented in Fig. 4.33. At higher frying temperature, the rate of moisture removal was rapid.

The relation between the process parameter and the moisture content was better understood by the second order regression equation terms tabulated in Table. 4.5 and 4.6. The individual coefficients (temperature and time), interaction coefficients (temperature and time), (pressure and time), square coefficients (temperature and time) showed negative effect on moisture content. An increase in these coefficients decreased the moisture content. The pressure as an individual and quadratic coefficients showed positive effect, indicating that the increase in pressure increased the moisture content. This might be due to the relation between the boiling point of water and pressure. At low pressure, the boiling point of water was less which favoured high moisture removal and *vice versa*.

$$MC = 0.90 - 1.19X_1 + 0.20X_2 - 0.18X_3 - 0.17X_1X_2 + 0.14\ X_1X_3 - \qquad \textbf{4.2}$$

$$0.043\ X_2X_3 - 0.75X_1{}^2 + 0.003\ X_2{}^2 - 0.022X_3{}^2 \qquad R^2 = 0.964$$

where, MC = Moisture content (%) ; X_1 = temperature (°C)

X_2 = pressure (kPa); X_3 = time (min)

The R^2 value of the quadratic model for VF-raw and VF-ripe experiment was 95.43% and 96.48%, respectively. The Eq. 4.2 represents the quadratic equation for the effect of process parameters on moisture content of VF-ripe. The higher R^2 value entailed the suitability of quadratic model with the experiment. The moisture content values ranged from 0.36 to 4.94% and from 0.43 to 5.67%, respectively, in VF-raw and VF-ripe. The obtained moisture content was in confirmation with the result of Maity *et al.* (2014) on vacuum fried jackfruit bulbs.

The safe level of water activity (a_w) of any fried product was 0.4 to 0.6 (Adams and Moss, 1995). The a_w of VF-raw ranged between 0.2 to 0.62 and that of VF-ripe was between 0.2 to 0.64. The changes in a_w of VF-ripe is represented in Fig. 4.34. The higher a_w value of 0.62 and 0.64, respectively was noted in VF-raw and VF-ripe, at the frying conditions 80°C, 18 kPa and 13 min. This might be due
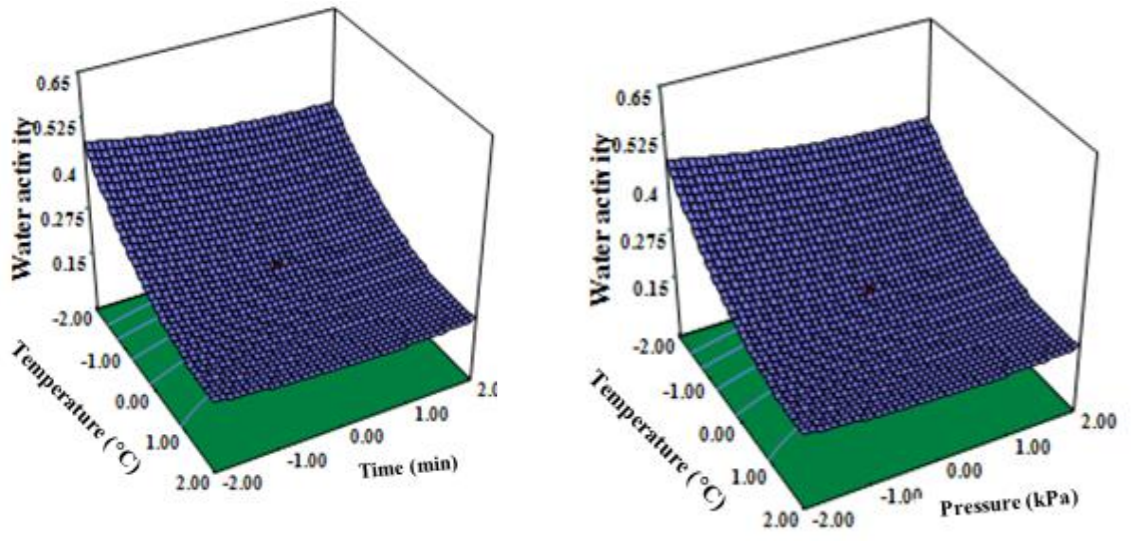
Fig. 4.34 Changes in water activity of VF-ripe with process parameters
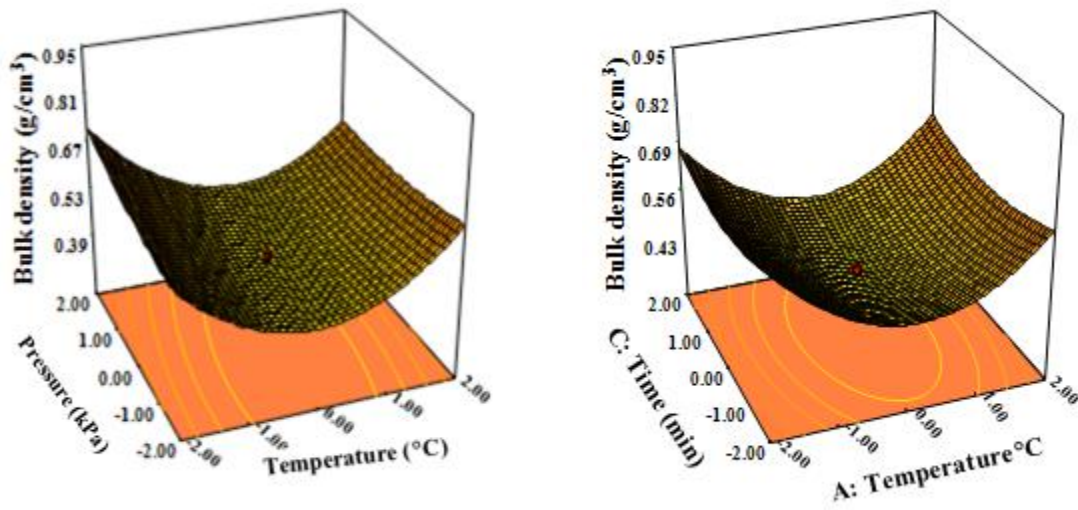
Fig. 4.35 Changes in bulk density of VF-ripe with process parameters

to high moisture retention at the corresponding frying conditions. The high moisture content favoured the increase in a_w at low frying temperature. The low a_w value of 0.2 was observed in both the VF-raw and VF-ripe, which were fried above 100°C temperature. The frying temperature played a significant (p<0.0001) role on a_w, while pressure and time were not significant.

The R^2 value of the quadratic model were 94.1% and 96.5%, respectively, in VF-raw and VF-ripe. The individual terms (temperature and time) were inversely proportional to a_w, while the pressure showed direct proportionality. Rafael *et al*. (2012) reported similar reduction in a_w of vacuum fried mango snack. The effect of interaction between process parameters could be determined by the regression values that are tabulated in Table 4.5 and 4.6. The interaction terms (temperature and time), (pressure and time) exhibited inverse proportionality, while interaction between temperature and pressure showed direct proportionality on a_w.

4.5.3 Bulk and True Density

The bulk and true densities exhibited similar variation with different process parameters and is represented in Fig. 4.35 and Fig. 4.36. Bulk density of the VF-raw ranged between 0.386 to 0.794 gcm^{-3} and VF-ripe was from 0.434 to 0.943 gcm^{-3}, respectively. Higher bulk density of 0.794 and 0.943 gcm^{-3}, respectively, was observed in VF-raw and VF-ripe, fried at 80°C and 18 kPa for 13 min. The vacuum fried product fried at 105°C, 6 kPa for 13 min exhibited lower bulk density of 0.386 and 0.434 gcm^{-3}, respectively, in VF-raw and   VF-ripe. At higher frying temperature of 130°C, pressure of 18 kPa and 13 min of frying time, slight increase in bulk density of 0.742 gcm^{-3} 0.863 gcm^{-3}, respectively, was observed in VF-raw and in VF-ripe. It could be observed that both moisture content and oil content of the chips played a very important role in the variation of bulk and true density. The bulk density was high initially at low frying temperature of 80°C and it decreased linearly with increase in frying temperatures from 90 and 105°C. Further, with an increase in frying temperature from 120 and 130°C, the bulk density showed slight increase in both VF-raw and

VF-ripe. The increase in bulk density at low frying temperature was due to high moisture content. The decrease in bulk density with increase in frying temperature was due to rapid removal of moisture. This was in agreement with the findings of Maneerote *et al.* (2009) who documented that the bulk density of vacuum fried rice crackers coated with fish powder increased with increase in frying temperature.

The quadratic model with regression value of 89.3% and 81.6%, respectively, in VF-raw and VF-ripe was best fitted to understand the variations of bulk density. The overall effect of process parameters showed significant difference (p<0.0001) to bulk density. The interaction terms where temperature was involved showed significant effect in bulk density.

The high true density of 1.72 and 1.84 gcm^{-3}, respectively, in VF-raw and VF-ripe was observed at low temperature of 80°C, pressure of 18 kPa and frying time of 13 min. The decrease in true density to 1.14 and 1.36 gcm^{-3}, respectively, in VF-raw and VF-ripe was observed at frying conditions of 105°C, 18 kPa and 13 min. The subsequent increase in true density of 1.63 and 1.78 gcm^{-3}, respectively, in VF-raw and VF-ripe was observed at higher frying temperature of 130°C and 18 kPa pressure for 13 min. The initial increase in true density at lower frying temperature (80°C) was due to high moisture content and the later increase in true density at higher frying temperature (130°C) was due to high oil content. Mayyawadee and Gerhard (2011) also observed similar increase in true density with increase in frying temperature of above 120°C in vacuum fried cassava crackers. The effect of overall individual process parameters, interaction and quadratic terms could be better understood by the tabulated values in Table 4.5 and 4.6.

All the three individual process parameters affected the true density of the vacuum fried banana chips positively. The R^2 values of 82.42 and 82.92%, respectively, for VF-raw and VF-ripe showed that the present quadratic model
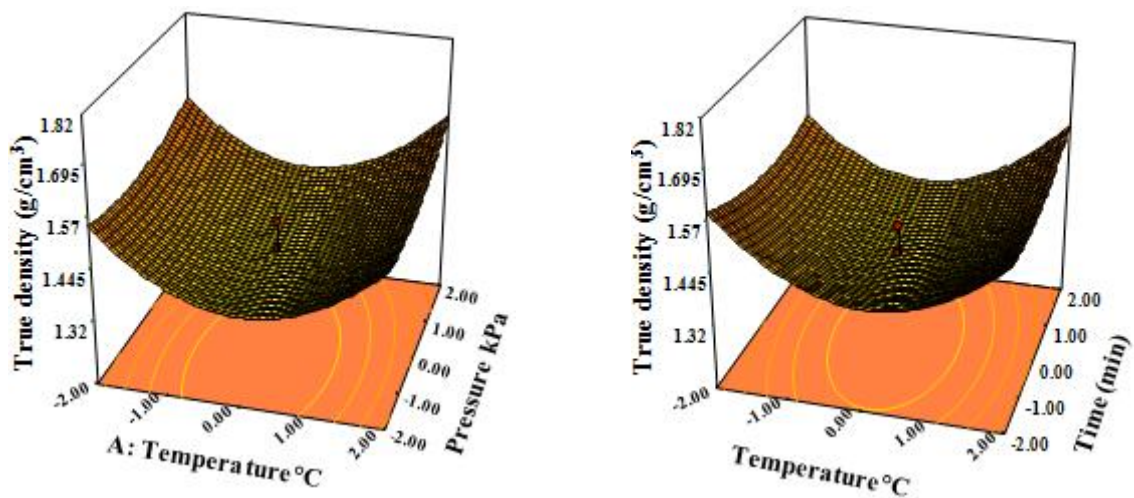
Fig. 4.36 Changes in true density of VF-ripe with process parameters
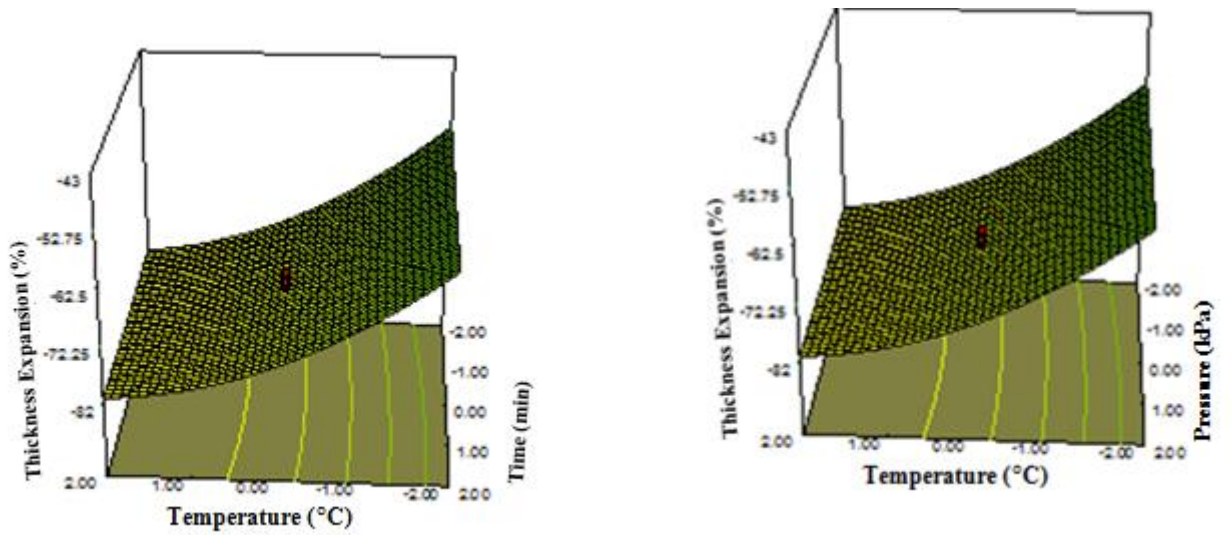
Fig. 4.37 Changes in thickness expansion of VF-ripe with process parameters

was more suitable for studying the kinetics of true density. The true density varied (p<0.0001) significantly with overall individual process parameters. The adequate precision was 7.83 and 7.052, respectively, for VF-raw for VF-ripe which indicated that the model could be used to predict the suitable response.

4.5.4 Thickness Expansion

The process parameters had no significant effect on thickness expansion of vacuum fried chips visually. But, the instrumental measurement of thickness showed statistical significance (p<0.0001) in thickness expansion with process parameters. The Fig. 4.37 represents the variation in thickness expansion with different process parameters. Higher percentage of thickness expansion of -72.43 and -82.5%, respectively, in VF-raw and VF-ripe at high frying temperature of 130°C, 18 kPa pressure and 13 min of frying time was observed. The increase in thickness expansion with increase in frying temperature, pressure and time was due to the removal of moisture content through capillary pores and higher oil uptake. The thickness expansion ranged from -38.5 to -72.4%, and from -43.5 to -82.5%, respectively, in VF-raw and VF-ripe. Ravli *et al.* (2013) observed similar trend of expansion with increase in temperature of vacuum fried potato chips.

The first order linear model was suitable with high regression coefficient of 83.2 and 80.3%, respectively, in VF-raw and VF-ripe. Among the individual terms, the temperature and time showed positive effect, whereas the pressure showed negative effect on the thickness expansion.

4.5.5 Colour Values

The colour values of the vacuum fried chips significantly varied (p<0.0001) with process parameters and is represented in Fig. 4.38. The L^* values of the VF-raw and VF-ripe ranged from 53.15 to 60.02 and from 37.54 to 58.63, respectively. All the process parameters were inversely proportional to the L^* values due to colour darkening. The maximum L^* values of 60.02 and 58.63, respectively, was observed in VF-raw and VF-ripe fried at 80°C and 18 kPa for 13 min. The minimum L^* values of 53.15 and 37.54, respectively, was observed in
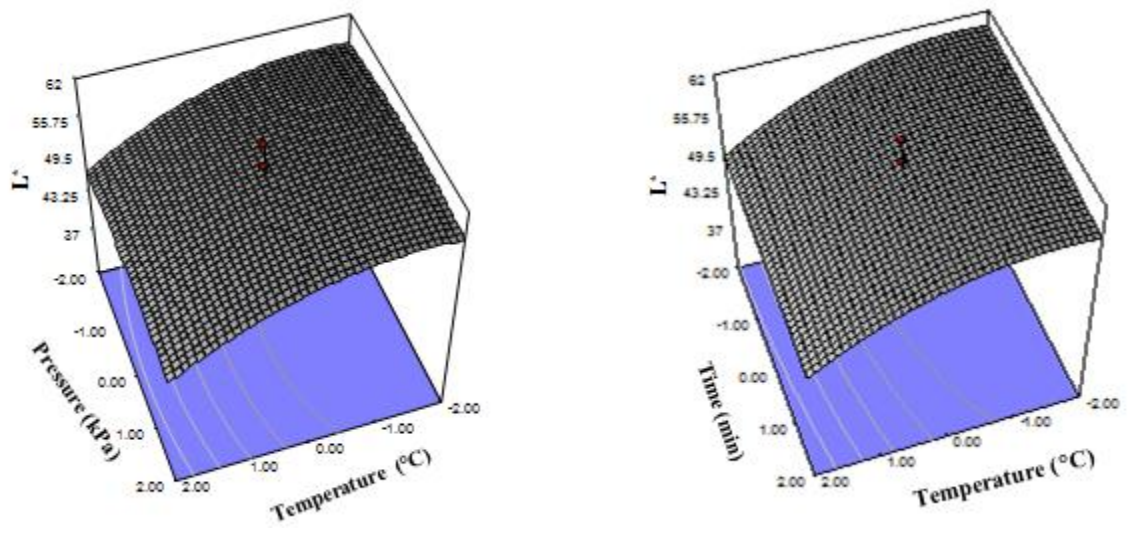
Fig. 4.38 Changes in L* value of VF-ripe with process parameters
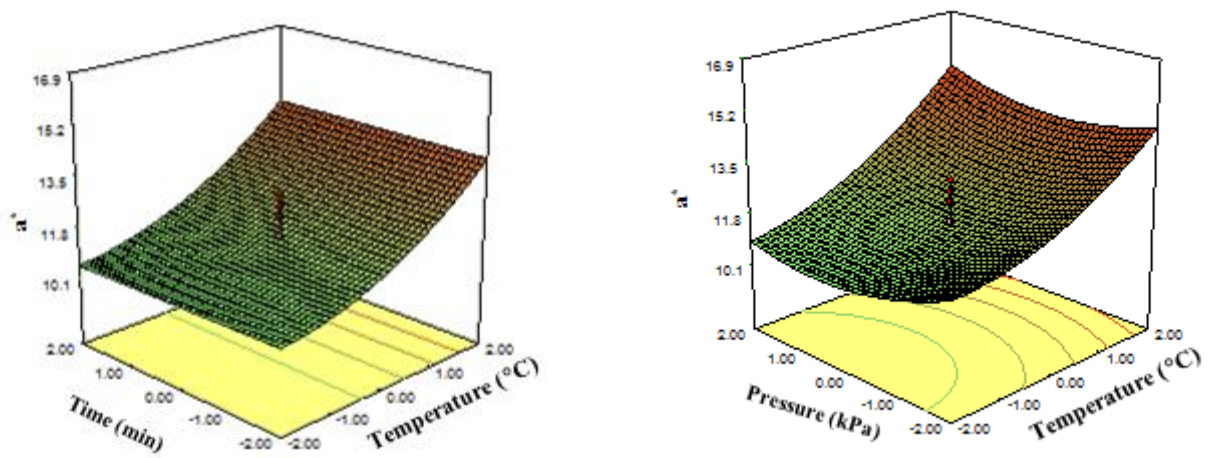
Fig. 4.39 Changes in a* value of VF-ripe with process parameters

VF-raw and VF-ripe fried at 130°C, 18 kPa and 13 min. Moyano *et al.* (2002) and Kumar *et al.* (2006) observed similar dark colour at higher frying temperature due to Maillard reaction.

The quadratic model showed best fit for the L^* value of vacuum fried chips with different process parameters. The regression co-efficient of the L^* values was 83.38 and 83.63%, respectively, for VF-raw and VF-ripe. It was evident from the regression equation values that are tabulated in Table 4.5 and 4.6, that the pressure had a positive effect, whereas the temperature and time had a negative effect on L^* values of VF-ripe.

The a^* and b^* values represented the redness and yellowness of the vacuum fried product. The Fig. 4.39 and Fig. 4.40 depicts the changes in a^* and b^* values of VF-ripe. The a^* values ranged from 3.42 to 8.96, and from 10.43 to 16.83, respectively, in VF-raw and VF-ripe. The redness value increased in VF-raw and VF-ripe, with increase in temperature. The temperature was directly proportional to colour darkening of the fried product. The a^* values showed (p<0.001) significance with temperature, while the time and pressure were insignificant for VF-raw and VF-ripe. It could be inferred from the tabulated regression terms represented in Table 4.5 and 4.6, that all the individual and interaction parameters had positive effect on a^* values.

