COMPARATIVE STUDY OF ATMOSPHERIC AND VACUUM DEEP FAT FRYING OF BANANA CHIPS (var. *Dwarf Cavendish*)

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DEPARTMENT OF AGRICULTURAL ENGINEERING

UNIVERSITY OF AGRICULTURAL SCIENCES

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Affectionately Dedicated to
My Beloved Parents

THIMMANNA
MANJULA

AND

My Chair person

Dr. V. PALANIMUTHU

DEPARTMENT OF AGRICULTURAL ENGINEERING
UNIVERSITY OF AGRICULTURAL SCIENCES
BENGALURU

CERTIFICATE

This is to certify that the thesis entitled **"COMPARATIVE STUDY OF ATMOSPHERIC AND VACUUM DEEP FAT FRYING OF BANANA CHIPS (var. *Dwarf Cavendish*)"** submitted in partial fulfilment of the requirements for the award of degree of **MASTERS OF TECHNOLOGY (Agricultural Engineering)** in **PROCESSING AND FOOD ENGINEERING** of the University of Agriculture Sciences, Bengaluru is a record of *bonafide* research work carried out by **Ms. SUREKHA, T., ID No. PALB 6347,** during the period of her study in the University under my guidance and supervision and no part of the thesis has been submitted for the award of any degree, diploma, associate-ship, fellowship or other similar titles.

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August, 2018 ***(SUREKHA, T.)***

COMPARATIVE STUDY OF ATMOSPHERIC AND VACUUM DEEP FAT FRYING OF BANANA CHIPS (var. *Dwarf Cavendish*)

SUREKHA, T.

ABSTRACT

Atmospheric and vacuum frying study of banana (var. *Dwarf Cavendish)* for production of banana chips was conducted. Physical properties of selected raw banana were: size-170±2 mm, diameter-26.42±2 mm, weight-116±5g, pulp-to-skin ratio-1.45±0.25%, skin thickness-4.7±0.2 mm and cutting strength-16,084±0.2 g_f. The edible raw pulp had: moisture-70.75%; TSS-3.1°B; acidity-1.62%; total sugar-1.24%; reducing sugars-0.61%, starch-21.24% and dry matter-29.25%. For chips production, fully matured, unripened banana was first manually peeled, cut into 2.5 mm thick slices, blanched and air dried for 10-15 minutes. Atmospheric deep fat frying was done at frying temperatures of 160, 180 and 200°C for 8, 9 and 10 minutes duration. Vacuum frying was done under vacuum levels of 640 and 400 mm Hg at frying temperatures of 80, 90 and 100°C for 15, 20, 25 and 30 minutes durations. Based on various quality parameters, best quality banana chips in atmospheric frying was obtained for frying @180°C for 9 minutes and in vacuum frying, it was obtained for frying under 400 mm Hg vacuum at 90°C for 25 minutes. The vacuum fried chips contained far less fat (24.82%) when compared to atmospheric fried chips (46.62%). Both atmospheric and vacuum fried banana chips were stored at ambient conditions for 2 months in polypropylene, LDPE and metalized multilayer polyethylene (MMP) packages with and without nitrogen gas flushing and MMP package with N_2 flushing was found to be good for banana chips storage. Production cost and Cost:Benefit Ratio for atmospheric and vacuum fried chips were – Rs.237.06 and 1:1.26; and Rs.295.03 and 1:1.69, respectively.

August, 2018

Department of Agricultural Engineering — **Dr. V. PALANIMUTHU**
UAS, GKVK, Bengaluru — Major Advisor

ಸಾಧಾರಣ ಮತ್ತು ನಿರ್ವಾತ (ವ್ಯಾಕ್ಯುಮ್) ವಾತಾವರಣದ ಒತ್ತಡದಲ್ಲಿ ಪಚ್ಚಬಾಳೆಕಾಯಿ (ತಳಿ. ಡ್ವಾರ್ಫ್ ಕ್ಯಾವೆಂಡಿಷ್) ಚಿಪ್ಸ್ ತಯಾರಿಕೆ – ಒಂದು ಹೋಲಿಕೆಯ ಅಧ್ಯಯನ