The values of b^* varied from 30.43 to 38.49 and from 29.49 to 59.34, respectively, in VF-raw and VF-ripe. Higher processing conditions of 130°C and 18 kPa for 13 min, increased the b^* values of VF-raw. The b^* values also showed significant difference (p<0.001) on processing parameters. The increase in a^* and b^* values were evident with increase in process parameters in VF-raw. It was indicated that increase in process parameters increased the redness and yellowness of the VF-raw. In VF-ripe, the increase in process parameters increased the a^* values and decreased the b^* values. This phenomenon indicated that increase in process parameters increased the redness and decreased the yellowness due to Maillard reaction in VF-ripe. Maity *et al.* (2014) reported similar increase in a^*
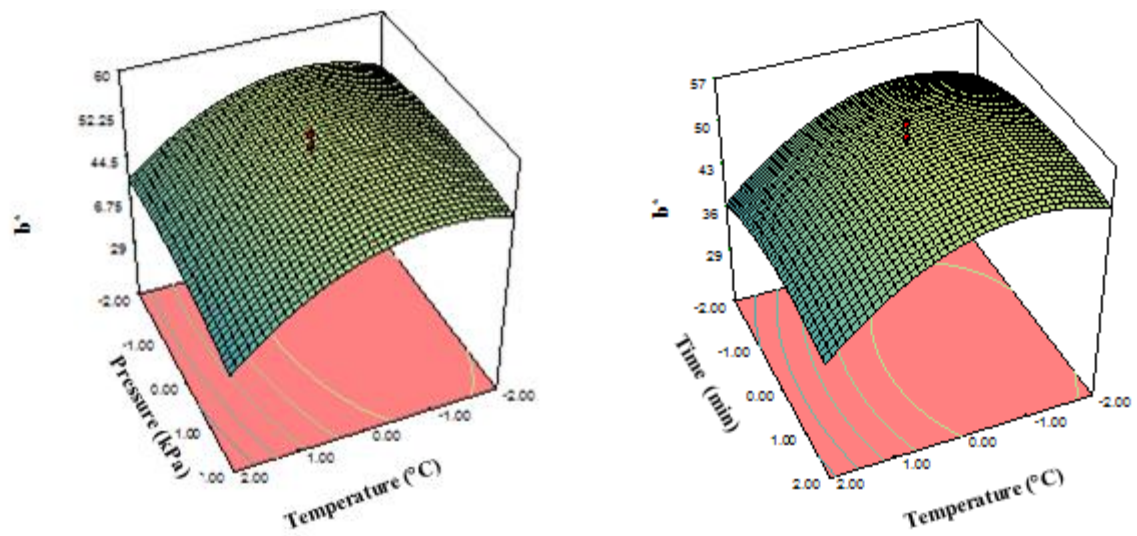
Fig. 4.40 Changes in b* value of VF-ripe with process parameters
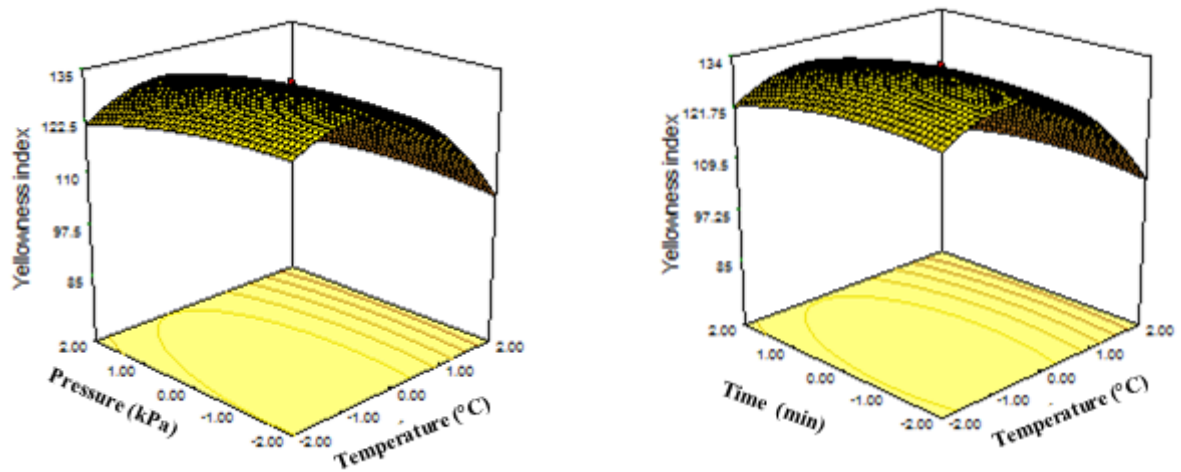
Fig. 4.41 Changes in yellowness index of VF-ripe with process

value and decrease in b* value at high frying temperature in vacuum fried jack fruit bulbs.

The quadratic model was best suited to describe the variations in a* and b* value with different processing conditions. The temperature was directly proportional to the a* values in VF-raw and VF-ripe. It was also observed that the temperature was directly proportional to b* value in VF-raw and inverse proportional to VF-ripe. The regression coefficients for a* value was 88.8 and 85.4%, respectively in VF-raw and VF-ripe. The regression coefficients for b* value was 88.8 and 85.4%, respectively in VF-raw and VF-ripe.

The yellowness index of VF-ripe varied ($p<0.005$) significantly with the process parameters. The Fig. 4.41 indicates the variation in yellowness index of VF-ripe. The yellowness index ranged between 95.32 to 134.1 in VF-ripe. The maximum yellowness index of 134.1 at the frying conditions of 105°C and 6 kPa for 13 min and minimum yellowness index value of 95.32 was noted at higher frying temperature of 130°C, 18 kPa pressure and 13 min time. This was due to the colour darkening at high frying temperature (Dueik and Bouchon 2011).

The regression equation terms tabulated in Table 4.6 illustrates that the process paramters were inversely proportional to the yellowness index. The regression co-eeficient and the adequate precision of yellowness index with varying process paramters were 83.32% and 8.73, respectively. An adequate precision of greater than 4 is a prerequisite for reliable prediction using mathematical models (Montgomery, 2001). Hence, the present quadaratic second order model was best suitable for the determination of changes in yellowness index by the process paramters.

4.5.6 Textural Changes

The process parameters had significant difference at 1% level in hardness value of VF-raw and VF-ripe. The Fig. 4.42 displays the changes in hardness value of VF-ripe with different processing conditions. An increase in hardness value of VF-raw and VF-ripe was noted at both the higher and lower frying temperatures. The maximum hardness of 4.67 and

5.35 N, respectively, was recorded in VF-raw and VF-ripe at frying conditions of 130°C, 18 kPa and 13 min. The increase in hardness value was due to the maximum exhaustion of moisture from the banana slices at higher temperature. Taiwo and Baik (2007) reported similar increase in hardness value of deep fat fried tapioca chips at higher frying temperature of 170°C for 120 s. The lower hardness value of 1.43 and 1.87 N, respectively, were exhibited in VF-raw and VF-ripe, at frying conditions of 105°C and 18 kPa for 13 min. This lower hardness value indicated higher degree of crispness in the fried product. The slight increase in hardness value of 2.95 and 3.52 N, respectively, were noted in VF-raw and VF-ripe at frying conditions of 80°C and 18 kPa for 13 min. This increase in hardness value was due to partial removal of moisture and low oil content that made the texture tough, rubbery and hard. The result was in agreement with Nuttapong and Thatchapol (2015) who documented high breaking force in vacuum fried banana product fried at 80°C, 70 mm of Hg for 15 min.

The second order quadratic model was best fitted to infer the changes in hardness value with frying conditions. The regression co-efficient value was 92.4 and 91.55%, respectively, for VF-raw and VF-ripe. The higher regression value suggested the suitability of quadratic model for the variation in hardness value. The regression equation values (Table 4.5 and 4.6) of VF-raw and VF-ripe indicated that the frying temperature, pressure and time affected positively on hardness value. The interaction terms where the temperature was involved showed positive effect, while the other interaction terms showed negative effect on hardness value.

4.5.7 Energy Content

The energy content was determined using the standard formula used by Ekanayake *et al*. (1999). The major nutrients carbohydrate, fat and protein were determined and the energy content was estimated for both VF-raw and VF-ripe. The Fig. 4.43 represents the energy content values of VF-ripe with different
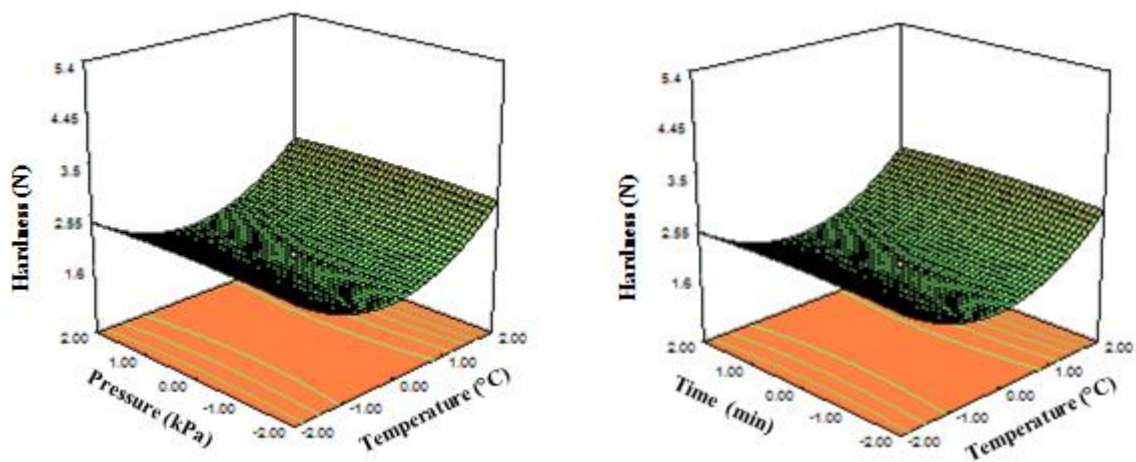
Fig. 4.42 Changes in hardness value of VF-ripe with process parameters
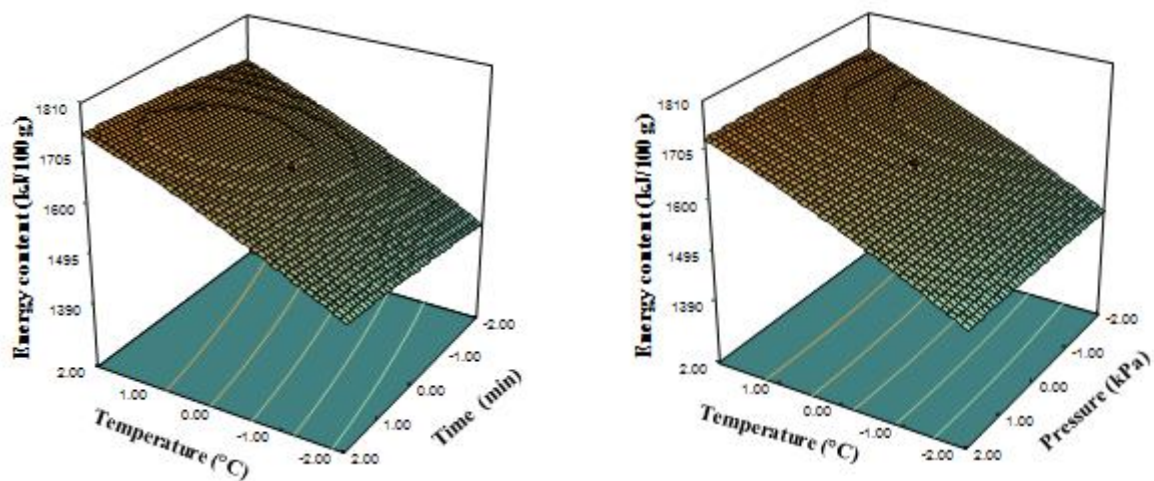
Fig. 4.43 Changes in energy content of VF-ripe with process parameters

process parameters. The energy content ranged from 1095 to 1492 kJ100 g^{-1} and from 1395 to 1804 kJ100 g^{-1}, respectively, in VF-raw and VF-ripe. A maximum energy content of 1492 and 1804 kJ/100 g, respectively, were observed in VF-raw and VF-ripe fried at 130°C and 18 kPa for 13 min. The energy content was directly proportional to the oil content. The higher energy content was due to high oil content at higher frying temperature. Stubbs *et al.* (1995) stated that the fat content increased the energy value of the food product. The minimum energy content of 1095 and 1395 kJ/100 g, respectively, was observed in VF-raw and VF-ripe fried at 80°C and 18 kPa for 13 min. The lower energy content was due to low oil content at lower frying temperature.

The linear first order model was best fitted with the energy content kinetics with different process parameters. The R^2 values were 96.7 and 97.9% for VF-raw and VF-ripe. The higher regression coefficient indicated the suitability of linear model to the present experiment. The process parameters were directly proportional to the energy content of VF-raw and VF-ripe.

4.5.8. Acrylamide Content

The acrylamide content of the ripened banana chips were determined using HPLC - DAD method. The results exhibited lower acrylamide content in the vacuum fried ripened banana chips than the atmospheric fried one. The changes in acrylamide content at different processing conditions are represented in Fig. 4.44. The maximum acrylamide content of 568 µgkg^{-1} was observed in chips processed at atmospheric condition and minimum acrylamide content of 112 µgkg^{-1} was observed in chips processed at 90°C and 18 kPa for 13 min. The lower acrylamide content at vacuum frying was due to reduced frying temperature that prevented Maillard reaction and browning. Shamla and Nisha (2014) reported acrylamide content of 1810 – 1944 µgkg^{-1} in atmospheric fried sweet plantain chips.

Montgomery (2001) reported that the statistical model was best fitted with the response variations if the adequate precision value was greater than 4. In the present study it was observed that, all the models fitted with the kinetics of the response had adequate precision value above 4. It could be inferred that the
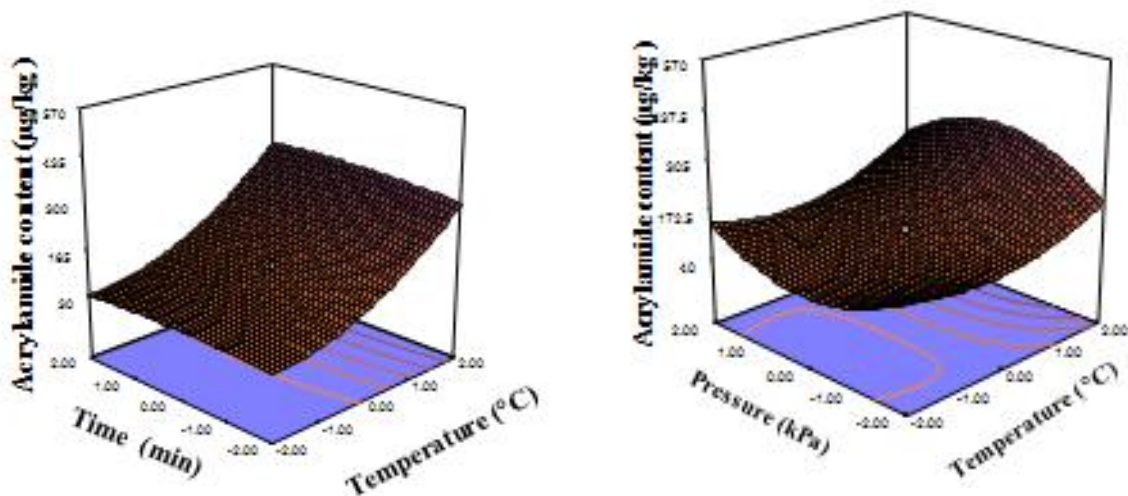
mod **Fig. 4.44 Changes in acrylamide content of VF-ripe with process parameters** different frying temperature, pressure and time.

The ANOVA table of overall individual, interaction and square terms of VF-raw and VF-ripe are represented in Table 4.5 and 4.6.

4.5.9 Sensory Evaluation

The sensory evaluation of VF-raw and VF-ripe fried with different processing was done with 9-point Hedonic scale and are presented in Table. 4.4.

The sensory evaluation exhibited good consumer preference for treatments that were fried at 105°C with 18 to 25 kPa pressure for 13 min. The Table. 4.4 illustrates the Hedonic score of sensory evaluation of VF-ripe. The VF-ripe fried at lower frying temperature of 80 and 90°C, exhibited rubbery texture due to incomplete frying. The VF-ripe fried at higher temperature of 120 and 130°C exhibited consumer's unacceptability due to browning. The atmospheric fried control sample scored 6.2 in overall acceptability which was lower than the VF-ripe fried at 105°C. The high sensory score of 8.6, 8.5, 8.4, 8.4, 8.5, 8.2, 8.5 and 8.6, respectively, were scored by the samples RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19.

The fuzzy logic comprehensive model exhibited similar results of Hedonic sensory score. The samples RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 ranked first followed by the samples RT17, RT6, RT11, RT14, RT8, RT20, RT3, RT16, RT9, RT15, RT1, RT4 and control. The preference between sensory attributes in RT2 were texture > colour and appearance > overall acceptability > taste > flavour. The higher ranking in the above eight samples were due to the production of attractive yellow coloured VF-ripe. The VF-ripe that were fried at lower (80 and 90°C) and higher (120 and 130°C) temperatures ranked least. The control sample was ranked last in fuzzy logic ranking.

Table. 4.4. Mean sensory score of vacuum fried ripened banana chips

Treatments	Colour & appearance	Texture	Flavour	Taste	Overall acceptability
RT1	6.5	6.8	6	6.2	6.5
RT2	8.5	8.3	8.6	8.5	8.6
RT3	5	5.5	5	5	5.2
RT4	4.5	4.6	5	4.8	5.5
RT5	8.5	8.3	8.6	8.5	8.5
RT6	8.2	7.5	8.3	7.5	7.2
RT7	8.5	8.3	8.2	8.5	8.4
RT8	6.2	6.3	6.1	6.4	6.3
RT9	5.2	5.5	5.4	5.2	5.6
RT10	8.5	8.6	8.3	8.4	8.4
RT11	6.4	6.2	6.3	6.2	6.4
RT12	8.6	8.2	8.4	8.6	8.5
RT13	8.2	8.4	8.5	8.2	8.2
RT14	6.2	6.5	6.6	6.4	6.7
RT15	5.7	5.6	5.3	5.5	5.4
RT16	5.1	5.3	5.4	5.2	5.5

RT17	7.5	7.6	7.4	7.8	7.5
RT18	8.3	8.5	8.2	8.3	8.5
RT19	8.2	8.5	8.5	8.2	8.6
RT20	6.5	6.8	6.5	6.4	6.3
Control	6.2	6.4	6.2	6.4	6.2

The sensory score of VF-raw was poor in both Hedonic scale and fuzzy logic comprehensive model, when compared with control sample. The retention of raw colour and flavour in VF-raw was the major reason for the consumer's unacceptability. The attractive yellow colour and cooked flavour in control sample made it to be ranked first among the raw banana chips. The reduced acceptability of VF-raw suggests further improvements in process protocol, before introduction to market. However, VF-ripe has scored high consumer preference which indicated the high marketing potential of this novel product. Hence, storage studies were conducted for VF-ripe.

4.6. Storage Studies

The storage studies were conducted for the VF-ripe that scored high in sensory analysis. The VF-raw was not considered for the storage study due to its poor consumer acceptability. The quality analyses for the selected treatments (RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19) were carried out in 30 days interval for 4 months duration. The VF-ripe were packed in nitrogen flushed LDPE (400 gauge) pouches and stored at ambient condition.

4.6.1 Oil Content

The storage period had no significant effect on the oil content of VF-ripe. The initial oil content of RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 were 13.56, 13.63, 13.53, 13.45, 13.54, 13.66, 13.46 and 13.65%, respectively. The Fig. 4.45 depicts the oil content of VF-ripe during storage period. The values of oil content remained unchanged for all the 120 days of storage. Manikantan *et al.* (2014) also observed no variation in oil content of stored raw *nendran* banana

chips that were packed in nano particles coated film. In the present study, the quality of banana chips was maintained due to the usage of nitrogen flushed package. The replacement of oxygen with inert nitrogen gas inside the package facilitated the storage of VF-ripe.

Table. 4.5 Regression coefficients of VF-raw

Quality parameters	Constant	X_1	X_2	X_3	$X_1 X_2$	$X_1 X_3$	$X_2 X_3$	X_1^2	X_2^2	X_3^2	R^2
Quadratic model											
Moisture content	0.78	- 1.08	0.19	- 0.17	- 0.17	0.13	0.061	-0.65	- 0.054	-0.027	0.963
Water activity	0.22	-0.11	0.013	-0.018	-7.50	7.50	-0.001	0.073	0.018	0.013	0.941
Bulk density	0.40	-0.026	-1.9	-0.011	-0.050	1.375	0.020	0.15	0.012	0.032	0.893
True density	1.14	0.11	0.014	-0.014	-0.034	0.031	-0.026	0.13	0.038	0.047	0.824
L^* value	58.12	-1.60	0.39	-0.47	0.28	-0.60	0.31	-0.42	5.85	- 0.17	0.834
a^* value	5.29	1.25	0.037	0.10	0.039	0.076	0.011	0.21	0.035	0.12	0.889
b^* value	35.34	2.44	-0.080	0.38	-0.072	-0.11	0.35	-0.27	0.088	-0.45	0.942
ΔE	-22.50	2.09	-0.44	0.018	0.24	-0.63	0.65	-0.49	0.13	-0.16	0.871
Hardness	1.85	0.21	6.923	0.069	8.750	0.16	- 0.014	0.89	- 0.05	- 0.04	0.924
Linear model											
Oil content	10.18	3.09	0.056	0.83							0.969
Thickness expansion	61.17	9.51	-1.05	0.58							0.832

Energy content	15.59	17.8	0.22	30.4							0.967

Table. 4.6 Regression coefficients of VF-ripe

Quality parameters	Constant	X_1	X_2	X_3	$X_1 X_2$	$X_1 X_3$	$X_2 X_3$	X_1^2	X_2^2	X_3^2	R^2
Quadratic model											
Moisture content	0.90	- 1.19	0.20	- 0.18	- 0.17	0.14	-0.043	-0.75	0.033	-0.022	0.954
Water activity	0.22	-0.12	0.021	-0.024	- 3.37	0.014	-7.87	-0.073	0.028	-0.018	0.965
Bulk density	0.43	-0.01	0.016	-4.96	-0.033	5.37	-0.022	0.19	0.023	0.051	0.905
True density	1.37	3.79	0.030	6.99	0.010	0.023	-0.040	0.17	0.040	0.042	0.829
L^* value	57.13	-5.16	0.12	-1.06	0.065	0.24	-0.080	-3.50	-1.13	-0.33	0.834
a^* value	11.67	1.79	0.12	4.8	0.26	0.035	0.20	0.73	0.68	5.27	0.819
b^* value	53.31	-5.77	-1.10	1.13	-1.06	-0.12	-0.91	-6.94	-1.62	-2.69	0.873
ΔE	0.86	-9.14	-1.10	0.065	0.73	0.15	-1.20	-9.71	-2.08	-3.02	0.885

Yellowness index	129.45	-8.75	-1.12	-0.022	0.61	-0.14	0.66	-11.33	-1.20	-2.46	0.837
Hardness	1.85	0.21	6.92	0.069	8.750	0.16	- 0.014	0.89	- 0.05	- 0.04	0.915
Linear model											
Oil content	13.33	3.15	0.06	0.62							0.983
Thickness expansion	69.98	12.1	-0.12	0.26							0.803
Energy content	16.2	59.2	1.74	11.3							0.979

4.6.2 Moisture Content and Water Activity (A_w)

The moisture content of VF-ripe increased significantly (p<0.0001) with storage period. However, the increase in moisture content was gradual for the first 90 days of storage, after which it increased rapidly. The Fig. 4.46 represents the changes in moisture content of VF-ripe during storage. The initial moisture content of the stored VF-ripe RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 were 0.86, 0.85, 0.74, 0.84, 0.86, 0.95, 0.97, and 0.98%, respectively. The moisture content of the stored VF-ripe ranged from 2.0 -2.5% after 90 days of storage. On further extended storage period to 120 days, the moisture content increased above 4% in the VF-ripe. The increase in moisture content was due to the transfer of moisture from the atmosphere into the package (Ikpeme *et al.,* 2007). The moisture content of the stored VF-ripe did not show significant variation among the treatments, since all the samples were fried under same temperature and time. Krishnankutty *et al.* (1981) observed similar trend in moisture content of deep fat fried banana chips during storage that were packed in LDPE pouches.

The a_w of the VF-ripe varied significantly (p<0.0001) with storage life. It was evident from the Fig. 4.47, that the storage period was directly proportional to the water activity. The a_w of fresh VF-ripe was ranged from 0.2 to 0.22. The a_w at 30, 60 and 90 days of storage was between (0.3 - 0.35, 0.3 - 0.36, and 0.4 - 0.43), respectively. The maximum increase in a_w of 0.6 was observed in the VF-ripe after 120 days of storage. The increase in a_w was due to the increase in moisture content of the product. The result was in agreement with the findings of Manikantan *et al.* (2014) who observed an increase in water activity of deep fat fried raw banana chips during storage.

4.6.3 Bulk and True Density

The bulk density and true density of VF-ripe showed significant variation (p<0.001) during storage and is represented in Fig. 4.48 and Fig. 4.49. The initial bulk density value of VF-ripe was 0.436, 0.453, 0.432, 0.442, 0.434, 0.456, 0.435
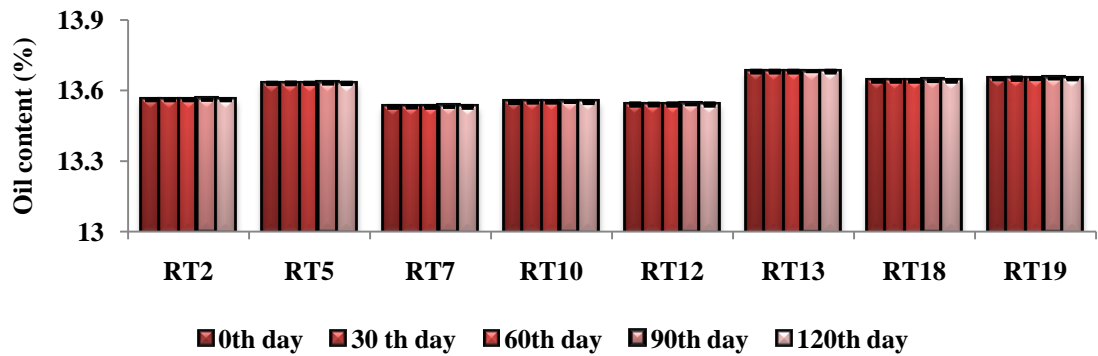
Fig. 4.45 Changes in oil content of VF-ripe during storage
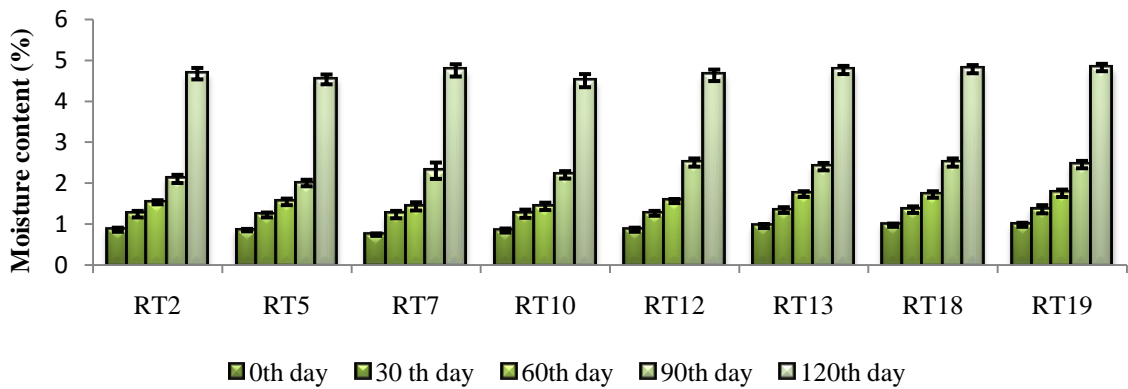
Fig. 4.46 Changes in moisture content of VF-ripe during storage
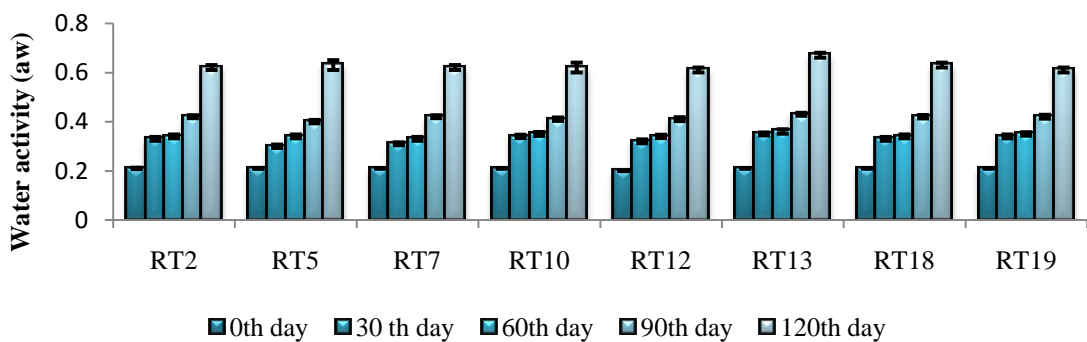
Fig. 4.47 Changes in water activity of VF-ripe during storage

and 0.437 gcm^{-3}, respectively in RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19. A slight increase in bulk density value at initial 90 days of storage was observed. However, a significant increase in bulk density value was observed after 120 days of storage. The bulk density of the stored samples RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 after 120 days of storage were 0.766, 0.753, 0.762, 0.757, 0.738, 0.749, 0.762 and 0.756 gcm^{-3}, respectively. The increase in bulk density after 120 days of storage was due to the increase in moisture content. There was no significant variation among the treatments due to its similar processing conditions.

The true density increased gradually during the initial 90 days of storage period. The initial true density values of RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 were 1.45, 1.38, 1.42, 1.36, 1.38, 1.4, 1.38 and 1.32 gcm^{-3}, respectively. The true density values of samples ranged from 1.723 to 1.834 gcm^{-3}, after 90 days of storage. The true density reached maximum value of 2.543 to 2.643 gcm^{-3}, after 120 days of storage. The increase in true density was due to the increase in moisture content of the stored samples. Maneerote *et al.* (2009) recorded an increase in bulk and true density with increase in moisture content of vacuum fried potato chips.

4.6.4 Thickness Expansion

The initial thickness expansion percentage of VF-ripe ranged from -75.5 to -76.4 %. The storage period did not show significant variation in the thickness expansion of VF-ripe and is represented in Fig. 4.50. Since, the thickness expansion of VF-ripe was mainly due to formation of air space during frying, the variation in thickness expansion was insignificant for all treatments upto 120 days of storage. It was also observed that no significant difference in thickness expansion among the treatments, since they were fried at same temperature and time. The result was in agreement with the findings of Krishnankutty *et al.* (1981) in the stored deep fat fried banana chips.
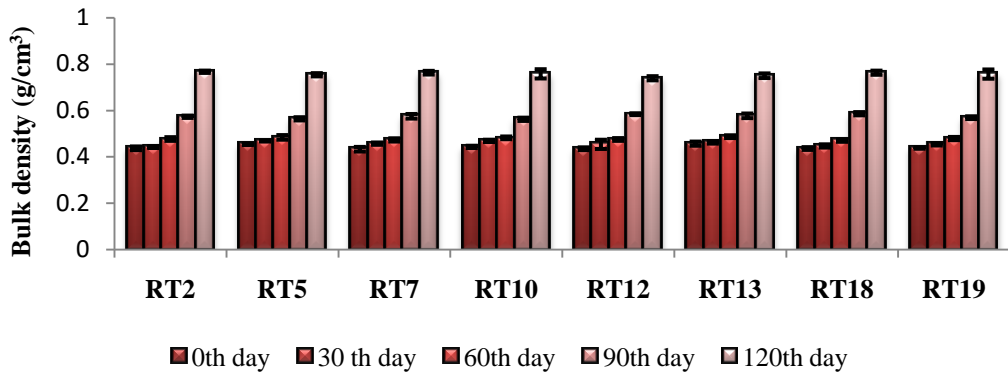
Fig. 4.48 Changes in bulk density of VF-ripe during storage
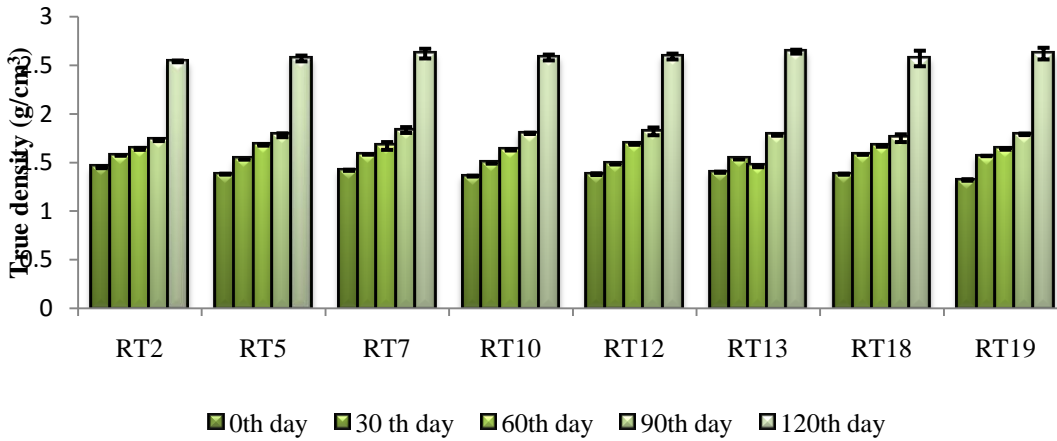
Fig. 4.49 Changes in true density of VF-ripe during storage
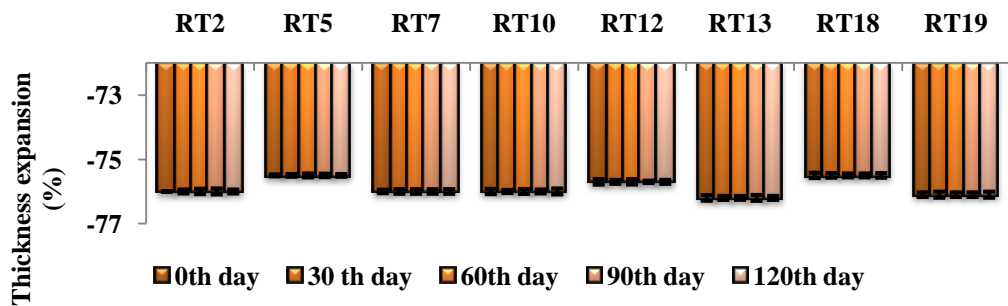
Fig. 4.50 Changes in thickness expansion of VF-ripe during storage

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4.6.5 Colour Values

The stored VF-ripe showed significant variation (p<0.0001) in L^*, a^* and b^* values. Slight variation in colour values were observed for the first initial 90 days of storage. However, the variation was much significant after 120 days of storage. The Fig. 4.51 represents the changes in L^* value during storage period. The L^* value ranged from 53.32 to 54.65, respectively, in fresh VF-ripe. The L^* value increased with increase in storage period. The maximum of L^* values were observed after 120 days of storage. The L^* values of 120 days stored VF-ripe were 62.01, 63.28, 62.64, 62.56, 63.74, 63.67 and 62.32, respectively, in RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19. The increase in L^* value indicated the increase in lightness which was mainly due to transmission of light through the packaging material. Kirwan and Strawbridge (2003) stated that the penetration of light influenced the colour of the packaged material.

The storage period was inversely proportional to a^* and b^* values. The decrease in a^* value indicated the reduction in redness, whereas the decrease in b^* value denoted the reduction in yellowness of the VF-ripe. The reduction in a^* and b^* values is represented in Fig. 4.52 and Fig. 4.53. The initial a^* values of VF-ripe were 11.53, 11.23, 10.36, 11.94, 11.54, 11.53, 10.86 and 10.92, respectively and the b^* values were 52.05, 53.4, 52.34, 53.35, 52.38, 52.63, 52.24 and 52.07, respectively in RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19. After 120 days of storage a^* values were 6.83, 6.57, 6.73, 6.58, 6.83, 6.35, 6.73 and 6.57, respectively, and the b^* values were 39.13, 38.5, 39.25, 38.52, 39.23, 38.64, 38.63 and 39.12, respectively.

The yellowness index mainly depend on the L^* and b^* values. The concomitant increase and decrease in L^* and b^* values, decreased the yellowness index of the VF-ripe. The storage period was inversely proportional to the yellowness index of the VF-ripe. The initial yellowness index of VF-ripe ranged from 133.2 to 134.1, respectively. The major reduction in yellowness index was observed after 120 days of storage. The yellowness index ranged between 86.63 to
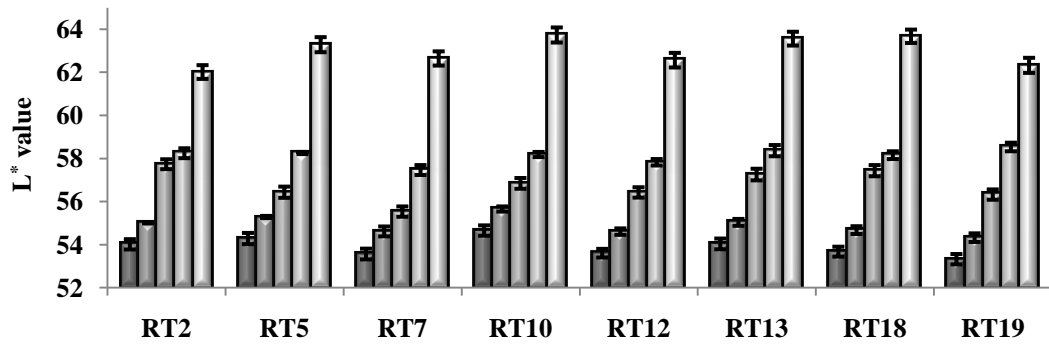
Fig. 4.51 Changes in L* value of VF-ripe during storage

0th day   30 th day   60th day   90th day   120th day
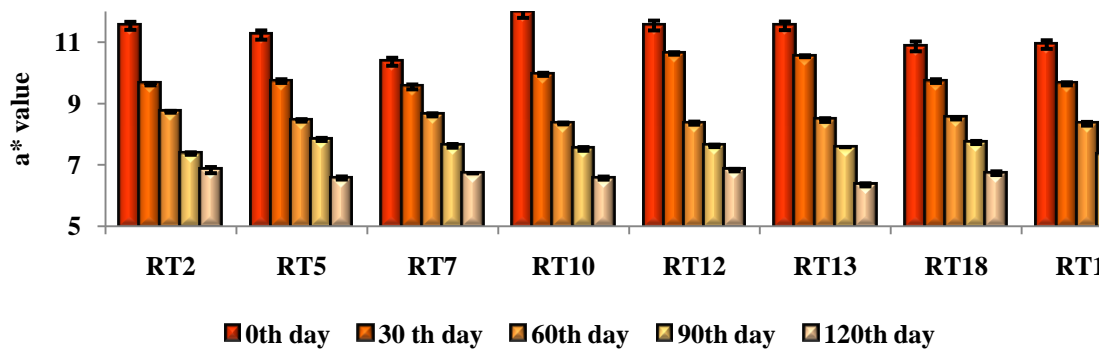
Fig. 4.52 Changes in a* value of VF-ripe during storage

0th day   30 th day   60th day   90th day   120th day
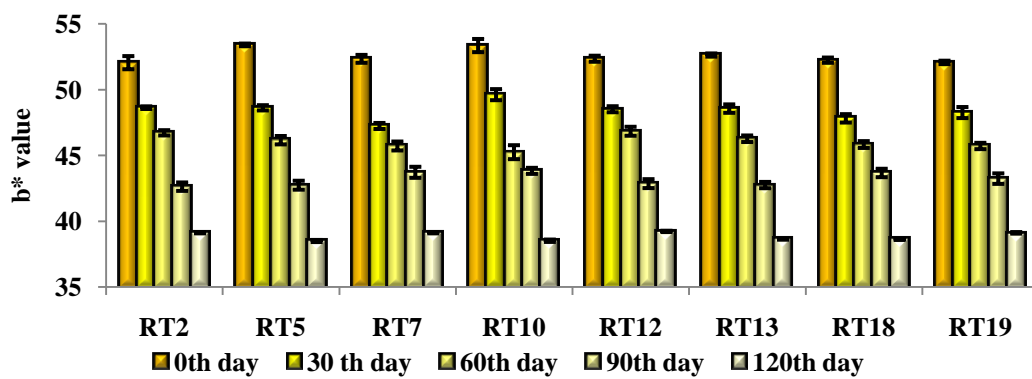
Fig. 4.53 Changes in b* value of VF-ripe during storage

90.42 after 120 days of storage period. From the reduction in a^*, b^* values and yellowness index and the increase in L^* values it could be inferred that the colour got lighter colour during storage. The result concurred with the study of Ammawath *et al.* (2002) who reported the colour degradation in banana chips that were packed in three different packaging materials *viz.,* LDPE, laminated aluminium and poly propylene with storage life.

4.6.6 Textural Changes

The hardness of fresh VF-ripe ranged from 1.6 to 1.9 N, respectively. The hardness value increased with increase in storage period. The Fig. 4.54 displays the changes in hardness values of VF-ripe on storage. The maximum hardness values ranged between 7.32 to 7.74 N which was observed in VF-ripe after 120 days of storage. The increase in hardness was associated with increase in moisture content and water activity that made the texture of VF-ripe tough and rubbery. The increase in breaking force indicated the reduction in degree of crispness (Manikantan *et al.,* 2014). The hardness values during 30, 60 and 90 days of storage showed a gradual increase from 2.4 to 2.6 N, from 3.44 to 3.68 N, and from 5.57 to 5.87 N, respectively. The result was in agreement with the observation of Ammawath *et al*. (2002) who recorded an increase in breaking force of banana chips on storage.

The statistical analysis was done for all the quality parameters during the storage period. The ANOVA tables of the statistical analysis are presented in the appendix-H1.

4.6.7 Sensory Evaluation

The sensory evaluation was done for the VF-ripe based on the 9-point Hedonic scale and fuzzy logic comprehensive model. Before each sensory evaluation of the stored samples, it was ensured that the samples were safe from microbial contamination through total plate count method. The good sensory score was obtained in the 9 - point Hedonic scale for the fresh, 30 and 60 days stored VF-ripe. The consumer preference for the VF-ripe declined from "8 - Like
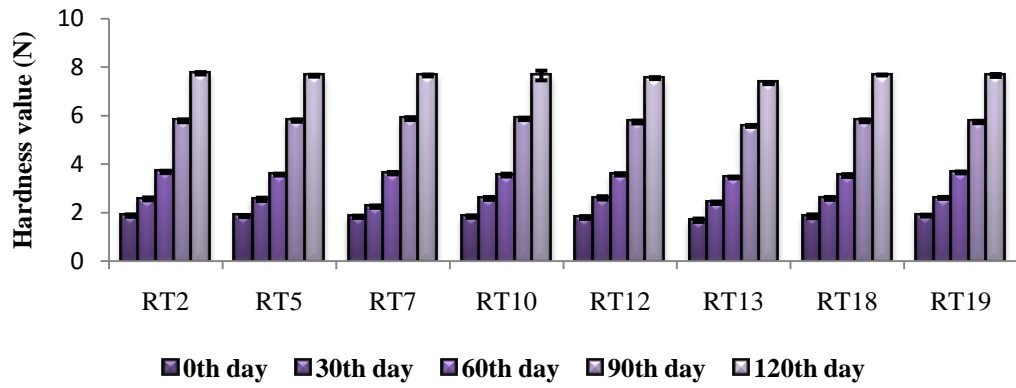
Fig. 4.54 Changes in hardness value of VF-ripe during storage
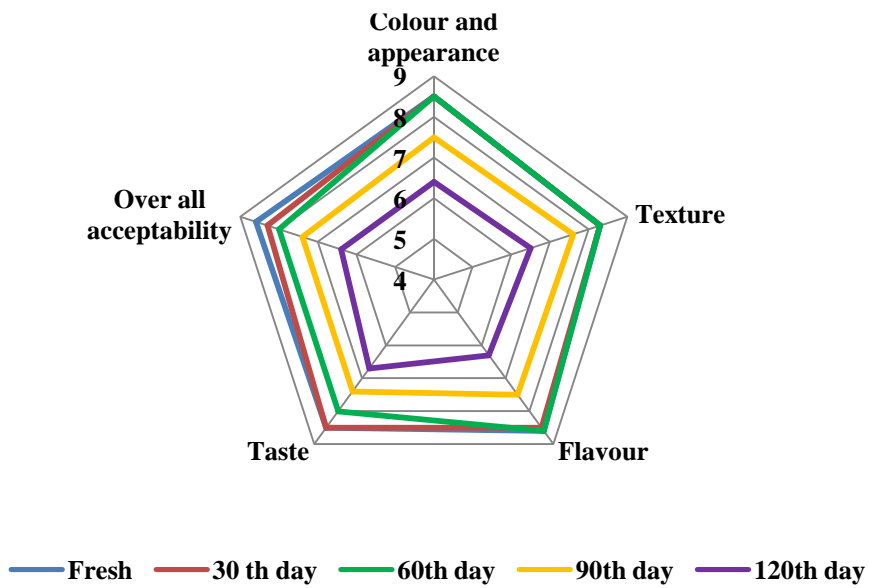
Fig. 4.55 Changes in sensory score of VF-ripe during storage in RT2

very much" to "7 - Like moderately" after 90 days of storage. The Fig. 4.55 represents the variation in sensory score of RT2 during storage period. The consumer acceptance was subsequently reduced to "6 - Like slightly" after 120 days of storage period. The texture and colour were major the sensory attributes in fried products (Krokida *et al.,* 2001). The reduced degree of crispness and colour of the VF-ripe with increase in storage duration affected the consumer preference. The sensory score of all the stored VF-ripe that were stored 0, 30, 60, 90 and 120 days were tabulated and given in appendix – H1.

The fuzzy logic ranking was done for RT2, RT5, RT7, RT10, RT12, RT13, RT18 and RT19 treatments with 30 days interval for 120 days duration. The ranking was done based on the storage days. The ranking order of RT2 was Fresh = 30th day = 60th day > 90th day > control > 120th day. The ranking was similar for all the VF-ripe treatments. The fuzzy logic ranking for all the treatments is attached in the appendix-H1.