ಸುರೇಖ, ಟಿ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಬಾಳೆಕಾಯಿ ಚಿಪ್ಸ್ ಉತ್ಪಾದನೆಗೆ ಬಲಿತ ಪಚ್ಚಬಾಳೆಕಾಯನ್ನು (ತಳಿ. ಡ್ವಾರ್ಫ್ ಕ್ಯಾವೆಂಡಿಷ್) ಸಾಧಾರಣ ಮತ್ತು ನಿರ್ವಾತ (ವ್ಯಾಕ್ಯುಮ್) ವಾತಾವರಣದಲ್ಲಿ ಕರಿಯುವ ವಿಧಾನವನ್ನು ಅಳವಡಿಸಿ ಅಧ್ಯಯನ ಮಾಡಲಾಯಿತು. ಆಯ್ದ ಬಾಳೆಕಾಯಿಯ ಭೌತಿಕ ಗುಣಲಕ್ಷಣಗಳನ್ನು ನೋಡಿದಾಗ ಅದರ ಗಾತ್ರ–170±2 ಮಿಮೀ, ವ್ಯಾಸ–26.42±2 ಮಿಮೀ, ತೂಕ–116±5 ಗ್ರಾಂ, ತಿರುಳು–ಚರ್ಮದ ಅನುಪಾತ–1.45±0.25 ಶೇ., ಚರ್ಮದ ದಪ್ಪ–4.7±0.2 ಮಿಮೀ ಮತ್ತು ಕತ್ತರಿಸುವ ಶಕ್ತಿ–16,084±0.2 g$_f$. ಕಂಡುಬಂದಿತು. ಸುಲಿದ ಬಾಳೆಕಾಯಿಯ ತಿರುಳಿನಲ್ಲಿ ತೇವಾಂಶ–70.75ಶೇ.; ಟಿ.ಎಸ್,ಎಸ್–3.1 °ಬ್ರಿಕ್ಸ್; ಆಮ್ಲತೆ–1.62ಶೇ.; ಒಟ್ಟು ಸಕ್ಕರೆ–1.24ಶೇ.; ಅಪಕರ್ಷಕ ಸಕ್ಕರೆ–0.61ಶೇ. ; ಪಿಷ್ಟ–21.24ಶೇ. ಮತ್ತು ಒಣ ವಸ್ತುವಿನ ಅಂಶ–29.25ಶೇ. ಕಂಡುಬಂದಿತು. ಚಿಪ್ಸ್ ಉತ್ಪಾದನೆಗೆ, ಬಲಿತ ಬಾಳೆಕಾಯಿಯನ್ನು ಮೊಟ್ಟಮೊದಲನೆಯದಾಗಿ ಕೈಯಿಂದ ಸಿಪ್ಪೆಯನ್ನು ಸುಲಿದು, 2.5 ಮಿಮೀ. ದಪ್ಪನೆಯ ಹೋಳುಗಳಾನ್ನಾಗಿ ಕತ್ತರಿಸಿ, ಬ್ಲಾಂಚಿಂಗ್ ಮಾಡಿದ ನಂತರ 10-15 ನಿಮಿಷಗಳ ಕಾಲ ತೆರೆದ ಗಾಳಿಯಲ್ಲಿ ಒಣಗಿಸಲಾಯಿತು. ಸಾಧಾರಣ ವಾತಾವರಣ ಒತ್ತಡದಲ್ಲಿ ಕರಿಯುವ ಬಾಳೆಕಾಯಿ ಚಿಪ್ಸನ್ನು ಉತ್ಪಾದಿಸಲು ಉಷ್ಣಾಂಶಗಳಾದ 160, 180 ಮತ್ತು 200 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್ ಹಾಗೂ ಕರಿಯುವ ಸಮಯ 8, 9, ಮತ್ತು 10 ನಿಮಿಷಗಳ ಅವಧಿಯನ್ನು ಅಳವಡಿಸಲಾಯಿತು ಮತ್ತು ಚಿಪ್ಸನ್ನು ವ್ಯಾಕ್ಯುಮ್ ಫ್ರೈಯಿಂಗ್ ವಿಧಾನದಲ್ಲಿ ಉತ್ಪಾದಿಸಲು 640 ಮತ್ತು 400 ಮಿಮೀ ಎಚ್‌ಜಿ ನಿರ್ವಾತ ಒತ್ತಡಗಳು ಹಾಗೂ 80, 90, 100 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್ ಉಷ್ಣಾಂಶಗಳು ಮತ್ತು 15, 20, 25 ಹಾಗೂ 30 ನಿಮಿಷಗಳ ಕರಿಯುವ ಸಮಯವನ್ನು ಪರಿಗಣಿಸಲಾಯಿತು. ಚಿಪ್ಸ್‌ನ ವಿವಿಧ ಗುಣಮಟ್ಟವನ್ನು ಗಮನಿಸಿದಾಗ, ಸಾಧಾರಣ ವಾತಾವರಣ ಒತ್ತಡದಲ್ಲಿ ಕರಿಯುವಿಕೆಯ ಮೂಲಕ ಉತ್ಪಾದಿಸಲು 180 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್ ಉಷ್ಣಾಂಶ ಹಾಗೂ 9 ನಿಮಿಷಗಳ ಕರಿಯುವಿಕೆಯ ಸಮಯ ಉತ್ತಮ ಮತ್ತು ವ್ಯಾಕ್ಯುಮ್ ಫ್ರೈಯರ್ನನಲ್ಲಿ ಚಿಪ್ಸ್ ಉತ್ಪಾದಿಸಲು 400 ಮಿಮೀ ಎಚ್‌ಜಿ ನಿರ್ವಾತ, 90 ಡಿಗ್ರಿ ಸೆಲ್ಸಿಯಸ್ ಉಷ್ಣಾಂಶ ಮತ್ತು 25 ನಿಮಿಷಗಳ ಕರಿಯುವಿಕೆಯ ಸಮಯ ಉತ್ತಮವಾದುದು ಎಂದು ಕಂಡುಬಂದಿದೆ. ಸಾಧಾರಣ ವಾತಾವರಣ ಒತ್ತಡದಲ್ಲಿ ಕರಿದ ಚಿಪ್ಸ್‌ಗಳಿಗೆ (46.62ಶೇ.) ಹೋಲಿಸಿದರೆ ನಿರ್ವಾತ ವಾತಾವರಣದಲ್ಲಿ ಕರಿದ ಚಿಪ್ಸ್‌ಗಳು (24.82ಶೇ.) ಅತೀ ಕಡಿಮೆ ಕೊಬ್ಬಿನ ಅಂಶವನ್ನು ಹೊಂದಿರುತ್ತವೆ. ಸಾಮಾನ್ಯ ಮತ್ತು ನಿರ್ವಾತ ವಾತಾವರಣ ಒತ್ತಡದ ವಿಧಾನಗಳಲ್ಲಿ ಕರಿದ ಬಾಳೆಕಾಯಿ ಚಿಪ್ಸ್‌ಗಳನ್ನು ಲೋ ಡೆನ್ಸಿಟಿ ಪಾಲಿಯಿಥಿಲೀನ್ (LDPE), ಪಾಲಿಪ್ರೋಪಿಲೀನ್ (PP) ಮತ್ತು ಮೆಟಲೈಸ್ಡ್ ಮಲ್ಟಿಲೇಯರ್ ಪಾಲಿಯಿಥಿಲೀನ್ (MMP) ಪ್ಯಾಕಿಂಗ್ ಚೀಲಗಳಲ್ಲಿ ನೈಟ್ರೋಜನ್ ಅನಿಲ ರಹಿತ ಮತ್ತು ಸಹಿತವಾಗಿ ಎರಡು ತಿಂಗಳ ಕಾಲ ಸಾಮಾನ್ಯ ತಾಪಮಾನದಲ್ಲಿ ಶೇಖರಿಸಿಡಲಾಯಿತು. ಬಾಳೆಕಾಯಿ ಚಿಪ್ಸ್ ಶೇಖರಿಸಿಡಲು ನೈಟ್ರೋಜನ್ ಅನಿಲ ತುಂಬಿದ MMP ಚೀಲಗಳು ಉತ್ತಮವಾಗಿದೆ ಎಂದು ಕಂಡುಬಂದಿದೆ. ಚಿಪ್ಸ್ ಉತ್ಪಾದನ ವೆಚ್ಚ ಮತ್ತು ವೆಚ್ಚ:ಲಾಭ ಅನುಪಾತವು ಸಾಧಾರಣ ವಾತಾವರಣದ ಒತ್ತಡದಲ್ಲಿ ಕರಿದ ಚಿಪ್ಸ್‌ಗೆ ರೂ. 237.06/ಕೆ.ಜಿ. ಮತ್ತು 1:1.26 ಹಾಗೂ ನಿರ್ವಾತದಲ್ಲಿ ಕರಿದ ಚಿಪ್ಸ್‌ಗೆ ರೂ. 295.03/ಕೆ.ಜಿ. ಮತ್ತು 1:1.69 ರಷ್ಟು ಅನುಕ್ರಮವಾಗಿ ಕಂಡುಬಂದಿರುತ್ತದೆ.