It was inferred from the sensory evaluation that the consumer preference of VF-ripe was poor after 90 days of storage. The reduction in overall acceptability of consumer was mainly due to the changes in crispness and colour of VF-ripe.

4.7 QUALITY CHANGES IN BLENDED OIL DURING VACUUM FRYING

The blended oil was evaluated for quality parameters after its repeated use for several batches of vacuum frying. Samples were analysed after each batch of vacuum frying during the standardisation of de-oiling and process parameters. The each batch of vacuum frying was for 13 min time at 105°C and 18 kPa. The cooling time of 30 min was given after each batch of vacuum frying. The total duration of study was 3 weeks with 4 batches of vacuum frying at regular every day. The changes in quality parameters *viz.,* fatty acid (FFA), peroxide value (PV), p-Anisidine value (p-AnV), total oxidation value (TOTOX value), iodine value (IV), total polar compound (TPC), viscosity and colour values of blended oil are discussed below.

4.7.1 Free Fatty Acid (FFA)

The initial FFA value of blended oil was 0.74 mg $KOHg^{-1}$. The FFA increased from 0.74 to 1.23 mg $KOHg^{-1}$ after sixty batches of vacuum frying at 105°C, 18 kPa and 13 min. The Fig. 4.58 illustrates the changes in FFA of blended oil on repeated use in vacuum frying. The increase in FFA indicated the deterioration of oil due to hydrolysis of triglycerols and oxidation of used fatty acid (Abdulkarim *et al.,* 2007). However, the increase in FFA after fifty two batches of vacuum frying was within the recommendable limit. The recommendable level of FFA is 1.0 mg $KOHg^{-1}$ (Smith *et al.,* 1986). The obtained result was in contrast with Sunisa *et al.,* (2011) who observed higher FFA value after three batches of deep fat frying of chicken nuggets at 190°C. Higher FFA value in blended oil (80:20, Rice bran and Palm oil) was observed by Monika and Kiran (2013) after three batches of atmospheric frying. The increase of FFA was significantly low in vacuum frying compared to atmospheric frying. This was due to the difference in frying temperature between atmospheric and vacuum frying.

4.7.2 Peroxide Value (PV)

The peroxide value of blended oil increased from 0.25 to 4.48 $meqO_2kg^{-1}$ after sixty batches of vacuum frying and is represented in Fig. 4.59. In atmospheric frying, the peroxide value of the oils increased rapidly after three batches of frying and then decreases with further frying. This was due to the instability of the formed peroxides that had broken down into secondary oxides like aldehydes and ketones. The increase in PV was due to reduction in unsaturated fatty acid on oxidation at higher frying temperature (Sunisa *et al.,* 2011). However, the changes in PV of the blended oil after sixty batches of vacuum frying was different from the regular phenomenon. The increase in PV of blended oil was within the recommendable level after sixty batches of frying. Shyu *et al.,* (1998) concluded that palm, lard and soyabean oil used in vacuum frying of carrot chips showed no significant changes in peroxides after six consecutive batches of frying at 105 °C for 20 min.
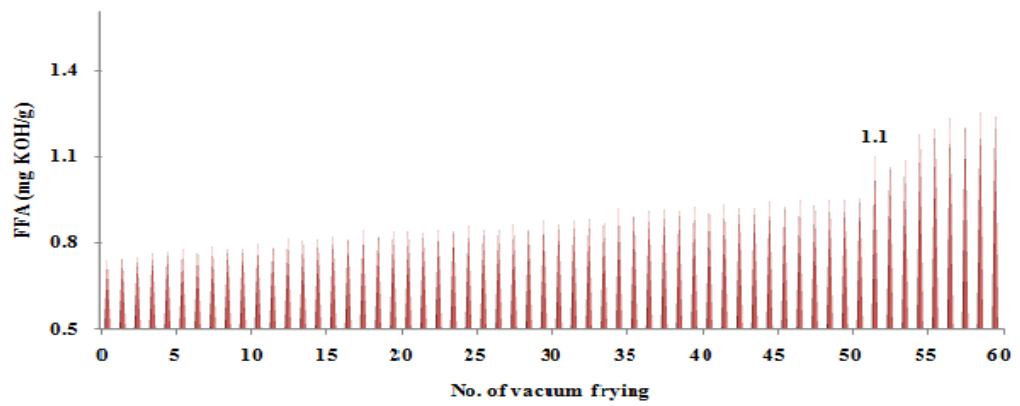
Fig. 4.56 Changes in free fatty acid value of blended oil on vacuum frying
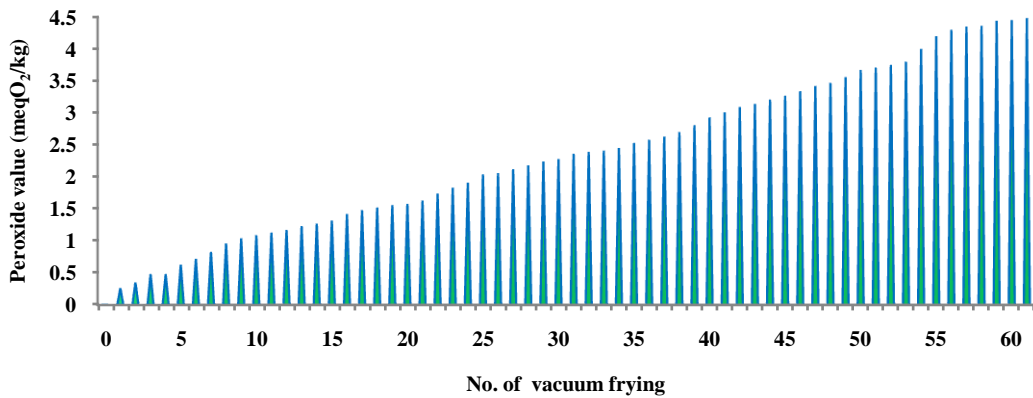
Fig. 4.57 Changes in peroxide value of blended oil on vacuum frying
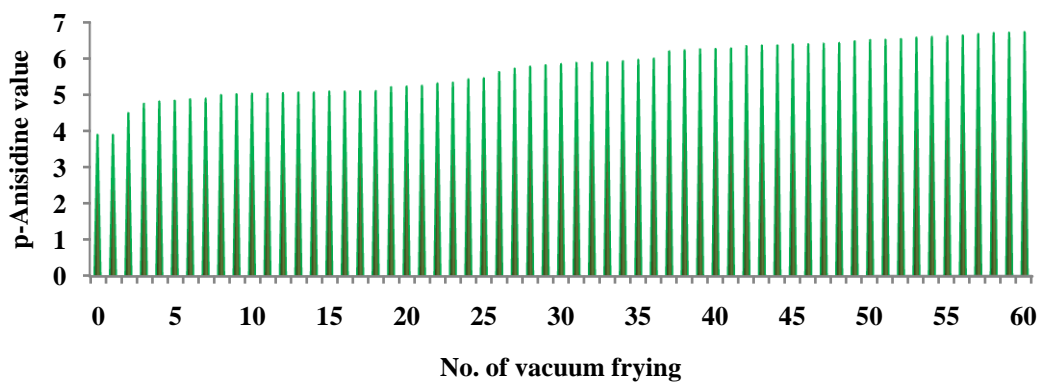
Fig. 4.58 Changes in p-anisidine value of blended oil on vacuum

4.7.3 P-Anisidine Value (Anv)

The p-Anisidine value was the indication of secondary oxidation that resulted due to thermal decomposition of hydroperoxides. The increase in AnV of the blended oil was significantly less with number of vacuum frying batches. The initial AnV of the blended oil was 3.9 which increased to 6.73 after consecutive use in sixty batches of vacuum frying. The Fig. 4.60 indicates the changes in AnV in vacuum frying. The increase in AnV in atmospheric frying was highly significant after three batches of frying. The study conducted by Prakash *et al.* (2016) on quality changes of mustard oil in atmospheric frying demonstrated a higher value of AnV. They found the oil to be unfit for edible usage after 15 h deep fat frying. The increase in AnV was mainly due to oxidation of oil (Bou *et al.,* 2012). The very low increase in AnV after sixty batches of vacuum frying at 105°C and 18 kPa for 13 min was due to adoption of comparatively low temperature and pressure than atmospheric frying.

4.7.4 Total Oxidation Value (TOTOX Value)

The changes in TOTOX value of the oil depend on the peroxide and p-Anisidine value. The TOTOX value is the representation of current oxidation status of the oil. Higher the TOTOX value, higher will be the oxidation degradation in the oil. The initial TOTOX value of the blended oil was 4.42 and it was increased to 15.69 after sixty consecutive batches of vacuum frying. The increase in TOTOX value of blended oil is illustrated in Fig. 4.61. The TOTOX value was directly proportional to PV, AnV and number of frying. Latha and Nasirullah (2014) observed the increase in TOTOX value in rice bran oil after several times of frying. The TOTOX value increased from 5.32 to 24.3 after 8 h of frying at 180°C. However, the increase of TOTOX value in vacuum frying was less significant compared to that during atmospheric frying. The absence of atmospheric air inside the vacuum frying chamber might be the reason for significant oxidative changes in blended oil that resulted in low TOTOX value.
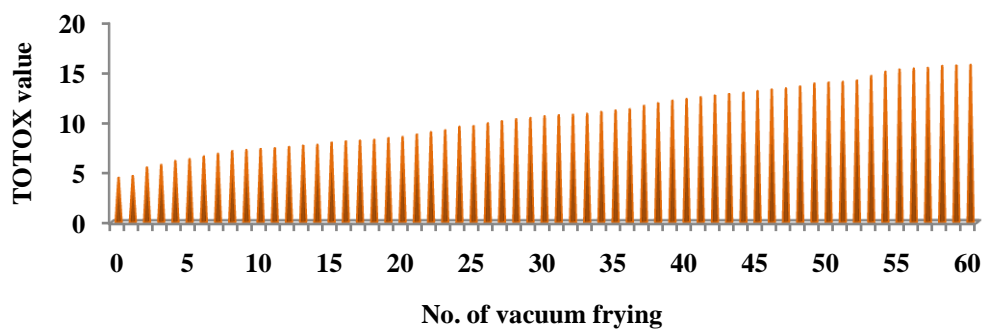
Fig. 4.59 Changes in total oxidation value of blended oil on vacuum frying
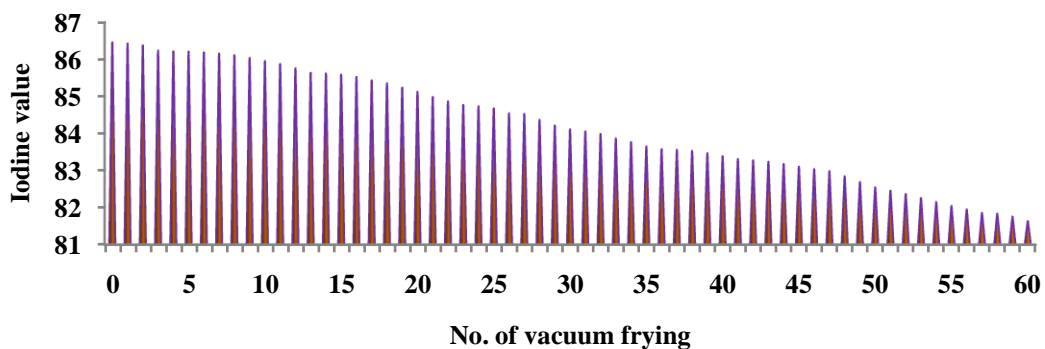
Fig. 4.60 Changes in iodine value of blended oil on vacuum frying
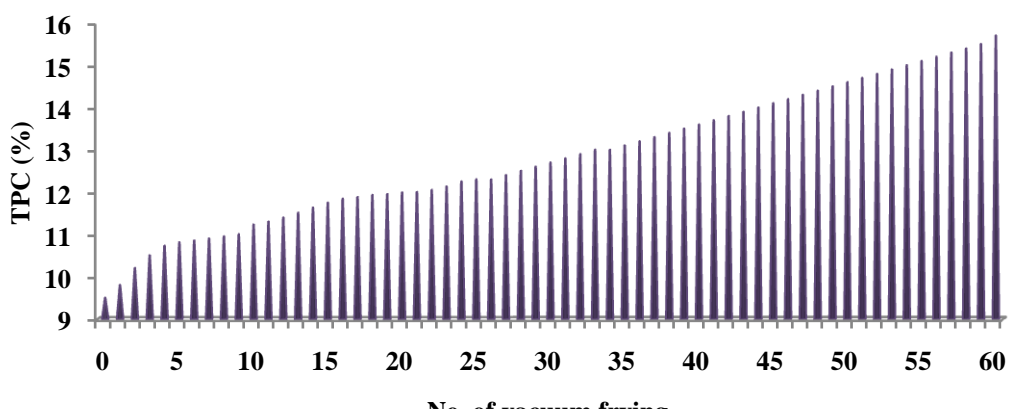
Fig. 4.61 Changes in total polar compounds of blended oil on vacuum frying

4.7.5 Iodine Value (IV)

The iodine value represents the degree of unsaturation of the oil. Higher the iodine value, higher will be the unsaturation level of oil which was desirable. The effect of number of vacuum frying batches was less significant on iodine value of the blended oil. The Fig. 4.62 depicts the changes in IV of blended oil during vacuum frying. The IV value of blended oil decreased from 86.45 to 81.63 in vacuum frying after sixty consecutive batches. The relatively constant IV value without much reduction even after sixty cycles indicated the higher degree of unsaturation in blended oil during vacuum frying which was due to low frying temperature and pressure. It was noteworthy that a single batch of atmospheric deep fat frying lead to sharp decrease in IV. Fan *et al.* (2013) observed 38% reduction in IV of palm oil in single atmospheric frying.

4.7.6 Total Polar Compounds (TPC)

The TPC was one of the major and easily measurable property of oil to decide the usability of edible oil. The threshold level of TPC in edible oil was 25 - 27 % (Mellema, 2003). The Fig. 4.63 indicates the changes in TPC of blended oil during vacuum frying. The TPC of fresh blended oil was 9.5% and it was increased to 15.7% after sixty batches of vacuum frying which was well below the threshold limit. This made the oil recommendable for usage even after sixty batches of frying. The slight increase in TPC was due to low frying temperature that inhibited the formation of polar compounds like polymeric, cyclic non volatile substances that resulted in oxidation and hydrolysis of oil (Debnath *et al.,* 2012).

4.7.7 Viscosity

The physical behaviour of oil plays a vital role to decide the oil stability. The prediction of frying oil stability with chemical properties alone will not always be accurate (Normand *et al.,* 2001). The viscosity of edible oil was usually affected by the polar compounds present in it. The viscosity of the blended oil was measured after each batch of vacuum frying of banana chips. The viscosity of
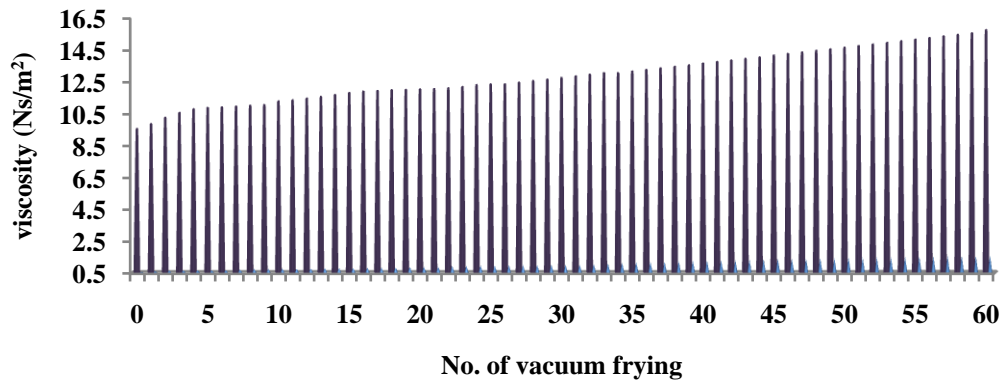
Fig. 4.62 Changes in viscosity of blended oil on vacuum frying
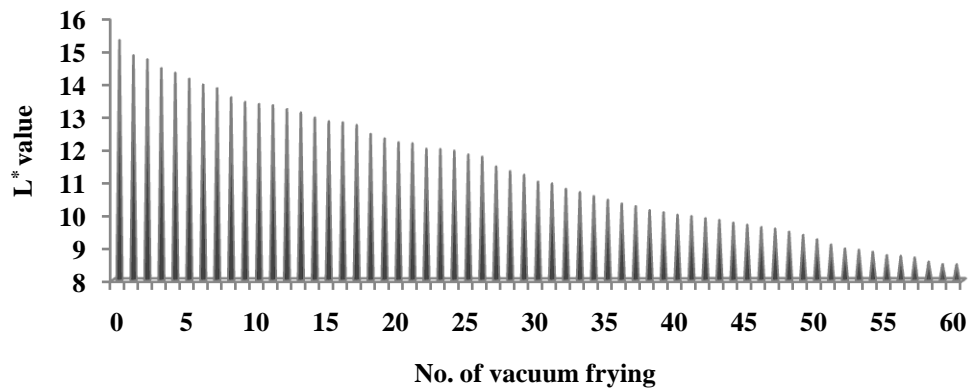
Fig. 4.63 Changes in L* value of blended oil on vacuum frying
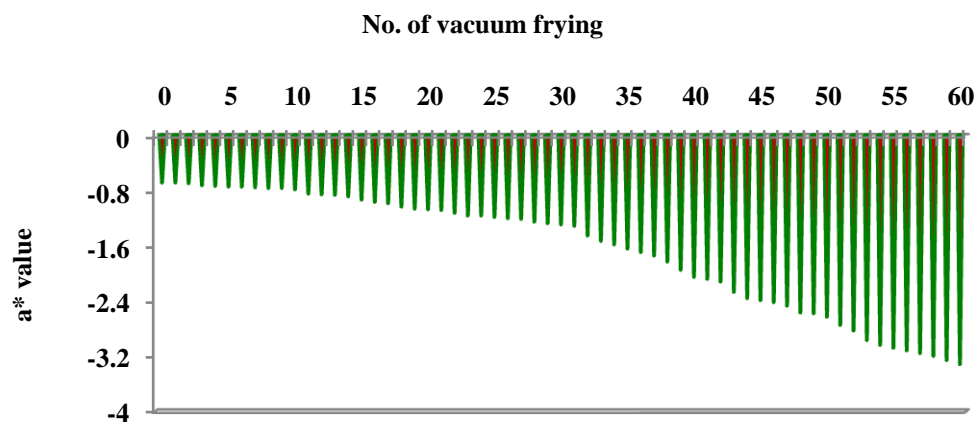
Fig. 4.64 Changes in a* value of blended oil on vacuum frying

blended oil increased linearly with increasing number of frying. However the increase was significantly less in oil for vacuum frying compared with that used for atmospheric frying. The increase in viscosity of the blended oil after three batches of atmospheric and vacuum frying was 1.25 and 0.64 Nsm^{-2}, respectively. The changes in viscosity during vacuum frying is represented in Fig. 4.64. The viscosity of the blended oil increased from 0.53 to 1.58 Nsm^{-2} after sixty batches of vacuum frying. The viscosity of oil increased due to polymerisation and increase in the length of free fatty acid chains (Gertz, 2000). The slight increase in viscosity of the blended oil was due to reduced polymerisation and slight increased TPC percentage.

4.7.8 Colour Values

The L^*, a^* and b^* values of the blended oil decreased from 15. 32 to 8.46, from -0.68 to -3.32 and from 2.13 to -5.35, respectively, after sixty batches of vacuum frying. The changes in L^*, a^* and b^* values are represented in Fig. 4.65, 4.66 and 4.67. The decrease in colour L^*, a^* and b^* values indicated the darkening of the vacuum fried oil. The colour of the oil usually darkened when subjected to deep fat frying. Gutierrez *et al.* (1988) stated that the presence of non polar compounds and unsaturated carbonyl compounds darkened the frying oil when subjected to high frying temperature. However, the reduced darkening observed in vacuum fried oil was due to low total polar compounds. The result was in agreement with the findings of Tarmizi *et al.* (2013) who observed relatively less darkening in the oil drained at vacuum condition than atmospheric environment. Since drainage at vacuum condition employed 50% low temperature than atmospheric condition, a reduction of 46.7% in darkness was noted in L^* value under vacuum compared to that of atmospheric condition.

The statistical analysis for the effect of vacuum frying on the oil quality was done using general factorial design. The ANOVA table of all the quality parameters of oil is given in appendix-H2. From the results it was observed that the free fatty acid of the blended oil increased beyond the recommendable limit
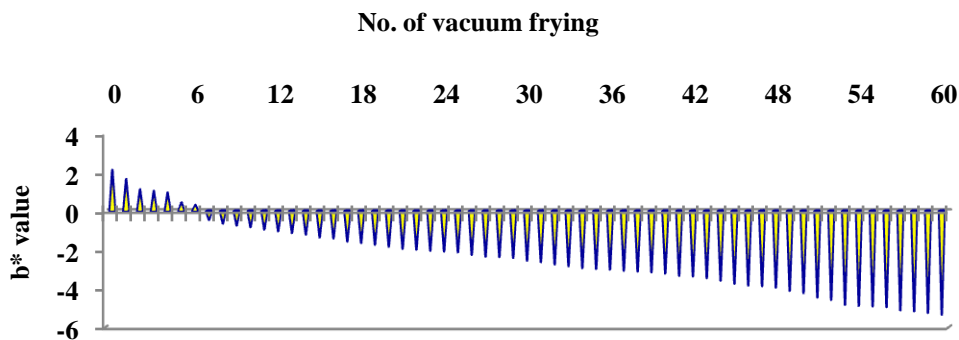
No. of vacuum frying

Fig. 4.65 Changes in b* value of blended oil on vacuum frying

after sixty batches of vacuum frying, whereas the increase in other quality parameters like peroxide value and total polar compound were within the allowable limit. However, the FFA value of blended oil after fifty two batches of vacuum frying was within the recommendable limit. Hence, the blended oil could be recommended upto fifty times of usage vacuum frying of banana chips. The obtained result was in agreement with the recommendation by Kumar, that the oil could be reused for more than fifty times in vacuum frying of gulab jamoons (Kumar, 2017).

4.8. COST ECONOMICS

The cost estimation for the preparation vacuum fried and ripened banana chips were worked out taking all aspects of fixed and variable costs involved in its production. The benefit: cost ratio for optimized vacuum fried ripened and raw banana chips packed in LDPE was (1.46:1 and 2.75:1). Since the benefit: ratio shows that the developed vacuum fried products are economically favourable and it can be successfully installed. The detailed calculation is presented in Appendix (C).

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Globally, India ranks first in banana production. The fruit is affordable to all categories of people and available year round. Consumption of single banana provides all the essential micronutrients to the body. In this context, extension of shelf life of this fruit along with value addition, assumes much significance. The *nendran* banana chips was one of the indigenously processed snack product from banana, which is popular throughout the state. However, consumption of deep fat fried snack products is unhealthy and leads to several diseases. It is noteworthy that, modern consumers are health conscious but not ready to compromise the taste of the food they consume. Hence, an alternative frying method offering a combination vacuum frying would be promising technology for the production of deep fat fried snack products. In vacuum frying technology, the food products were subjected to low frying temperature and pressure which preserves the quality of frying oil, reduces the oil content and improves the quality of fried product.

The present investigation was carried out to develop an effective vacuum frying system and evaluate it for the production of raw and ripened *nendran* banana chips. The brief summarisation of the results of the investigation is presented in this chapter.

The developed vacuum frying system consisted of a storage chamber (30 l capacity) and fryer chamber (diameter 406 mm and 984 mm length) made of stainless steel (SS 316). Both the chambers were provided with electric heaters of 1.5 kW. The de-oiling system consisted of 0.5 hp motor mounted at the top of the frying chamber. The shaft of the de-oiling motor was connected to the holder of the frying basket. Frying basket was made of stainless steel (SS 316) with bottom curved (30º) provided with closure. The pressure was maintained using 3 hp water ring vacuum pump of 30 m^3h^{-1} capacity. Two separate pneumatically operated spherical disc butterfly valves were attached with each chamber to create vacuum inside the chambers. Pressure difference was created through vent valves using

nitrogen gas between the chambers to transfer oil. The nitrogen gas was used in order to maintain the oil quality, since creation of pressure gradient using air enhances the chance of oxidative rancidity in the oil. The oil was transferred from the storage tank to frying tank and vice versa through SS ball valves.

Cooling system included cooling tower of 10 l capacity attached with 1 hp water pump with head flow of 5 to 10 lpm (litre per minute). Vapour removed during frying was condensed using shell and tube heat exchanger. The vapour was collected through a closed basin fitted with ball valve. The control system of vacuum frying equipment was communicated through OMRON PLC with HMI (Human Machine Interface). Additional facilities used for the operation of vacuum frying system was a compressor with air pressure of 600 kPa provided with a pneumatic manifold that could withstand 100 kPa pressure. The total power consumption of the developed system was 12.5 kW.

Experiments with the developed vacuum frying system were conducted in four steps. Selection of oil suitable for vacuum frying, optimisation of centrifugation parameters for de-oiling, pre-treatment for vacuum frying and processing parameters of vacuum fryer to produce superior quality vacuum fried raw and ripened banana chips, shelf life of the product and quality of the oil were also assessed.

The four edible vegetable oils and one oil blend (Rice bran and Palm oil at 80:20) were tested for the production of vacuum fried banana chips. The coconut, rice bran oil, palm oil, corn oil and the blended oil (Rice bran: Palm oil, 80:20) were used for vacuum frying. The critical quality parameters of the fried product colour, oil content and sensory analysis, the quality parameters – free fatty acid (FFA), peroxide value (PV), p-anisidine value (AnV), total oxidation value (TOTOX), iodine value (IV), total polar compound (TPC) value, colour values and viscosity of the fried oil were observed.

The low oil content of 12.5 and 24.6%, respectively, was observed in VF-raw and VF-ripe, fried in palm oil. The VF-raw and VF-ripe fried in blended

oil had the oil content 12.8 and 25.5%, respectively. The vacuum fried ripened banana chips fried in rice bran, palm and blended oils was top ranked in sensory evaluation using fuzzy logic when compared to chips fried in corn oil, coconut oil and atmospheric fried chips. The sensory preference was poor for the vacuum fried raw banana chips than atmospheric fried chips. The colour values of the vacuum fried banana chips had higher yellowness index that ranged from 130.3 to 132.37 than the atmospheric fried chips. The colour values of raw banana chips exhibited lighter colour than the atmospheric fried raw banana chips.

The FFA, PV, AnV, TOTOX, IV and TPC values of the used blended oil was 0.86 mg $KOHg^{-1}$, 0.48 $meqO_2kg^{-1}$, 4.5, 5.46, 84.2 and 10.5%, respectively. The viscosity of all the frying oils got increased after vacuum frying and the viscosity of blended oil increased from 0.53 to 0.62 Nsm^{-2}. The colour values of the fried oils decreased indicating the darkening of oil. Though rice bran oil possessed high thermal and oxidation stability, it had drawbacks like higher AnV and low iodine value. To overcome this, blending of rice bran oil with palm oil was done to formulate a blended oil in the ratio 80:20. Hence, the blended oil was selected to carry out further experiments.

Post frying centrifugation was done to remove the surface oil of the vacuum fried banana chips. The centrifugation speed of 1000 rpm for 5 min effectively removed 74.1 and 71.4% oil, respectively, in VF-raw and VF-ripe. The other product properties of VF-raw and VF-ripe $viz.,$ moisture content, water activity, thickness expansion remained unchanged with different centrifugation parameters. The bulk density, true density and hardness decreased with increase in centrifugation speed. The colour values L^* and b^* increased, while a^* value decreased with increase in centrifugation speed and time. Higher consumer acceptability of VF-ripe was observed for all de-oiling speed and time, while the atmospheric fried ripened banana scored poor consumer acceptability. The consumer acceptability of vacuum fried raw banana chips was below satisfactory and the atmospheric fried raw banana chips showed good consumer satisfaction.

The selection of frying oil and de-oiling parameters was followed by the standardisation of pre-treatments for the sliced raw and ripened bananas to improve the quality of fried product. The quality properties of pre-treatments like blanching cum drying (2 min water blanching and drying at 65℃ for 3 h), freezing for 12 h and dipping in 1.5% guar gum for 5 min were compared with untreated vacuum and atmospheric fried banana chips. The oil content of untreated, de-oiled vacuum fried raw and ripened banana chips was 8.3 and 13.35%, respectively. The sensory evaluation of the untreated chips as well as that of chips pre-treated with freezing and gum coating ranked first than the atmospheric fried and blanched cum dried pre-treatment. Both pre-treated and untreated vacuum fried raw banana chips was unsatisfactory in sensory preference than atmospheric fried raw banana chips.

The experiment IV was carried out for the standardisation of process parameters *viz.,* temperature (90, 100, 110 and 120°C), pressure (10, 15, 20 and 25 kPa) and time (10, 12, 14 and 16 min) of frying for the production of VF- raw and VF-ripe. The blended oil (rice bran: palm oil, 80:20) was used for conducting frying experiments and de-oiling was carried out at a centrifugation speed of 1000 rpm for 5 min in all treatments. The treatments were done using central composite rotatable design and twenty treatments on raw and ripened vacuum fried banana chips. The vacuum fried ripened banana chips at 105°C and 18 kPa for 13 min exhibited higher sensory score with oil content of 13.35%, moisture content of 0.84% (*d.b*), water activity of 0.21, bulk density of 0.442 gcm^{-3}, true density of 1.36 gcm^{-3}, thickness expansion of -77%, hardness of 1.64 N, yellowness index of 134.6, energy value of 1624.7 kJ/100g and acrylamide content of 122.8 μgkg^{-1}. The reduced acceptability of VF-raw suggested further improvements in process protocol, before introduction to market. However, VF-ripe has scored high consumer preference which indicated the high marketing potential of this novel product. Hence, storage studies were conducted for VF-ripe fried at 105°C.

The thirty and sixty days stored vacuum fried ripened banana chips packed in nitrogen flushed 400 gauge LDPE package showed equal sensory score with

fresh vacuum fried ripened banana chips. The consumer preference for the VF-ripe declined from "8 - Like very much" to "7 - Like moderately" after 90 days of storage. The oil content of the stored VF-ripe remained unchanged throughout 120 days of storage. The crispness, moisture content, water activity, lightness values got increased and the yellowness and redness value got decreased linearly after thirty days of storage. The cost economics for the production of VF-ripe was Rs.364/kg with cost benefit ratio of 1:2.76.

The blended oil was evaluated for quality parameters after its repeated use for several batches of vacuum frying. Each batch of vacuum frying was done for 13 min time at 105°C and 18 kPa. The FFA was within the acceptable limit upto 52 batches of vacuum frying. Other quality parameters of oil like, peroxide value (PV), p-Anisidine value (AnV), total oxidation value (TOTOX value) and viscosity increased linearly after each batch of vacuum frying. The total polar compound (TPC) of the blended oil increased from 9.5 to 15.7%, which was well below the threshold level for oil usage. The colour of the oil got darkened only after sixty batches of vacuum frying.

Based on the results the following conclusions may be drawn

- The developed vacuum fryer could be efficiently used for the production of vacuum fried ripened banana chips

- The blended oil (rice bran : palm oil; 80:20) was better than other selected individual oils

- Centrifugation of 1000 rpm for 5 min showed highest removal of surface oil with reduction of 74.1 and 71.4%, respectively, in VF-raw and VF-ripe

- The vacuum frying with de-oiling nullified the effect of pre-treatments

- The process condition at 105°C and 18 kPa for 13 min produced a novel healthy snack with low oil content and acrylamide content

- The cost of vacuum fried ripened banana chips was Rs. 364/ kg

- The storage life of the vacuum fried banana chips was up to 90 days

- The quality of oil could be maintained in vacuum frying up to fifty two batches of frying

- Process protocol of raw banana chips should be improved prior to commercialisation.

Further investigations are to be directed towards

- The developed vacuum frying system can be evaluated with other different fruits, vegetables, pulses, fish, meat, milk and poultry products.
- A continuous vacuum frying system can be developed to increase the production at large scale.

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CHAPTER - VII

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Appendices

APPENDIX - A

Sensory score card for vacuum fried banana chips

Sample code	Colour & Appearance	Texture	Flavour	Taste	Overall acceptability
T1					
T2					
T3					
T4					
T5					
T6					

Hedonic scale

9 - Like extremely

8 - Like very much

7 - Like Moderately

6 - Like slightly

5 - Neither like nor dislike

4 - Dislike slightly

3 - Dislike moderately

2 - Dislike very much

1 - Dislike extremely

Name and signature of sensory panel:

Date:

APPENDIX - B

Fuzzy logic - Model calculation table

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

Sensory attribute	Scale factor	T1	T1 FMF	T1 NFMF	T2	T2 FMF	T2 NFMF	T3	T3 FMF	T3 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 banana chips

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

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

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

APPENDIX - C

Cost economics of developed vacuum fried banana chips

Estimation of cost of production for vacuum fried banana chips

Cost of machineries and building cost

Cost of vacuum frying machine	=	Rs. 20,00,000/-
Cost of banana slicer	=	Rs. 25,000/-
Cost of cooling tray	=	Rs. 20,000/-
Cost of packaging machine	=	Rs. 3,00,000/-
Building cost (5000 sq.ft) @ 1500/sq.ft	=	Rs. 75,00,000/-
Miscellaneous item	=	Rs. 50,000/-
Total cost	=	Rs.98,77,000/-

Assumptions

Life span (L)	=	10 years
Annual working hours (H)	=	275 days (per day 8 hours) = 2200 hours
Salvage value (S)	=	10% of initial cost
Interest on initial cost (i)	=	15% annually
Repair & maintenance	=	10% of initial cost
Insurance & taxes	=	2% of initial cost
Electricity charge	=	Rs. 7/unit
Labour wages/person	=	Rs. 500/day

1. Total fixed cost

i. Depreciation $= \dfrac{C - S}{L \times H} = \dfrac{9877000 - 987700}{10 \times 2200} = $ Rs 404.04/h

ii. Interest $= \dfrac{C + S}{2} \times \dfrac{i}{H} = \dfrac{9877000 + 987700}{2} \times \dfrac{15}{100 \times 2200}$

$= $ Rs. 370.38/h

iii. Insurance & taxes $= 2\%$ of initial cost

$$\dfrac{2}{100 \times 2200} \times 9877000 = \text{Rs. } 89.78/h$$

Total fixed cost $= $ i + ii + iii = **Rs. 864/h**

2.Total variable cost

i. Repair & maintenance $= 5\%$ of initial cost

$$\dfrac{10}{100 \times 2200} \times 4938500$$

$= $ Rs. 448.97/h

ii. Electricity cost

a) Energy consumed by the vacuum fryer $= 12.5$ kw/h

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

$$12.5 \times 8 \times 7$$

$$= \text{Rs.700/day}$$

b) Energy consumed by slicer, cooling tray and packaging machine $= 2 \text{ kw/h}$

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

$$2 \times 8 \times 7$$

$$= \text{Rs. 112/day}$$

iii. Labour cost (2 persons) $= \text{Rs. 1000/day}$

iv. Packaging cost $= \text{Rs. 4000/day}$

v. Cost of raw material for preparation of vacuum fried banana chips

Sl. No.	Raw materials	Quantity (kg)	Unit rate (per kg)	Total amount (Rs.)
1	Raw Banana	1100	25	27,500
2	Ripened banana	1200	35	42,000
3	Frying oil	150	80	90,000

Therefore variable cost (raw banana chips = i + ii + iii + iv + v

$$= \text{Rs.1,30,021.88/-}$$

Variable cost (ripened banana chips) = i + ii + iii + iv + v

$$= \text{Rs. 1,38,260.94/-}$$

Therefore total cost of production of 400 kg of vacuum fried raw banana chips

$$= \text{Fixed cost} + \text{Variable cost}$$

$$= 6912 + 130021.88$$

= Rs. 136933.88/400 kg of vacuum fried raw banana chips

= Rs. 342/ kg of vacuum fried banana chips

Therefore total cost of production of 400 kg of vacuum fried ripened banana chips

= Fixed cost + Variable cost

= 6912 + 138260.94

= Rs. 1, 45,172.9/400 kg of vacuum fried ripened banana chips

= Rs. 363/ kg of vacuum fried banana chips

The market selling price of 1kg of vacuum fried ripened banana chips is Rs.1000/ kg

$$\text{Cost benefit ratio} = \frac{1000}{363} = 2.75$$

The benefit cost ratio for the production of vacuum fried ripened banana chips was found to be 2.75:1.

By assuming a selling price of Rs.500/kg, the benefit cost ratio for the production of vacuum fried raw banana chips was found to be 1.46:1.

Appendix D1

Table. D.1 Multi response optimisation constraints of experiment

SI. No.	Parameters	Goal	Lower limit	Upper limit
	Frying oil	in range	O_1	O_5
1	TPC (%)	Minimise	9.5	39
2	Peroxide value	Minimise	0.09	9.54
3	p-Anisidine value	Minimise	0.4	9.01
4	TOTOX value	Minimise	0.95	23.9
5	Iodine value	Maximise	6.74	106
6	FFA	Minimise	0.04	31
7	L^*	Minimise	4.6	27.3
8	a^*	Minimise	-0.98	0.93
9	b^*	Minimise	-0.93	4.6
10	Viscosity	Minimise	0.12	1.53
	Ripened banana chips	in range	O1	O4
11	L^*	Maximise	48.4	66.3
12	a^*	Maximise	10.86	15.32
13	b^*	Maximise	43.9	58.7
14	Oil content	Minimise	24.3	31.3
	Raw banana chips	in range	O_1	O_5
15	L^*	Maximise	47.4	60
16	a^*	Maximise	6.4	7.93

| 17 | b* | Maximise | 34.9 | 37.9 |
| 18 | Oil content | Minimise | 11.9 | 15.3 |

Factor – A Frying with different oil

ANOVA for properties of oil

Table.D2.1   **FFA**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5266.62	14	376.19	1808.30	< 0.0001	0.46	7.44
Factor - A	5266.62	14	376.19	1808.30	< 0.0001		
Pure error	6.24	30	0.21				
Cor total	5272.86	44		*			

Table.D2.2   **Peroxide value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	255.73	14	18.27	135.02	< 0.0001	0.37	1.45
Factor - A	255.73	14	18.27	135.02	< 0.0001		
Pure error	4.06	30	0.14				
Cor total	246.27	35		*			

Table.D2.3   **p-Anisidine value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	223.52	14	15.97	56.18	< 0.0001	0.53	4.82
Factor - A	223.52	14	15.97	56.18	< 0.0001		
Pure error	8.53	30	0.28				
Cor total	232.05	44		*			

Table.D2.4   **TOTOX**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1338.43	14	95.60	177.76	< 0.0001	0.73	9.98
Factor - A	1338.43	14	95.60	177.76	< 0.0001		
Pure error	16.13	30	0.54				
Cor total	1354.57	44		*			

Table.D2.5   **Iodine value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	52020.81	14	3715.77	3567.09	< 0.0001	1.02	1.53
Factor - A	52020.81	14	3715.77	3567.09	< 0.0001		
Pure error	31.25	30	1.04				
Cor total	52052.06	44		*			

Table.D2.6   **TPC**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3502.74	14	250.20	616.28	< 0.0001	0.64	4.36
Factor - A	3502.74	14	250.20	616.28	< 0.0001		

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Pure error	12.18	30	0.41				
Cor total	3514.92	44		*			

Table.D2.7   **Viscosity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5.69	14	0.41	28.08	< 0.0001	0.12	27.00
Factor - A	5.69	14	0.41	28.08	< 0.0001		
Pure error	0.43	30	0.014				
Cor total	6.12	44		*			

Table.D2.8 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1407.93	14	100.57	353.88	< 0.0001	0.53	3.95
Factor - A	1407.93	14	100.57	353.88	< 0.0001		
Pure error	8.53	30	0.28				
Cor total	1416.45	44		*			

Table.D2.9 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	8.56	14	0.61	309.90	< 0.0001	0.044	8.23
Factor - A	8.56	14	0.61	309.90	< 0.0001		
Pure error	0.059	30	1.973E-003				
Cor total	8.62	44		*			

Table.D2.10 b^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	57.05	14	4.07	361.17	< 0.0001	0.11	8.73
Factor - A	57.05	14	4.07	361.17	< 0.0001		
Pure error	0.34	30	0.011				
Cor total	57.39	44		*			

ANOVA – Properties of VF-raw in different frying oil

Table.D2.11				L^*			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	480.11	3	160.04	69.71	< 0.0001	1.52	2.61
Factor - A	480.11	3	160.04	69.71	< 0.0001		
Pure error	27.55	12	2.30				
Cor total	54.60	35		*			

Table.D2.12				a^*			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	20.44	3	6.81	9.47	< 0.0001	0.85	6.77
Factor - A	20.44	3	6.81	9.47	< 0.0001		
Pure error	8.63	12	0.72				
Cor total	29.07	15		*			

Table.D2.13				b^*			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	472.45	3	157.48	180.85	< 0.0001	0.93	1.72
Factor - A	472.45	3	157.48	180.85	< 0.0001		
Pure error	10.45	12	0.87				
Cor total	482.90	15		*			

Table.D2.14 ΔE

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1522.73	3	507.58	5191.49	< 0.0001	0.31	7.05
Factor - A	1522.73	3	507.58	5191.49	< 0.0001		
Pure error	1.17	12	0.098				
Cor total	1523.90	15		*			

Table.D2.15 **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	378.10	3	126.03	24.37	< 0.0001	2.27	4.59
Factor - A	378.10	3	126.03	24.37	< 0.0001		
Pure error	62.06	12	5.17				
Cor total	440.15	15		*			

ANOVA – Properties of VF-ripe in different frying oils

Table.D2.16 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	309.09	3	103.03	178.70	< 0.0001	0.76	1.36
Factor - A	309.09	3	103.03	178.70	< 0.0001		
Pure error	6.92	12	0.58				
Cor total	316.01	15		*			

Table.D2.17 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1.70	3	0.57	5.35	< 0.0001	0.33	4.72

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Factor - A	1.70	3	0.57	5.35	< 0.0001		
Pure error	1.27	12	0.11				
Cor total	2.97	15		*			

Table.D2.18   **b***

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5.09	3	1.70	4.12	< 0.0001	0.64	1.77
Factor - A	5.09	3	1.70	4.12	< 0.0001		
Pure error	4.94	12	0.41				
Cor total	10.03	15		**			

Table.D2.19   **ΔE**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	114.72	3	38.24	1.80	0.2002	4.61	37.45
Factor - A	114.72	3	38.24	1.80	0.2002		
Pure error	254.48	12	21.21				
Cor total	369.20	15		Not *			

Table.D2.20   **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	12.05	3	4.02	38.02	< 0.0001	0.33	2.38
Factor - A	12.05	3	4.02	38.02	< 0.0001		
Pure error	1.27	12	0.11				
Cor total	13.31	15		*			

- **Significant ** Not Significant**

Table.D2.21.Changes in oil quality parameters

Testing	Oil sample	Total polar compounds (TPC)	Peroxide value (meq/kg oil)	p-anisidine value (AnV)	Iodine value	Free fatty acid value (mg KOH/g oil)	Total oxidation value (TOTOX)	Viscosity N.s/m^2	L^*	a^*	b^*
Fresh oil	O_1	34.0	3.36	5.7	9.5	26.0	12.4	0.20	27.23	0.91	4.30
	O_2	10.5	0.32	5.2	98.4	0.84	5.84	0.32	15.45	-0.55	2.29
	O_3	10.0	0.21	0.6	56.2	0.06	1.02	0.79	12.18	-0.91	1.52
	O_4	11.1	0.25	2.84	105	0.12	3.35	0.01	12.67	-0.85	0.46
	O_5	9.5	0.26	3.9	86.45	0.74	4.22	0.56	15.32	-0.68	2.13
After 1st frying	O_1	35.7	4.46	8.65	8.03	32.0	17.5	0.23	25.16	-0.74	1.32
	O_2	11.2	0.43	5.8	95.4	1.24	7.66	0.35	10.75	-0.33	-0.14
	O_3	11.8	0.23	1.35	48.6	0.93	1.77	0.92	10.64	-0.88	1.21
	O_4	13.5	0.59	4.63	96.3	0.14	5.81	0.03	8.54	-0.82	0.80
	O_5	10.2	0.34	4.2	85.34	0.82	4.88	0.58	13.42	-0.57	1.24
After 2nd frying	O_1	38.5	5.54	9.3	6.74	37.0	21.4	0.26	17.54	-0.53	-0.86
	O_2	11.5	0.64	5.9	93.7	1.96	8.68	0.38	8.36	-0.16	0.96
	O_3	12.6	0.32	1.53	44.2	0.98	4.17	1.47	10.07	-0.63	0.87

	O₄	15.3	0.74	5.35	82.3	0.16	6.83	0.07	5.23	-0.69	0.99
	O₅	10.5	0.48	4.5	84.2	0.86	5.46	0.62	12.45	-0.42	1.12

Table.D2.22. Properties of VF-raw fried with different oils

Treatments	Oil content (%) of VF-raw	L^*	a^*	b^*	ΔE
O_1	14.6	58.65	6.11	37.02	-10.84
O_2	13.2	54.76	5.87	36.35	-9.07
O_3	12.5	54.4	5.73	36.3	-9.96
O_4	14.6	46.24	7.21	35.7	-20.16
O_5	12.8	54.6	5.6	35.3	-6.95