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ಕೃಷಿ ತಂತ್ರಜ್ಞಾನ ವಿಭಾಗ
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ಡಾ. ವಿ. ಪಳನಿಮುತ್ತು
ಮುಖ್ಯ ಸಲಹೆಗಾರರು

Production of Low Fat Banana Chips (var. *Dwarf Cavendish*) by Deep Fat Vacuum Frying

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INTRODUCTION

- Banana chips, a remarkable snack, is prepared by deep fat frying of matured, unripe fruit at atmospheric or vacuum pressures
- *Dwarf cavendish* is a popular commercial banana variety which is processed into wide range of products including chips / crisps
- Crispiness is the most important quality parameter of chips and is mainly depend on frying temperature, frying duration and frying pressure
- Vacuum fried chips normally contain much less fat than atmospheric fried ones and considered as healthy snack
- An attempt was made to produce quality banana chips using Vacuum deep fat fryer and optimize process parameters

OBJECTIVE

- **To optimize deep fat vacuum frying process parameters for quality banana chips**

MATERIAL AND METHODS

MATERIALS: Well matured, unripe banana fruit (var. *Dwarf Cavendish*), potassium metabisulphite, refined sunflower oil, dry chilli powder, salt

TREATMENT DETAILS:

Independent variables:

- Frying vacuum - 2 levels (640 & 400 mm Hg)
- Frying temperature - 3 levels (80, 90 & 100 ºC)
- Frying time - 4 levels (15, 20, 25 & 30 min)

Dependent variables:

- Sensory quality of processed chips using 9 point Hedonic Scale (Ranganna, 1986)
- Oil uptake of fried chips

Process Flow Chart for Vacuum Fried Banana Chips

Fully mature, unripe Banana
↓
Washing, Peeling
↓
Cut into slices (2.5 mm)
↓
Blanching @ 60ºC for 5 min in 1% KMS
↓
Vacuum frying
↓
Centrifugation (deoiling fried chip) & Cooling
↓
Addition of salt (2%) & chilli powder (1%)
↓
Mixing & Packaging
↓
Vacuum fried Banana chips

EXPERIMENTAL RESULTS

- Banana chips fried under 400 mm Hg of vacuum and fried @90°C or more generally obtained better sensory scores.
- The oil uptake of vacuum fried banana chips were in the range of 22.42 to 26.94% (Table 1a &1b).
- Under vacuum frying, it was observed that a minimum of 25 min of frying time was required to get better quality banana chips.
- Banana chips fried under 400 mm Hg of vacuum level at 90ºC frying temperature for 25 minutes showed highest sensory scores with respect to color (7.80), texture (8.40), flavor (8.10), taste (8.00) and overall acceptability (8.51).

Table 1: Sensory scores for various quality attributes & oil uptake of vacuum fried banana chips prepared at different frying temperature - time combinations

1(a) Under 640 mm Hg vacuum

Treatment	Colour	Texture	Flavour	Taste	Overall acceptability	Oil uptake %
$V_1T_1t_1$	6.24	6.17	6.05	5.86	6.07	23.92
$V_1T_1t_2$	6.16	6.44	6.20	6.05	6.10	24.10
$V_1T_1t_3$	6.02	6.07	6.20	6.06	6.04	24.53
$V_1T_1t_4$	6.27	6.40	6.32	6.10	6.20	24.74
$V_1T_2t_1$	6.87	6.41	6.15	5.90	6.30	24.96
$V_1T_2t_2$	6.89	6.75	6.66	6.31	6.40	25.27
$V_1T_2t_3$	7.12	6.65	6.47	6.19	6.65	25.45
$V_1T_2t_4$	7.02	6.30	6.50	6.90	6.72	25.64
$V_1T_3t_1$	6.32	6.12	6.02	6.03	6.20	25.82
$V_1T_3t_2$	6.31	6.45	6.05	6.08	6.36	26.01
$V_1T_3t_3$	5.83	6.15	6.17	6.14	6.21	26.57
$V_1T_3t_4$	6.23	6.18	6.35	6.32	6.31	26.94