Table.D2.23. Fuzzy logic ranking of VF-raw with different oils

Sample	Ranking of treatments	Ranking of attributes
Vacuum fried raw banana chips	O_1	Texture > Taste > Flavour = OA >C&A
	O_2	Texture = Flavour = Taste >OA = C&A
	O_3	Texture = Flavour = Taste >OA > C&A
	O_4	Texture > Flavour >Taste = OA >C&A
	O_5	Texture > Flavour > Taste = OA >C&A
	Control	C&A > OA > Flavour = Texture = Taste

APPENDIX – E1

Table. E1.1 Treatment details of VF-raw and VF-ripe

Treatments		Centrifugation		Treatments		Centrifugation	
VF-raw	VF-ripe	Speed (rpm)	Time (min)	VF-raw	VF-ripe	Speed (rpm)	Time (min)
D1	RD1	400	0	D11	RD11	800	0
D2	RD2		3	D12	RD12		3
D3	RD3		5	D13	RD13		5
D4	RD4		7	D14	RD14		7
D5	RD5		9	D15	RD15		9
D6	RD6	600	0	D16	RD16	1000	0
D7	RD7		3	D17	RD17		3
D8	RD8		5	D18	RD18		5
D9	RD9		7	D19	RD19		7
D10	RD10		9	D20	RD20		9
Control	Corresponding atmospheric fried raw and ripened banana chips						

APPENDIX – E2

Table. E2.1 Changes in quality attributes of VF-raw on centrifugation

Treatments	Oil content (%)	Moisture content (%)	Water activity a_w	Bulk density (g/cm^3)	True density (g/cm^3)	Thickness expansion (%)	Hardness (N)
D1	22.63	0.962	0.21	0.964	1.46	-65.75	1.98
D2	16.64	0.961	0.21	0.892	1.54	-65.3	1.87
D3	14.65	0.961	0.22	0.783	1.58	-65.6	1.75
D4	12.56	0.962	0.2	0.758	1.63	-65.8	1.67
D5	11.94	0.961	0.21	0.758	1.63	-65.7	1.6
D6	22.63	0.962	0.21	0.964	1.46	-65.43	1.85
D7	14.5	0.961	0.2	0.894	1.58	-65.5	1.75
D8	12.4	0.963	0.2	0.753	1.65	-65.6	1.63
D9	11.3	0.960	0.2	0.681	1.65	-65.8	1.56
D10	10.54	0.961	0.21	0. 681	1.65	-65.9	1.57
D11	22.63	0.963	0.22	0.964	1.46	-65.6	1.95
D12	12.6	0.961	0.23	0.673	1.64	-65.8	1.86

D13	11.43	0.960	0.22	0.634	1.68	-65.8	1.79
D14	10.95	0.960	0.22	0.631	1.68	-65.5	1.76
D15	9.65	0.962	0.23	0.631	1.69	-65.4	1.65
D16	22.63	0.962	0.23	0.964	1.46	-65.9	1.98
D17	11.5	0.964	0.22	0.524	1.65	-65.9	1.64
D18	8.35	0.962	0.22	0.413	1.76	-65.3	1.47
D19	8.32	0.963	0.22	0.413	1.76	-65.5	1.43
D20	8.3	0.962	0.22	0.413	1.76	-65.8	1.46
Control	32.63	2.120	0.20	1. 358	1.42	-72.9	1.98

Table. E2.2 Changes in colour values and sensory attributes of VF-raw on centrifugation

Treatments	L^*	a^*	b^*	ΔE	Colour & appearance	Texture	Flavour	Taste	Overall acceptability
D1	59.5	6.11	37.6	-8.64	3.4	2.7	2.8	3.2	2.6
D2	59.7	6.1	36.72	-8.5	2.5	2.5	2.6	3.5	2.4
D3	59.7	6.1	36.93	-8.45	2.6	2.3	3.2	3.6	3.2
D4	60.3	5.9	36.7	-8.64	2.4	2.8	2.4	3.4	3.5

D5	60.6	5.9	38.5	-8.67	2.3	2.6	3.1	3.6	3.5
D6	59.5	6.11	35.6	-11.05	2.0	2.5	2.5	3.2	2.6
D7	59.8	6.1	36.33	-10.03	2.5	3.1	2.6	3.4	3.6
D8	59.98	5.9	37.1	-9.53	2.7	3.4	3.5	2.5	3.2
D9	60.2	5.8	37.2	-9.4	2.4	2.6	3.2	2.8	2.5
D10	60.4	5.8	38.3	-7.56	2.5	2.3	3.7	2.4	2.4
D11	59.5	6.11	35.6	-11.53	3.2	2.7	2.5	3.5	2.3
D12	60.3	5.9	36.4	-9.63	3.0	3.2	2.4	3.2	3.5
D13	60.6	5.9	36.4	-9.45	2.8	2.6	2.4	2.6	3.4
D14	60.3	5.87	37.5	-6.8	3.4	3.0	2.3	2.7	3.6
D15	60.4	5.7	38.5	-4.67	2.6	3.6	2.7	2.5	3.4
D16	59.5	6.11	35.6	-11.93	2.8	3.2	2.0	2.6	3.3
D17	59.7	5.9	36.4	-10.51	2.5	2.8	3.2	2.3	3.6
D18	60.2	5.9	38.5	-7.64	3.1	2.7	3.4	2.5	3.2
D19	60.3	5.9	38.4	-7.57	2.6	2.5	2.4	2.6	2.6
D20	60.5	5.8	38.6	-7.53	2.4	2.6	2.5	2.3	2.1
Control	56.57	8.01	41.35	-9.23	8.2	7.36	7.64	7.4	8.4

Table. E2.3 Fuzzy ranking of de-oiled VF-raw

Treatments	Ranking of sensory attributes
D1	C&A = OA > Texture > Taste > Flavour
D2	OA = C&A > Texture = Taste = Flavour
D3	OA = Texture = Taste > C&A > Flavour
D4	OA > C&A = Texture > Taste =Flavour
D5	OA > C&A = Texture > Taste > Flavour
D6	OA = Taste > C&A = Texture > Flavour
D7	OA > C&A = Texture = Taste > Flavour
D8	Texture > Taste = OA > C&A > Flavour
D9	C&A > Texture > Taste > OA = Flavour
D10	OA = Texture = Taste > C&A = Flavour
D11	OA > C&A = Texture = Taste > Flavour
D12	OA > C&A = Texture = Taste > Flavour
D13	OA = Taste > C&A = Texture > Flavour
D14	OA > Taste = C&A = Texture > Flavour
D15	OA = C&A = Texture > Taste > Flavour
D16	OA = C&A > Texture = Taste = Flavour
D17	OA > Taste = C&A = Texture = Flavour
D18	OA = C&A = Texture = Taste > Flavour
D19	C&A = Texture = Taste > OA > Flavour
D20	OA > C&A = Texture = Taste > Flavour
Control	OA=Flavour>C&A>Texture>Taste

OA - Overall acceptability; C&A – Colour and appearance

Table. E2.3 Fuzzy ranking of de-oiled VF-ripe

Treatments	Ranking of sensory attributes
RD1	C&A = OA > Texture > Taste > Flavour
RD2	OA = C&A > Texture = Taste = Flavour
RD3	OA = Texture = Taste > C&A > Flavour
RD4	OA > C&A = Texture > Taste > Flavour
RD5	OA > C&A = Texture > Taste > Flavour
RD6	OA = Taste > C&A = Texture > Flavour
RD7	OA > C&A = Texture = Taste > Flavour
RD8	Texture > Taste = OA > C&A > Flavour
RD9	C&A > Texture > Taste > OA = Flavour
RD10	OA = Texture = Taste > C&A > Flavour
RD11	OA > C&A = Texture = Taste > Flavour
RD12	OA > C&A = Texture = Taste > Flavour
RD13	OA = Taste > C&A = Texture > Flavour
RD14	Taste > OA = C&A = Texture > Flavour
RD15	OA = C&A = Texture > Taste > Flavour
RD16	OA = C&A > Texture = Taste > Flavour
RD17	Taste > OA = C&A = Texture > Flavour
RD18	OA = C&A = Texture = Taste > Flavour
RD19	C&A = Texture = Taste > OA > Flavour
RD20	Taste > OA = C&A = Texture > Flavour
Control	OA=Flavour>C&A>Texture>Taste

OA - Overall acceptability; C&A – Colour and appearance

Table. E3.1 Multi response optimisation constraints of experiment

SI. No.	Parameters	Goal	Lower limit	Upper limit
De-oiling – VF-raw		**in range**	**D1**	**D20**
1	Oil content	Minimise	7.3	15.87
2	Moisture content	Minimise	0.5	2.8
3	Water activity	Minimise	0.15	0.32
4	Bulk density	Minimise	0.3	1.2
5	True density	Minimise	0.54	2.43
6	Thickness	Maximise	-63.7	-68.98
7	L^*	Maximise	55.3	65.84
8	a^*	Maximise	5.1	6.84
9	b^*	Maximise	32.5	43.6
10	ΔE	In range	-3.64	-45.2
11	Texture	Minimise	1.12	2.54
De-oiling – VF-ripe		**in range**	**RD1**	**RD20**
12	Oil content	Minimise	12.5	32.6
13	Moisture content	Minimise	0.5	1.2
14	Water activity	Minimise	0.15	0.32
15	Bulk density	Minimise	0.3	1.2
16	True density	Minimise	0.54	2.43
17	Thickness	Maximise	-70.4	-80.53

18	L^*	Maximise	45.3	65.78
19	a^*	Maximise	6.74	11.64
20	b^*	Maximise	33.6	45.28
21	Yellowness Index	Maximise	95.3	105.85
22	ΔE	Minimise	-5.35	-30.6
23	Texture	Minimise	1.56	3.28

APPENDIX – E4

ANOVA Tables for the quality paramters of VF-raw on centrifugation

Table. E4.1 — **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	326.05	24	13.59	653.95	< 0.0001	0.14	1.16
Factor - A	326.05	24	13.59	653.95	< 0.0001		
Pure error	1.04	50	0.021				
Cor total	327.09	74	*				

Table. E4.2 — **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	6.141	24	2.559	1.08	0.3994	0.015	2.27
Factor - A	6.141	24	2.559	1.08	0.3994		
Pure error	0.012	50	2.373E-004				
Cor total	0.018	74	**				

Table. E4.3 — **Water activity**

Source	Sum of	df	Mean	F value	p-value	Std. Dev.	C.V

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1.467	24	6.111	1.02	0.4629	7.746E-003	3.70
Factor - A	1.467	24	6.111	1.02	0.4629		
Pure error	3.000	50	6.000E-005				
Cor total	4.467	74	**				

Table. E4.4   **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2.22	24	0.092	17918.76	< 0.0001	2.272E-003	0.35
Factor - A	2.22	24	0.092	17918.76	< 0.0001		
Pure error	2.580	50	5.160E-006				
Cor total	2.22	74	*				

Table. E4.5   **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3.11	24	0.13	410.40	< 0.0001	0.018	1.08
Factor - A	3.11	24	0.13	410.40	< 0.0001		
Pure error	0.016	50	3.160E-004				
Cor total	3.13	74	*				

Table. E4.6   **Thickness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.72	24	0.030	0.91	0.5889	0.18	0.28
Factor - A	0.72	24	0.030	0.91	0.5889		
Pure error	1.65	50	0.033				
Cor total	2.38	74	**				

Table. E4.7 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	22.55	24	0.94	7.25	< 0.0001	0.36	0.60
Factor - A	22.55	24	0.94	7.25	< 0.0001		
Pure error	6.48	50	0.13				
Cor total	29.04	74		*			

Table. E4.8 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1.24	24	0.052	16.17	< 0.0001	0.057	0.95
Factor - A	1.24	24	0.052	16.17	< 0.0001		
Pure error	0.16	50	3.203E-003				
Cor total	1.40	74		*			

Table.E4.9 b^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	93.43	24	3.89	162.52	< 0.0001	0.15	0.42
Factor - A	93.43	24	3.89	162.52	< 0.0001		
Pure error	2.92	50	0.058				
Cor total	887.97	74		*			

Table. E4.10 ΔE

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	14791.13	24	616.30	249.19	< 0.0001	1.57	9.92
Factor - A	14791.13	24	616.30	249.19	< 0.0001		
Pure error	0.032	50	6.373E-004				

| Cor total | 16.37 | 74 | | * | | | |

Table. E4.11 **Texture**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2.47	24	0.10	57.91	< 0.0001	0.042	2.42
Factor - A	2.47	24	0.10	57.91	< 0.0001		
Pure error	0.089	50	1.781E-003				
Cor total	2.56	74		*			

APPENDIX – E5

ANOVA Tables for the quality paramters of VF-ripe on centrifugation

Table. E5.1 **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2198.96	24	91.62	504.58	< 0.0001	0.43	1.67
Factor - A	2198.96	24	91.62	504.58	< 0.0001		
Pure error	0.000	0	0.11				
Cor total	2208.04	74		*			

Table. E5.2 **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3.023E-003	24	1.260E-004	1.04	0.4431	0.011	1.18
Factor - A	3.023E-003	24	1.260E-004	1.04	0.4431		
Pure error	6.077E-003	50	1.215E-004				
Cor total	9.100E-003	74		**			

Table. E5.3   **Water activity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2.301E-003	24	9.589	0.95	0.5364	0.010	4.69
Factor - A	2.301E-003	24	9.589	0.95	0.5364		
Pure error	5.025E-003	50	1.005E-004				
Cor total	7.327E-003	74	**				

Table. E5.4   **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2.22	24	0.092	17918.76	< 0.0001	2.272E-003	0.35
Factor - A	2.22	24	0.092	17918.76	< 0.0001		
Pure error	2.580E-004	50	5.160E-006				
Cor total	2.22	74	*				

Table. E5.5   **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3.11	24	0.13	410.40	< 0.0001	0.018	1.08
Factor - A	3.11	24	0.13	410.40	< 0.0001		
Pure error	0.016	50	3.160E-004				
Cor total	3.13	74	*				

Table. E5.6   **Thickness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.46	24	0.019	0.38	0.9938	0.22	0.29
Factor - A	0.46	24	0.019	0.38	0.9938		
Pure error	2.50	50	0.050				
Cor total	2.96	74		**			

Table. E5.7 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1607.43	24	66.98	1649.88	< 0.0001	0.20	0.37
Factor - A	1607.43	24	66.98	1649.88	< 0.0001		
Pure error	2.03	50	0.041				
Cor total	1609.46	74		*			

Table. E5.8 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	85.08	24	3.55	3.49	< 0.0001	1.01	11.68
Factor - A	85.08	24	3.55	3.49	< 0.0001		
Pure error	50.77	50	1.02				
Cor total	135.85	74		*			

Table. E5.9 b^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	885.05	24	36.88	632.05	< 0.0001	0.24	0.63
Factor - A	885.05	24	36.88	632.05	< 0.0001		
Pure error	2.92	50	0.058				
Cor total	887.97	74		*			

Table. E5.10 **Yellowness Index**

Source	Sum of	df	Mean	F value	p-value	Std. Dev.	C.V

	squares		square		prob>F		(%)
Model	231.66	24	9.65	542.10	< 0.0001	0.13	0.13
Factor - A	231.66	24	9.65	542.10	< 0.0001		
Pure error	0.89	50	0.018				
Cor total	232.55	74		*			

Table. E5.11   **ΔE**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	4330.50	24	180.44	13.73	< 0.0001	3.62	19.92
Factor - A	4330.50	24	180.44	13.73	< 0.0001		
Pure error	656.90	50	13.14				
Cor total	4987.40	74		*			

Table. E5.12   **Texture**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	16.34	24	0.68	1068.12	< 0.0001	0.025	1.04
Factor - A	16.34	24	0.68	1068.12	< 0.0001		
Pure error	0.032	50	6.373E-004				
Cor total	16.37	74		*			

- Significant ** Not Significant
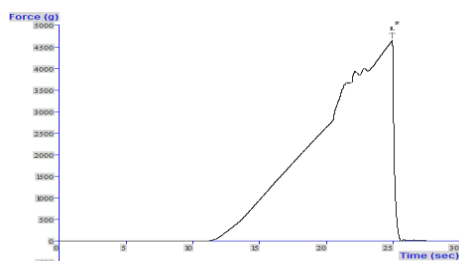
Fig.E5.1 Model graph of texture analysis of vacuum fried banana chips

APPENDIX – F1

Table.F1.1 Details of pre-treated vacuum fried banana chips

VF - raw	VF-ripe	Pre-treatments
P1	RP1	Blanching cum drying
P2	RP2	Gum coating
P3	RP3	Freezing
Control	Control	Untreated
Atm-raw	Atm-ripe	Atmospheric fried raw and ripened banana chips

Table.F1.2 Changes in quality attributes of VF-raw with pre-treatments

S.No	Quality attributes	P1	P2	P3	Control	Atm-raw
1	Oil content (%)	7.540	8.25	34.52	8.35	32.63
2	Moisture content (%)	0.531	2.34	0.684	0.692	2.120
3	Water activity (a_w)	0.213	0.231	0.220	0.22	0.20
4	Bulk density (g/cm^3)	0.392	0.435	1.624	0.413	1.538
5	True density (g/cm^3)	1.792	1.724	1.330	1.76	1.82
6	Thickness expansion (%)	-65.95	-69.4	-94.20	-65.3	-72.9
7	Hardness (N)	2.460	1.520	1.210	1.43	1.98
	Colour values					
8	L*	53.50	57.30	60.34	60.2	56.57
9	a*	8.420	7.320	5.190	5.9	08.01
10	b*	37.40	36.42	35.64	37.4	41.35
11	ΔE	-21.93	-18.21	-13.08	-7.64	-9.23
	Sensory attributes					
12	Colour and appearance	2.6	2.4	2.5	2.4	8.2
13	Texture	2.7	3.0	3.5	2.7	7.36
14	Flavour	2.4	2.1	3.0	3.4	7.64

| 15 | Taste | 2.0 | 3.0 | 3.0 | 2.5 | 7.4 |
| 16 | Overall acceptability | 2.2 | 2.7 | 3.0 | 3.2 | 8.4 |

Table.F1.3 Fuzzy ranking of pre-treated vacuum fried raw banana chips

Treatments	Ranking of sensory attributes
P1	Texture = Taste > Flavour > OA = C&A
P2	Texture > Flavour > Taste > OA = C&A
P3	OA = Flavour = Texture > C&A > Taste
Control	OA = C&A > Texture = Flavour = Taste
Atm.raw	C&A > OA > Texture > Taste > Flavour

OA - Overall acceptability; C&A – Colour and appearance

APPENDIX – F2
Table. F2.1 Multi response optimisation constraints of experiment

SI. No.	Parameters	Goal	Lower limit	Upper limit
Pre-treatments – VFRaBC		in range	P1	P3
1	Oil content	Minimise	7.5	40.87
2	Moisture content	Minimise	0.5	1.0
3	Water activity	Minimise	0.15	0.3
4	Bulk density	Minimise	0.3	1.2
5	True density	Minimise	0.54	2.43
7	Thickness expansion	Maximise	-63.7	-68.98
8	L^*	Maximise	55.3	65.84
9	a^*	Maximise	5.1	6.84
10	b^*	Maximise	32.5	43.6
11	ΔE	In range	-3.64	-45.2
12	Texture	Minimise	1.12	2.54

Pre-treatments – VFRBC		in range	RP1	RP3
13	Oil content	Minimise	12.5	32.6
14	Moisture content	Minimise	0.5	1.2
15	Water activity	Minimise	0.15	0.32
16	Bulk density	Minimise	0.3	1.2
17	True density	Minimise	0.54	2.43
19	Thickness expansion	Maximise	-70.4	-80.53
20	L^*	Maximise	45.3	65.78
21	a^*	Maximise	6.74	11.64
22	b^*	Maximise	33.6	45.28
23	Yellowness Index	Maximise	95.3	105.85
24	ΔE	Minimise	-5.35	-30.6
25	Texture	Minimise	1.56	3.28

APPENDIX – F3

ANOVA Tables for the quality paramters of vacuum fried raw banana chips

Table. F3.1				Oil content			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3749.90	4	1249.97	45698.44	< 0.0001	0.17	0.75
Factor - A	3749.90	4	1249.97	45698.44	< 0.0001		
Pure error	0.44	21	0.027				
Cor total	3750.34	20		*			

Table. F3.2   **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.43	4	0.14	1705.97	< 0.0001	9.141E-003	1.30
Factor - A	0.43	4	0.14	1705.97	< 0.0001		
Pure error	1.337E-003	21	8.355E-005				
Cor total	0.43	20		*			

Table. F3.3   **Water activity (a_w)**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1.432E-003	4	4.773E-004	185.34	< 0.0001	1.605E-003	0.73
Factor - A	1.432E-003	4	4.773E-004	185.34	< 0.0001		
Pure error	4.120E-005	21	2.575E-006				
Cor total	1.473E-003	20	*				

Table. F3.4   **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.82	4	0.27	10099.06	< 0.0001	5.196E-003	0.67
Factor - A	0.82	4	0.27	10099.06	< 0.0001		
Pure error	4.320E-004	21	2.700E-005				
Cor total	0.82	20		*			

Table. F3.5   **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)

Model	0.11	4	0.037	156.46	< 0.0001	0.015	0.99
Factor - A	0.11	4	0.037	156.46	< 0.0001		
Pure error	3.800E-003	21	2.375E-004				
Cor total	0.12	20		*			

Table. F3.6   **Porosity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.30	4	0.099	911.30	< 0.0001	0.010	2.09
Factor - A	0.30	4	0.099	911.30	< 0.0001		
Pure error	1.743E-003	21	1.089E-004				
Cor total	0.30	20		*			

Table. F3.7   **Thickness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2517.89	4	839.30	19654.39	< 0.0001	0.21	0.27
Factor - A	2517.89	4	839.30	19654.39	< 0.0001		
Pure error	0.68	21	0.043				
Cor total	2518.58	20		*			

Table. F3.8   **L***

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	400.75	4	133.58	4218.01	< 0.0001	0.18	0.31
Factor - A	400.75	4	133.58	4218.01	< 0.0001		
Pure error	0.51	21	0.032				
Cor total	401.26	20		*			

Table. F3.9 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5.12	4	1.71	651.64	< 0.0001	0.051	0.66
Factor - A	5.12	4	1.71	651.64	< 0.0001		
Pure error	0.042	21	2.620E-003				
Cor total	5.16	20	*				

Table. F3.10 b^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	97.17	4	32.39	1085.02	< 0.0001	0.17	0.45
Factor - A	97.17	4	32.39	1085.02	< 0.0001		
Pure error	0.48	21	0.030				
Cor total	97.65	20	*				

Table. F3.11 ΔE

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	7884.80	4	2628.27	1.32	< 0.0001	44.69	16.57
Factor - A	7884.80	4	2628.27	1.32	< 0.0001		
Pure error	31949.84	21	1996.87				
Cor total	39834.64	20	*				

Table. F3.12 Texture

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	4.46	4	1.49	1461.73	< 0.0001	0.032	1.92
Factor - A	4.46	4	1.49	1461.73	< 0.0001		
Pure error	0.016	21	1.018E-003				
Cor total	4.48	20	*				

ANOVA Tables for the quality paramters of vacuum fried ripened banana chips

Table. F4.1 — **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3800.17	4	1266.72	38720.60	< 0.0001	0.18	0.71
Factor - A	3800.17	4	1266.72	38720.60	< 0.0001		
Pure error	0.52	21	0.033				
Cor total	3800.70	20		*			

Table. F4.2 — **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.88	4	0.29	42.39	< 0.0001	0.083	8.39
Factor - A	0.88	4	0.29	42.39	< 0.0001		
Pure error	0.11	21	6.941E-003				
Cor total	0.99	20		*			

Table. F4.3 — **Water activity (a_w)**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.037	4	0.012	137.56	< 0.0001	9.425E-003	3.91
Factor - A	0.037	4	0.012	137.56	< 0.0001		
Pure error	1.421E-003	21	8.882E-005				
Cor total	0.038	20	*				

Table. F4.4 — **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)

Model	1.16	4	0.39	4905.95	< 0.0001	8.890E-003	1.29
Factor - A	1.16	4	0.39	4905.95	< 0.0001		
Pure error	1.264E-003	21	7.903E-005				
Cor total	1.16	20		*			

Table. F4.5   **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.67	4	0.22	151.98	< 0.0001	0.038	2.25
Factor - A	0.67	4	0.22	151.98	< 0.0001		
Pure error	0.023	21	1.467E-003				
Cor total	0.69	20		*			

Table. F4.6   **Porosity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.72	4	0.24	70885.29	< 0.0001	1.846E-003	0.32
Factor - A	0.72	4	0.24	70885.29	< 0.0001		
Pure error	5.451E-005	21	3.407E-006				
Cor total	0.72	20		*			

Table. F4.7   **Thickness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	32324.83	4	10774.94	4885.28	< 0.0001	1.49	1.53
Factor - A	32324.83	4	10774.94	4885.28	< 0.0001		
Pure error	35.29	21	2.21				
Cor total	32360.12	20		*			

Table. F4.8 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	453.68	4	151.23	3088.46	< 0.0001	0.22	0.39
Factor - A	453.68	4	151.23	3088.46	< 0.0001		
Pure error	0.78	21	0.049				
Cor total	454.46	20		*			

Table. F4.9 a^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	122.13	4	40.71	1571.71	< 0.0001	0.16	1.48
Factor - A	122.13	4	40.71	1571.71	< 0.0001		
Pure error	0.41	21	0.026				
Cor total	122.55	20		*			

Table. F4.10 b^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	267.88	4	89.29	150.12	< 0.0001	0.77	1.69
Factor - A	267.88	4	89.29	150.12	< 0.0001		
Pure error	277.40	21	277.40				
Cor total	887.97	20		*			

Table. F4.11 ΔE

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	658.55	4	219.52	171.71	< 0.0001	1.13	13.43
Factor - A	658.55	4	219.52	171.71	< 0.0001		
Pure error	20.45	21	1.28				

Cor total	679.01	20		*			

Table. F4.12 **Yellowness index**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2106.15	4	702.05	28675.60	< 0.0001	0.16	0.13
Factor - A	2106.15	4	702.05	28675.60	< 0.0001		
Pure error	0.39	21	0.024				
Cor total	2106.54	20		*			

Table. F4.12 **Texture**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	13.32	4	4.44	692.92	< 0.0001	0.08	3.91
Factor - A	13.32	4	4.44	692.92	< 0.0001		
Pure error	0.10	21	6.407E-003				
Cor total	13.42	20		*			

- Significant

APPENDIX – G1

Table.G1.1 Treatment details for optimisation of process paramter

S.No	Treatments		Temperature (°C)	Pressure (kPa)	Time (min)
	VF-raw	**VF-ripe**			
1	T1	RT1	130	18	13
2	T2	RT2	105	18	13
3	T3	RT3	90	10	16
4	T4	RT4	80	18	13
5	T5	RT5	105	18	13
6	T6	RT6	105	18	8
7	T7	RT7	105	6	13
8	T8	RT8	120	10	16
9	T9	RT9	90	10	10
10	T10	RT10	105	18	13
11	T11	RT11	120	10	10
12	T12	RT12	105	18	13
13	T13	RT13	105	30	13
14	T14	RT14	120	25	10
15	T15	RT15	90	25	10
16	T16	RT16	90	25	13
17	T17	RT17	105	18	18
18	T18	RT18	105	18	13
19	T19	RT19	105	18	13
20	T20	RT20	120	25	16

Table.G1.2 Properties of VF-raw under different processing conditions

Treatments	Oil content (%)	Moisture content (%)	Water activity a_w	Bulk density (g/cm^3)	True density (g/cm^3)	Thickness expansion (%)	Hardness (N)	Energy content (kJ/100g)
T1	15.35	0.364	0.21	0.742	1.63	-72.43	4.67	1491.5
T2	10.63	0.753	0.21	0.394	1.32	-65.8	1.46	1333.6
T3	8.64	1.563	0.45	0.632	1.46	-47.3	2.21	1238.3
T4	4.36	4.942	0.62	0.794	1.74	-38.5	2.95	1095.3
T5	10.21	0.784	0.21	0.432	1.14	-63.2	1.53	1299.2
T6	9.53	1.124	0.31	0.493	1.28	-64.3	1.44	1284.9
T7	10.46	0.683	0.2	0.362	1.23	-65.7	1.52	1326.7
T8	13.27	0.534	0.2	0.653	1.56	-68.4	2.24	1424.1
T9	5.72	2.425	0.42	0.652	1.43	-46.3	1.95	1144.1
T10	10.36	0.724	0.2	0.412	1.14	-65.3	1.64	1303
T11	12.36	0.645	0.2	0.698	1.54	-67.8	2.12	1396.1
T12	10.35	0.741	0.2	0.386	1.02	-63.6	1.63	1304.6

T13	10.75	1.231	0.34	0.405	1.23	-62.4	1.46	1332.9
T14	12.6	0.721	0.2	0.496	1.51	-67.3	2.15	1391.1
T15	5.63	2.953	0.45	0.682	1.57	-45.2	1.95	1124
T16	8.26	2.567	0.42	0.713	1.36	-47.2	1.98	1222.3
T17	11.74	0.638	0.2	0.387	1.23	-64.6	1.63	1365
T18	10.34	0.851	0.2	0.425	1.23	-63.5	1.57	1304
T19	9.35	0.846	0.2	0.396	1.12	-63.2	1.54	1278
T20	13.78	0.624	0.2	0.667	1.56	-68.3	2.24	1451.7

Table. G1.2 Changes in colour values and sensory attributes of VF-raw under different processing conditions

Treatments	L^*	a^*	b^*	ΔE	Colour & appearance	Texture	Flavour	Taste	Overall acceptability
T1	53.15	8.96	38.49	-20.65	3.4	2.7	2.8	3.2	2.6
T2	58.3	5.11	35.7	-22.14	2.5	2.5	2.6	3.5	2.4
T3	59.74	4.63	32.51	-24.37	2.6	2.3	3.2	3.6	3.2
T4	60.02	3.24	30.43	-27.56	2.4	2.8	2.4	3.4	3.5

T5	58.28	5.12	35.42	-22.43	2.3	2.6	3.1	3.6	3.5
T6	58.86	5.75	32.3	-24.34	2.0	2.5	2.5	3.2	2.6
T7	59.56	5.36	35.34	-20.99	2.5	3.1	2.6	3.4	3.6
T8	54.64	6.74	36.63	-23.24	2.7	3.4	3.5	2.5	3.2
T9	59.45	4.68	32.34	-24.78	2.4	2.6	3.2	2.8	2.5
T10	57.65	5.23	35.35	-23.02	2.5	2.3	3.7	2.4	2.4
T11	58.32	6.12	38.42	-18.39	3.2	2.7	2.5	3.5	2.3
T12	57.6	5.52	35.29	-22.84	3.0	3.2	2.4	3.2	3.5
T13	56.03	5.86	35.63	-23.73	2.8	2.6	2.4	2.6	3.4
T14	57.61	6.32	36.41	-20.91	3.4	3.0	2.3	2.7	3.6
T15	59.21	4.36	32.15	-25.53	2.6	3.6	2.7	2.5	3.4
T16	59.16	4.63	32.2	-25.26	2.8	3.2	2.0	2.6	3.3
T17	57.64	5.96	35.65	-22	2.5	2.8	3.2	2.3	3.6
T18	58.67	5.37	35.24	-21.97	3.1	2.7	3.4	2.5	3.2
T19	58.32	5.32	35.07	-22.54	2.6	2.5	2.4	2.6	2.6
T20	56.73	6.53	37.56	-20.43	2.4	2.6	2.5	2.3	2.1

Table. G2.1 Multi response optimisation constraints of experiment

SI. No.	Parameters	Goal	Lower limit	Upper limit
Process parameters - VF-raw		**in range**	**T1**	**T20**
1	Oil content	Minimise	7.3	15.87
2	Moisture content	Minimise	0.5	2.8
3	Water activity	Minimise	0.15	0.32
4	Bulk density	Minimise	0.3	1.2
5	True density	Minimise	0.54	2.43
6	Thickness	Maximise	-63.7	-68.98
7	L^*	Maximise	55.3	65.84
8	a^*	Maximise	5.1	6.84
9	b^*	Maximise	32.5	43.6
10	ΔE	In range	-3.64	-45.2
11	Texture	Minimise	1.12	2.54
Process paramters - VF-ripe		**in range**	**RT1**	**RT20**
12	Oil content	Minimise	12.5	32.6
13	Moisture content	Minimise	0.5	1.2
14	Water activity	Minimise	0.15	0.32
15	Bulk density	Minimise	0.3	1.2
16	True density	Minimise	0.54	2.43

17	Thickness	Maximise	-70.4	-80.53
18	L^*	Maximise	45.3	65.78
19	a^*	Maximise	6.74	11.64
20	b^*	Maximise	33.6	45.28
21	Yellowness Index	Maximise	95.3	105.85
22	ΔE	Minimise	-5.35	-30.6
23	Texture	Minimise	1.56	3.28

ANOVA for Response surface quadratic model – VF - raw

Table. G3.1 | Oil content

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	140.15	3	46.72	167.71	< 0.0001	0.49	3.66
A -temperature	130.66	1	130.66	469.06	< 0.0001		
B- pressure	0.043	1	0.043	0.15	0.6991		
C- time	9.44	1	9.44	33.90	< 0.0001		
Residual	4.46	16	0.28				
Lack of fit	3.48	11	0.32	1.62	0.3094	**	
Pure error	0.97	5	0.19				
Cor total	144.61	19			*		

Table. G3.2 | Moisture content

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	23.24	9	2.58	29.06	< 0.0001	0.30	23.19
A -temperature	15.79	1	15.79	177.65	< 0.0001		
B- pressure	0.50	1	0.50	5.65	0.0387		
C- time	0.38	1	0.38	4.26	0.0660		
AB	0.23	1	0.23	2.62	0.1363		
AC	0.14	1	0.14	1.52	0.2456		
BC	0.030	1	0.030	0.34	0.5740		
A^2	6.15	1	6.15	69.24	< 0.0001		
B^2	0.042	1	0.042	0.47	0.5088		
C^2	0.010	1	0.010	0.12	0.7388		
Residual	0.89	10	0.089				
Lack of fit	0.83	5	0.17	14.94	0.0050	**	

Source	Sum of squares	df	Mean square				
Pure error	0.056	5	0.011				
Cor total	24.13	19				*	

Table. G3.3				**Water activity**			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.26	9	0.029	17.73	< 0.0001	0.040	13.85
A -temperature	0.17	1	0.17	106.38	< 0.0001		
B- pressure	2.254	1	2.254	1.39	0.2660		
C- time	4.395	1	4.395	2.71	0.1309		
AB	4.500	1	4.500	0.28	0.6101		
AC	4.500	1	4.500	0.28	0.6101		
BC	0.000	1	0.000	0.000	1.0000		
A^2	0.077	1	0.077	47.30	< 0.0001		
B^2	4.773	1	4.773	2.94	0.1172		
C^2	2.397	1	2.397	1.48	0.2523		
Residual	0.016	10	1.624E-003				
Lack of fit	0.012	5	2.408	2.87	0.8363	**	
Pure error	4.200	5	8.400E-004				
Cor total	0.32	19			*		

Table. G3.4				**Bulk density**			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.36	9	0.040	9.34	0.0008	0.065	12.25
A -temperature	*9.30*	*1*	9.30	2.19	0.1693		
B- pressure	*8.649*	*1*	8.649	0.20	0.6612		
C- time	*1.545*	*1*	1.545	0.36	0.5595		
AB	*0.020*	*1*	0.020	4.79	0.0535		

AC	*1.513*	*1*	1.513	3.567	0.9536		
BC	*3.321*	*1*	3.321	0.78	0.3969		
A^2	*0.32*	*1*	0.32	74.62	< 0.0001		
B^2	*2.155*	*1*	2.155	0.51	0.4922		
C^2	*0.015*	*1*	0.015	3.53	0.0899		
Residual	0.042	10	4.240				
Lack of fit	*0.041*	*5*	8.139	23.89	0.8617	**	
Pure error	*1.703*	*5*	3.407E-004				
Cor total	0.40	19			*		

Table. G3.5 — **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.46	9	0.051	5.21	0.0083	0.099	7.66
A -temperature	0.17	1	0.17	17.06	0.0020		
B- pressure	2.643	1	2.643	0.27	0.6140		
C- time	2.758	1	2.758	0.28	0.6065		
AB	9.112	1	9.112	0.93	0.3566		
AC	7.813	1	7.813	0.80	0.3919		
BC	5.512	1	5.512	0.57	0.4695		
A^2	0.24	1	0.24	24.42	0.0006		
B^2	0.021	1	0.021	2.18	0.1707		
C^2	0.032	1	0.032	3.30	0.0994		
Residual	0.098	10	9.755				
Lack of fit	0.032	5	6.481	0.50	0.7691	**	
Pure error	0.065	5	0.013				
Cor total	0.55	19			*		

Table. G3.6 — **Thickness expansion**

Source	Sum of	df	Mean	F value	p-value	Std.	C.V (%)

	squares		square		prob>F	Dev.	
Model	1254.51	3	418.17	26.55	< 0.0001	4.37	6.49
A -temperature	1234.87	1	1234.87	78.41	< 0.0001		
B- pressure	15.08	1	15.08	0.96	0.3424		
C- time	4.56	1	4.56	0.29	0.5977		
Residual	251.99	16	15.75				
Lack of fit	245.43	11	22.31	17.01	0.0029	**	
Pure error	6.56	5	1.31				
Cor total	1506.50	19			*		

L^* value

Table. G3.7

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	47.39	9	5.27	5.58	0.0064	0.97	1.68
A -temperature	34.84	1	34.84	36.90	0.0001		
B- pressure	2.12	1	2.12	2.24	0.1652		
C- time	2.97	1	2.97	3.15	0.1064		
AB	0.61	1	0.61	0.64	0.4421		
AC	2.88	1	2.88	3.05	0.1113		
BC	0.76	1	0.76	0.80	0.3918		
A^2	2.57	1	2.57	2.72	0.1303		
B^2	4.933E-004	1	4.933E-004	5.223E-004	0.9822		
C^2	0.40	1	0.40	0.42	0.5296		
Residual	9.44	10	0.94				
Lack of fit	8.55	5	1.71	9.61	0.0133	**	
Pure error	0.89	5	0.18				
Cor total	56.83	19			*		

Table. G3.8				a* value			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	22.23	9	2.47	8.84	0.0011	0.97	1.68
A -temperature	21.24	1	21.24	75.97	< 0.0001		
B- pressure	0.019	1	0.019	0.068	0.7990		
C- time	0.14	1	0.14	0.52	0.4891		
AB	0.012	1	0.012	0.043	0.8399		
AC	0.047	1	0.047	0.17	0.6919		
BC	1.012	1	1.012	3.622	0.9532		
A^2	0.63	1	0.63	2.24	0.1653		
B^2	0.018	1	0.018	0.064	0.8054		
C^2	0.21	1	0.21	0.77	0.4022		
Residual	2.80	10	0.28				
Lack of fit	2.67	5	0.53	21.49	0.0022	**	
Pure error	0.12	5	0.025				
Cor total	25.03	19			*		

Table. G3.9				b* value			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	88.76	9	9.86	18.17	< 0.0001	0.74	2.11
A -temperature	81.56	1	81.56	150.30	< 0.0001		
B- pressure	0.087	1	0.087	0.16	0.6967		
C- time	1.99	1	1.99	3.67	0.0845		
AB	0.042	1	0.042	0.077	0.7864		
AC	0.092	1	0.092	0.17	0.6885		
BC	0.99	1	0.99	1.83	0.2057		
A^2	1.09	1	1.09	2.01	0.1871		

B^2	0.11	1	0.11	0.20	0.6615		
C^2	2.87	1	2.87	5.29	0.0443		
Residual	5.43	10	0.54				
Lack of fit	5.21	5	1.04	23.52	0.0017	**	
Pure error	0.22	5	0.044				
Cor total	4.18	19			*		

Table. G3.10 — ΔE^* **value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	73.60	9	8.18	7.53	0.0020	1.04	4.56
A -temperature	59.86	1	59.86	55.09	< 0.0001		
B- pressure	2.60	1	2.60	2.39	0.1530		
C- time	4.409E-003	1	4.409E-003	4.058E-003	0.9505		
AB	0.47	1	0.47	0.43	0.5275		
AC	3.19	1	3.19	2.93	0.1175		
BC	3.37	1	3.37	3.10	0.1088		
A^2	3.44	1	3.44	3.16	0.1057		
B^2	0.24	1	0.24	0.22	0.6495		
C^2	0.36	1	0.36	0.33	0.5783		
Residual	10.86	10	1.09				
Lack of fit	10.06	5	2.01	12.54	0.0074	**	
Pure error	0.80	5	0.16				
Cor total	84.47	19			*		

Table. G3.11 — **Hardness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	9.59	9	1.07	13.53	0.0002	0.28	14.07
A -temperature	0.92	1	0.92	11.73	0.0065		

	6.630	1	6.630	0.084	0.7776		
B- pressure	6.630	1	6.630	0.084	0.7776		
C- time	0.049	1	0.049	0.62	0.4477		
AB	8.450	1	8.450	0.11	0.7500		
AC	8.000	1	8.000	0.010	0.9217		
BC	8.450	1	8.450	0.11	0.7500		
A^2	8.09	1	8.09	102.70	< 0.0001		
B^2	0.073	1	0.073	0.92	0.3589		
C^2	0.044	1	0.044	0.56	0.4726		
Residual	0.79	10	0.079				
Lack of fit	0.76	5	0.15	33.72	0.0007	**	
Pure error	0.023	5	4.537E-003				
Cor total	10.38	19			*		

Table. G3.12   **Energy content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2.002	3	1.58	159.87	< 0.0001	2.43	1.56
A - temperature	1.875	1	1.875	449.27	< 0.0001		
B- pressure	0.65	1	0.65	1.546	0.9691		
C- time	12659.53	1	12659.53	30.33	< 0.0001		
Residual	6678.68	16	417.42				
Lack of fit	5111.05	11	464.64	1.48	0.3486	**	
Pure error	1567.63	5	313.53				
Cor total	2.069E+005	19			*		

APPENDIX – G4

ANOVA for Response surface quadratic model – VF - ripe

Table. G4.1   **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	140.35	3	46.78	143.84	< 0.0001	0.34	4.88
A -temperature	135.12	1	135.12	415.46	< 0.0001		
B- pressure	0.056	1	0.056	0.17	0.6846		
C- time	5.17	1	5.17	15.90	0.0011		
Residual	5.20	16	0.33	5.20			
Lack of fit	3.82	11	0.35	1.26	0.4254	**	
Pure error	1.38	5	0.28				
Cor total	145.55	19			*		

Table. G4.2   **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	28.90	9	3.21	23.22	< 0.0001	0.37	25.68
A -temperature	19.37	1	19.37	140.05	< 0.0001		
B- pressure	0.57	1	0.57	4.11	0.0700		
C- time	0.43	1	0.43	3.10	0.1089		
AB	0.24	1	0.24	1.74	0.2161		
AC	0.17	1	0.17	1.20	0.2987		
BC	0.015	1	0.015	0.11	0.7525		
A^2	8.06	1	8.06	58.26	< 0.0001		
B^2	0.015	1	0.015	0.11	0.7460		
C^2	6.982E-003	1	6.982E-003	0.050	0.8267		
Residual	1.38	10	0.14				
Lack of fit	1.36	5	0.27	65.95	0.1241	**	
Pure error	0.021	5	4.131E-003				
Cor total	30.29	19			*		

Table. G4.3   **Water activity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.30	9	0.034	31.42	< 0.0001	0.033	10.98
A -temperature	0.20	1	0.20	189.46	< 0.0001		
B- pressure	5.842E-003	1	5.842E-003	5.42	0.0421		
C- time	7.803	1	7.803	7.25	0.0226		
AB	9.112	1	9.112	0.085	0.7771		
AC	1.540	1	1.540	1.43	0.2593		
BC	4.96	1	4.96	0.46	0.5127		
A^2	0.077	1	0.077	71.64	< 0.0001		
B^2	0.012	1	0.012	10.82	0.0082		
C^2	4.582	1	4.582	4.26	0.0661		
Residual	0.011	10	1.077				
Lack of fit	8.468	5	1.69	3.68	0.0895	**	
Pure error	2.301	5	4.602E-004				
Cor total	0.32	19			*		

Table. G4.4   **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.38	9	0.043	4.94	0.0100	0.093	16.23
A -temperature	0.17	1	0.17	19.16	0.0014		
B- pressure	3.500	1	3.500	0.40	0.5389		
C- time	5.254	1	5.254	0.61	0.4537		
AB	8.778	1	8.778	1.02	0.3374		
AC	3.081	1	3.081	0.36	0.5638		
BC	6.613	1	6.613	7.649	0.9320		
A^2	0.19	1	0.19	22.20	0.0008		

B^2	1.222	1	1.222	1.413	0.9708	
C^2	0.011	1	0.011	1.23	0.2930	
Residual	0.086	10	8.645			
Lack of fit	0.039	5	7.727	0.81	0.5896	**
Pure error	0.048	5	9.563E-003			
Cor total	0.47	19			*	

Table. G4.5 — True density

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.45	9	0.050	5.40	0.0073	0.096	6.23
A - temperature	1.966	1	1.966	0.021	0.8870		
B- pressure	0.012	1	0.012	1.31	0.2795		
C- time	6.673	1	6.673	7.216	0.9791		
AB	8.00	1	8.00	0.087	0.7747		
AC	4.05	1	4.05	0.44	0.5231		
BC	0.013	1	0.013	1.38	0.2666		
A^2	0.40	1	0.40	43.61	< 0.0001		
B^2	0.023	1	0.023	2.49	0.1453		
C^2	0.025	1	0.025	2.72	0.1301		
Residual	0.092	10	9.247E-003.755				
Lack of fit	0.084	5	0.017	9.41	0.9140	**	
Pure error	8.883E-003	5	1.777E-003				
Cor total	0.54	19			*		

Table. G4.6 — Thickness expansion

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2023.96	3	674.65	21.78	< 0.0001	5.57	7.89

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
A -temperature	2022.85	1	2022.85	65.30	< 0.0001		
B- pressure	0.20	1	0.20	6.485E-003	0.9368		
C- time	0.91	1	0.91	0.030	0.8657		
Residual	495.67	16	30.98				
Lack of fit	477.80	11	43.44	12.15	0.0064	**	
Pure error	17.87	5	3.57				
Cor total	2519.63	19			*		

Table. G4.7 L^* **value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	565.04	9	62.78	5.61	0.0063	3.35	6.23
A -temperature	363.01	1	363.01	32.43	0.0002		
B- pressure	0.20	1	0.20	0.018	0.8952		
C- time	15.34	1	15.34	1.37	0.2689		
AB	0.034	1	0.034	3.019	0.9573		
AC	0.44	1	0.44	0.039	0.8465		
BC	0.051	1	0.051	4.573	0.9474		
A^2	176.92	1	176.92	15.80	0.0026		
B^2	18.45	1	18.45	1.65	0.2282		
C^2	1.61	1	1.61	0.14	0.7125		
Residual	111.95	10	11.20				
Lack of fit	71.69	5	14.34	1.78	0.2710	**	
Pure error	40.26	5	8.05				
Cor total	676.99	19			*		

Table. G4.8 a^* **value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	61.97	13	4.77	1.98	0.0002	1.36	10.80

Source	Sum of squares	df	Mean square	F value	p-value prob>F		
A -temperature	9.99	1	9.99	4.15	0.0002		
B- pressure	1.67	1	1.67	0.70	0.4364		
C- time	0.026	1	0.026	0.011	0.9200		
AB	0.54	1	0.54	0.22	0.6524		
AC	9.800	1	9.800	4.068	0.9512		
BC	0.33	1	0.33	0.14	0.7248		
A^2	7.68	1	7.68	3.19	0.1244		
B^2	6.61	1	6.61	2.74	0.1488		
C^2	4.010	1	4.010	1.665	0.9901		
Residual	18.62	10	1.86				
Lack of fit	11.64	5	2.33	1.67	0.2938	**	
Pure error	6.97	5	1.39				
Cor total	76.43	19			*		

Table. G4.9				b^* value			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	88.76	9	9.86	18.17	< 0.0001	0.74	2.11
A -temperature	81.56	1	81.56	150.30	< 0.0001		
B- pressure	0.087	1	0.087	0.16	0.6967		
C- time	1.99	1	1.99	3.67	0.0845		
AB	0.042	1	0.042	0.077	0.7864		
AC	0.092	1	0.092	0.17	0.6885		
BC	0.99	1	0.99	1.83	0.2057		
A^2	1.09	1	1.09	2.01	0.1871		
B^2	0.11	1	0.11	0.20	0.6615		
C^2	2.87	1	2.87	5.29	0.0443		
Residual	5.43	10	0.54				
Lack of fit	5.21	5	1.04	23.52	0.0017	**	

Pure error	0.22	5	0.044				
Cor total	4.18	19			*		

Table. G4.10 — ΔE^* **value**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	73.60	9	8.18	7.53	0.0020	1.04	4.56
A -temperature	59.86	1	59.86	55.09	< 0.0001		
B- pressure	2.60	1	2.60	2.39	0.1530		
C- time	4.409	1	4.409	4.058	0.9505		
AB	0.47	1	0.47	0.43	0.5275		
AC	3.19	1	3.19	2.93	0.1175		
BC	3.37	1	3.37	3.10	0.1088		
A^2	3.44	1	3.44	3.16	0.1057		
B^2	0.24	1	0.24	0.22	0.6495		
C^2	0.36	1	0.36	0.33	0.5783		
Residual	10.86	10	1.09				
Lack of fit	10.06	5	2.01	12.54	0.0074	**	
Pure error	0.80	5	0.16				
Cor total	84.47	19			*		

Table. G4.11 — **Yellowness Index**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	2945.34	9	327.26	5.72	< 0.0001	0.56	6.34
A -temperature	1046.67	1	1046.67	18.30	0.0016		
B- pressure	17.06	1	17.06	0.30	0.5970		
C- time	6.853	1	6.853	1.198	0.9915		
AB	3.00	1	3.00	0.052	0.8235		
AC	0.15	1	0.15	2.644	0.9600		

BC	3.51	1	3.51	0.061	0.8093		
A^2	1849.03	1	1849.03	32.32	0.0002		
B^2	20.92	1	20.92	0.37	0.5588		
C^2	87.09	1	87.09	1.52	0.2455		
Residual	572.10	10	57.21				
Lack of fit	475.37	5	95.07	4.91	0.527	**	
Pure error	96.73	5	19.35				
Cor total	17.45	19			*		

Table. G4.12			**Energy content**				
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1.988	3	8.45	258.31	< 0.0001	0.28	14.07
A -temperature	1.916	1	1.916	6.81	< 0.0001		
B- pressure	166.20	1	166.20	0.65	0.4327		
C- time	7046.68	1	7046.68	27.47	< 0.0001		
Residual	4104.75	16	256.55				
Lack of fit	4026.24	11	366.02	23.31	0.4123	**	
Pure error	78.50	5	15.70				
Cor total	2.029	19			*		

Table. G4.13			**Acrylamide content**				
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	46.71	5	9069.34	1.982	< 0.0001	00.34	44.02
A -temperature	220.93	1	220.93	18.13	0.0017		
B- pressure	5.42	1	5.42	0.043	0.0097		
C- time	5.85	1	5.85	0.061	0.0002		
AB	2.98	1	2.98	0.078	0.0059		
AC	9.26	1	9.26	0.068	0.0093		

BC	365.31	1	365.31	0.081	0.7823		
A^2	18.39	1	18.39	13.15	0.0046		
B^2	5.21	1	5.21	0.36	0.0015		
C^2	5.14	1	5.14	0.43	0.0052		
Residual	346.94	10	34.69				
Lack of fit	1.516	9	841.20	3.71	0.0264	**	
Pure error	0.23	5	0.046				
Cor total	1.96	19			*		

Table. G4.14   **Hardness**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	9.59	9	1.07	13.53	0.0002	0.28	14.07
A -temperature	0.92	1	0.92	11.73	0.0065		
B- pressure	6.630	1	6.630	0.084	0.7776		
C- time	0.049x	1	0.049	0.62	0.4477		
AB	8.450	1	8.450	0.11	0.7500		
AC	8.000	1	8.000	0.010	0.9217		
BC	8.450	1	8.450	0.11	0.7500		
A^2	8.09	1	8.09	102.70	< 0.0001		
B^2	0.073	1	0.073	0.92	0.3589		
C^2	0.044	1	0.044	0.56	0.4726		
Residual	0.79	10	0.079				
Lack of fit	0.76	5	0.15	33.72	0.0007	**	
Pure error	0.023	5	4.537E-003				
Cor total	10.38	19			*		

- Significant ** Not Significant

ANOVA for Linear model – storage studies of VF - ripe

Table. H1.1 — **Oil content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.12	11	0.011	6.366E+007	< 0.0001	0.002	1.84
A -Product	0.12	7	0.017	6.366E+007	< 0.0001		
B-Time	0.000	4	0.000	0.000			
Residual	0.000	28	0.000				
Cor total	0.12	39			*		

Table. H1.2 — **Moisture content**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	73.10	11	6.65	977.38	< 0.0001	0.082	3.84
A -Product	0.34	7	0.049	7.25	< 0.0001		
B-Time	72.76	4	18.19	2675.10	< 0.0001		
Residual	0.19	28	6.800E-003				
Cor total	73.29	39			*		

Table. H1.3 — **Water activity**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.76	11	0.070	664.48	< 0.0001	0.010	2.66
A -Product	2.870	7	4.100	3.92	0.0043		
B-Time	0.76	4	0.19	1820.45	< 0.0001		
Residual	2.93	28	1.046E-004				
Cor total	73.29	39			*		

Table. H1.4 — **Bulk density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	0.55	11	0.050	640.30	< 0.0001	0.0134	1.63
A -Product	3.391	7	4.844	0.62	0.7322		
B-Time	0.76	4	0.19	1820.45	< 0.0001		
Residual	2.930	28	1.046E-004				
Cor total	73.29	39			*		

Table. H1.5   **True density**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	7.14	11	0.65	283.01	< 0.0001	0.048	2.68
A -Product	0.012	7	1.650E-003	0.72	0.6565		
B-Time	7.13	4	1.78	777.03	< 0.0001		
Residual	0.064	28	2.294E-003				
Cor total	7.20	39			*		

Table. H1.6   **Thickness Expansion**

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	104.78	11	9.53	39.62	< 0.0001	0.49	13.74
A -Product	67.02	7	9.57	39.82	< 0.0001		
B-Time	37.76	4	9.44	39.26	< 0.0001		
Residual	6.73	28	0.24				
Cor total	111.51	39			*		

Table. H1.7 L^*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	409.28	11	37.21	197.86	< 0.0001	0.43	0.76
A -Product	4.85	7	0.69	3.68	0.0061		
B-Time	404.43	4	101.11	537.68	< 0.0001		
Residual	5.27	28	0.19				

| Cor total | 414.55 | 39 | | | * | | |

Table. H1.8   a*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	108.26	11	9.84	100.27	< 0.0001	0.31	3.57
A -Product	0.80	7	0.11	1.16	0.3547		
B-Time	107.46	4	26.86	273.71	< 0.0001		
Residual	2.75	28	0.098				
Cor total	111.01	39			*		

Table. H1.8   b*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	860.79	11	78.25	248.05	< 0.0001	0.56	1.23
A -Product	1.00	7	0.14	0.45	0.8595		
B-Time	859.79	4	214.95	681.35	< 0.0001		
Residual	8.83	28	0.32				
Cor total	869.63	39			*		

Table. H1.9   Yellowness Index

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	97.13	11	1099.74	542.71	< 0.0001	0.56	1.23
A -Product	13.33	7	1.90	0.94	0.4923		
B-Time	83.80	4	3020.95	1490.81	< 0.0001		
Residual	56.74	28	2.03				
Cor total	53.87	39			*		

Table. H1.10   Hardness

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	183.83	11	16.71	2916.17	< 0.0001	0.076	1.78

A -Product	0.20	7	0.028	4.91	0.0010
B-Time	183.64	4	45.91	8010.87	< 0.0001
Residual	0.16	28	5.731E-003		
Cor total	3.99	39			*

Table. H1.11 Changes in colour values and sensory attributes of VF-ripe on Storage

Storage period days	Colour & appearance	Texture	Flavour	Taste	Overall acceptability
RT2
0	8.5	8.3	8.6	8.5	8.6
30	8.5	8.3	8.6	8.5	8.6
60	8.5	8.3	8.6	8.5	8.6
90	7.2	7.3	7.2	7	7.5
120	5.3	5.4	5.3	5.4	5.5
Control	6.2	6.4	6.2	6.4	6.2
RT5
0	8.5	8.3	8.6	8.5	8.5
30	8.5	8.3	8.6	8.5	8.5
60	8.5	8.3	8.6	8.5	8.5
90	7.4	7.3	7.1	7	7.4
120	5.3	5.2	5.2	5.0	5.4
Control	6.2	6.4	6.2	6.4	6.2
RT7
0	8.5	8.3	8.2	8.5	8.4
30	8.5	8.3	8.2	8.5	8.4

60	8.5	8.3	8.2	8.5	8.4
90	7.2	7.5	7.4	7.6	7.3
120	5.7	6.3	5.2	5.3	5.3
Control	6.2	6.4	6.2	6.4	6.2
RT10					
0	8.5	8.6	8.3	8.4	8.4
30	8.5	8.6	8.3	8.4	8.4
60	8.5	8.6	8.3	8.4	8.4
90	7.3	7.5	7.4	7.3	7.4
120	5.4	5.4	5.2	5.3	5.5
Control	6.2	6.4	6.2	6.4	6.2
RT12					
0	8.6	8.2	8.4	8.6	8.5
30	8.6	8.2	8.4	8.6	8.5
60	8.6	8.2	8.4	8.6	8.5
90	7.8	7.3	7.5	7.4	7.3
120	5.3	5.4	5.5	5.6	5.4
Control	6.2	6.4	6.2	6.4	6.2
RT13					
0	8.2	8.4	8.5	8.2	8.2
30	8.2	8.4	8.5	8.2	8.2
60	8.2	8.4	8.5	8.2	8.2
90	7.5	7.7	7.3	7.5	7.4
120	5.4	5.3	5.4	5.6	5.5
Control	6.2	6.4	6.2	6.4	6.2
RT18					

0	8.3	8.5	8.2	8.3	8.5
30	8.3	8.5	8.2	8.3	8.5
60	8.3	8.5	8.2	8.3	8.5
90	7.5	7.7	7.6	7.4	7.5
120	5.3	5.4	5.5	5.3	5.4
Control	6.2	6.4	6.2	6.4	6.2
RT19					
0	8.2	8.5	8.5	8.2	8.6
30	8.2	8.5	8.5	8.2	8.6
60	8.2	8.5	8.5	8.2	8.6
90	7.5	7.4	7.6	7.2	7.5
120	5.4	5.4	5.3	5.4	5.5
Control	6.2	6.4	6.2	6.4	6.2

Table. H1.12 Fuzzy ranking of stored VF-ripe

Storage period in days	Ranking of sensory attributes
RT2	
0	C&A = OA > Texture > Taste > Flavour
30	OA = C&A > Texture = Taste = Flavour
60	OA = Texture = Taste > C&A > Flavour
90	OA > C&A > Taste =Flavour = Texture
120	OA > C&A = Texture > Taste > Flavour
Control	OA = Taste > C&A = Texture > Flavour
RT5	
0	Texture > Taste = OA > C&A > Flavour
30	C&A > Texture > Taste > OA = Flavour
60	OA = Texture = Taste > Flavour = C&A
90	OA > C&A = Texture = Taste > Flavour
120	OA > C&A = Flavour >Texture = Taste
Control	OA =Flavour > Taste > C&A = Texture
RT7	
0	OA = C&A = Texture > Flavour > Taste

30	OA = C&A > Texture = Taste = Flavour
60	OA > Taste = Texture = Flavour C = &A
90	OA = C&A = Texture = Taste > Flavour
120	C&A = Texture > Flavour = Taste > OA
Control	OA > C&A = Texture = Taste > Flavour
RT10	
0	OA = C&A = Texture > Taste > Flavour
30	OA = C&A > Texture = Taste = Flavour
60	OA > Taste = C&A = Texture = Flavour
90	OA = C&A = Texture = Taste > Flavour
120	C&A = Texture = Taste > OA > Flavour
Control	OA > C&A = Texture = Taste > Flavour
RT12	
0	OA = C&A = Texture > Taste > Flavour
30	OA = C&A > Texture = Flavour = Taste
60	OA > Taste = C&A = Texture = Flavour
90	OA = C&A = Texture = Taste > Flavour
120	C&A = Texture = Flavour >Taste > OA
Control	OA > C&A = Flavour >Texture = Taste
RT13	
0	OA = C&A = Texture > Taste > Flavour
30	OA = C&A > Taste = Flavour =Texture
60	OA > Taste = C&A = Texture = Flavour
90	OA = C&A = Texture = Flavour > Taste
120	Taste > OA > Flavour= C&A = Texture
Control	OA > C&A = Texture = Taste > Flavour
RT18	
0	OA = C&A = Texture > Taste > Flavour
30	OA = C&A > Texture = Flavour =Taste
60	OA > Taste = C&A = Texture = Flavour
90	OA = C&A = > Flavour Texture = Taste
120	C&A = Texture >Flavour = Taste > OA
Control	OA > C&A = Taste = Texture > Flavour
RT19	
0	OA = C&A = Texture > Flavour >Taste
30	OA = C&A > Texture = Taste = Flavour
60	Flavour= OA > Taste = C&A = Texture
90	OA = C&A = Texture> Flavour = Taste
120	C&A = Texture = Taste > OA > Flavour
Control	OA > C&A >Flavour = Texture = Taste

Appendix - H2

ANOVA for Response Linear model – Blended oil on vacuum frying

Table. H2.1	Free fatty acid						
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5266.62	14	376.19	1808.30	< 0.0001	0.46	14.04
A -Product	5266.62	14	376.19	1808.30	< 0.0001		
Pure Error	6.24	30	0.21				
Cor total	72.86	44			*		

Table. H2.2	Peroxide value						
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	255.73	14	18.27	135.02	< 0.0001	0.37	25.42
A -Product	255.73	14	18.27	135.02	< 0.0001		
Pure Error	4.06	30	0.14				
Cor total	259.79	44			*		

Table. H2.3	p-Anisidine value						
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	223.52	14	15.97	56.18	< 0.0001	0.53	11.05
A -Product	223.52	14	15.97	56.18	< 0.0001		
Pure Error	8.53	30	0.28				
Cor total	232.05	44			*		

Table. H2.4	Total oxidation value						
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1338.43	14	95.60	177.76	< 0.0001	0.73	9.98
A -Product	1338.43	14	95.60	177.76	< 0.0001		
Pure Error	16.13	30	0.54				

| Cor total | 4.57 | 44 | | | * | | |

Table. H2.5				Iodine value			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	20.81	14	3715.77	3567.09	< 0.0001	1.02	1.53
A -Product	20.81	14	3715.77	3567.09	< 0.0001		
Pure Error	31.25	30	1.04				
Cor total	52.06	44			*		

Table. H2.6				Total polar compound			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	3502.74	14	250.20	616.28	< 0.0001	0.64	4.36
A -Product	3502.74	14	250.20	616.28	< 0.0001		
Pure Error	12.18	30	0.41				
Cor total	14.92	44			*		

Table. H2.7				Viscosity			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	5.69	14	0.41	28.08	< 0.0001	0.12	27.00
A -Product	5.69	14	0.41	28.08	< 0.0001		
Pure Error	0.43	30	0.014				
Cor total	6.12	44			*		

Table. H2.8				L*			
Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	1407.93	14	100.57	353.88	< 0.0001	0.53	3.95
A -Product	1407.93	14	100.57	353.88	< 0.0001		

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Pure Error	8.53	30	0.28				
Cor total	1416.45	44			*		

Table. H2.9 a*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	8.56	14	0.61	309.90	< 0.0001	0.044	8.23
A -Product	8.56	14	0.61	309.90	< 0.0001		
Pure Error	0.059	30	1.973E-003				
Cor total	8.62	44			*		

Table. H2.10 b*

Source	Sum of squares	df	Mean square	F value	p-value prob>F	Std. Dev.	C.V (%)
Model	57.05	14	4.07	361.17	< 0.0001	0.11	8.73
A -Product	57.05	14	4.07	361.17	< 0.0001		
Pure Error	0.34	30	0.011				
Cor total	57.39	44			*		

Abstract

DEVELOPMENT AND EVALUATION OF A VACUUM FRYING SYSTEM FOR BANANA CHIPS (*Musa spp.*)

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Frying is an indigenous cooking method. The deep fat frying produces crispy textured and tasty fruits and vegetable products with increased fat content. The property of oil and fried product gets degraded during deep fat frying. The vacuum frying could be an alternative technology that involves low frying temperature and pressure aids in reduced oil absorption in fried product and preserves the quality of frying oil. Accordingly an advanced vacuum frying system with dual chambers, oil storage and a frying chamber with de-oiling system was developed to produce vacuum fried raw and ripened banana chips. The developed vacuum frying system was batch type with product capacity of 12 kgh^{-1} and frying oil tank capacity of 30 l. The properties of the product and oil were evaluated and standardisation of process parameters was done with the developed vacuum frying system.

The oil blend (Rice bran and Palm oil) at 80:20 was identified as suitable frying oil with high oxidation and thermal stability among coconut, rice bran, palm, corn and blended oils. Effective de-oiling was attained with removal of 74.1 and 71.4% oil, respectively, in VF-raw and VF-ripe centrifuged at 1000 rpm for 5 min. The vacuum frying with de-oiling nullified the effect of pre-treatments like blanching cum drying, freezing and gum coating for the production of VF-raw and VF-ripe. The quality parameters like oil content, moisture content, energy, texture, bulk density, true density, colour values, thickness expansion and sensory acceptability of vacuum fried raw and ripened banana chips were evaluated at different processing conditions.

The processing conditions of vacuum frying at 105°C and 18 kPa for 13 min produced improved quality of VF-ripe with low oil content (13.35%), acrylamide content (122.8 µgkg^{-1}), moisture content (0.869%), water activity (0.21), L* (57.28) a* (12.23), b* (56.4), yellowness index (131.3) bulk density (0.453 gcm^{-3}), true density (1.38 gcm^{-3}), thickness expansion (-74%) and good organoleptic properties with high sensory score of 8.6. The process protocol for the production of VF-raw has to be improved to attain consumer acceptability.

The vacuum fried ripened banana chips processed at 105°C for 13 min, packed in 400 gauge LDPE with nitrogen flushed packaging showed good consumer acceptability upto 90 days of storage. After 90 days of storage, the products exhibited poor consumer acceptability due to reduced degree of crispness. The FFA value of the blended oil was within the acceptable limit upto 52 batches of frying at 105°C and 18 kPa for 13 min. The total polar compound of the blended oil increased from 9.5 to 15.7% after sixty batches which was within the safe level. The production cost formulated based on fixed and variable cost for per kg of vacuum fried raw and ripened banana chips was Rs.342/- and Rs.363/- respectively.