1(b) Under 400 mm Hg vacuum

Treatment	Colour	Texture	Flavour	Taste	Overall acceptability	Oil uptake %
$V_2T_1t_1$	4.95	5.12	5.00	5.24	5.03	22.42
$V_2T_1t_2$	5.43	5.67	5.35	4.72	5.51	22.84
$V_2T_1t_3$	5.88	5.53	5.19	5.12	5.52	23.68
$V_2T_1t_4$	5.27	5.49	5.50	6.00	5.90	23.87
$V_2T_2t_1$	6.52	6.25	6.07	5.97	6.02	24.05
$V_2T_2t_2$	7.52	7.25	7.15	7.33	7.23	24.50
$V_2T_2t_3$	7.80	8.40	8.10	8.00	8.51	24.82
$V_2T_2t_4$	7.05	7.10	7.50	7.42	7.20	25.12
$V_2T_3t_1$	7.50	7.05	7.32	7.05	7.25	25.50
$V_2T_3t_2$	7.25	7.17	7.22	6.95	7.05	25.89
$V_2T_3t_3$	7.55	7.20	7.10	7.05	7.22	26.02
$V_2T_3t_4$	7.45	7.65	7.60	7.70	7.52	26.46

V_1: 640 mm Hg T_1: 80 ºC T_2: 90 ºC T_3: 100 ºC
V_2: 400 mm Hg t_1: 15 min t_2: 20 min t_3: 25min t_4:30min

DISCUSSION

- Generally, frying duration required was observed to be much higher (>25 min) under vacuum frying when compared to traditional atmospheric frying (<10 min).
- Vacuum frying significantly lowered the final oil content in banana chips when compared to atmospheric frying (≈42%) (Diamante *et al*., 2015).
- Degradation of frying oil quality slowed down due to milder frying conditions employed in vacuum frying and therefore the oil could be used for more number of frying cycles.

Banana (var. *Dwarf Cavendish*) &Raw Chips

Vacuum Deep Fat Fryer

Raw Chip Cutter Blade

Vacuum Fried Chips

Centrifugation Unit

SUMMARY

- Vacuum frying at 90ºC for 25 min under 400 mm Hg resulted in better quality Banana chips especially in terms of colour.
- Compared to traditional atmospheric fried chips, the oil content of vacuum fried chips was much lower and therefore is considered a healthier snack.

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ADVISORY COMMITTEE

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SYMBOLS	ABBREVIATIONS
%	Per cent
*	Significant
@	At the rate of
Al	Aluminium
et al.	And others
etc	Etcetera
Fig.	Figure
g_f	Gram force
h	Hour
H_2SO_4	Sulphuric acid
i.e	That is
kcal	Kilo calories
kg	Kilogram
LDPE	Low Density Polyethylene
MMP	Metalized Multilayer Polyethylene
PP	Polypropylene
meq	Miliequivalent
mg	Milligram
ml	Milliter
No	Number
NS	Non significant
°C	Degree centigrade
rpm	Revolution per minute
sec, s	Second
SEm	Standard Error of mean
cm	Centimeter
HCl	Hydrochloric acid
NaOH	Sodium hydroxide
N	Normality
° Brix	Degree brix
TSS	Total soluble solids
$CaCl_2$	Calcium chloride

I INTRODUCTION

Banana, belonging to the family *Musaceae*, probably originated in South East Asia. It grows best in humid lowland tropics but also grown commercially within the subtropics. Banana is grown for its fruit, fiber and foliage. The banana variety *Dwarf Cavendish* belongs to *Musa* AAA ('Cavendish' subgroup) family and botanically its fruit is a parthenocarpic berry. It is one of the most important banana cultivars for fresh consumption and is tolerant to a wide range of climates including cool conditions.

Banana is perhaps the most popular fruit in the world and is a major fruit in the international trade. It is the fifth largest agricultural commodity in world trade after cereals, sugar, coffee and cocoa (Singh, *et al.,* 2016). The annual world production of banana is about 113.28 million tonnes during the year 2016. India, Ecuador, Brazil and China alone produce half of the total banana produced in the world. India produced about 26.5 million tonnes of banana (in 2015), accounting for 33.41% of the total fruits production (highest share) in the country. Unlike the other important fruits produced in this country like mango, citrus, guava and grapes which are mostly seasonal, the banana is available throughout the year. The major banana growing states in India are Tamil Nadu, Maharashtra, Karnataka, Gujarat, Andhra Pradesh, Bihar, Assam and Madhya Pradesh (Anonymous, 2001).

Cavendish group of banana cultivars (triploid type) are the most popular edible varieties which constitute to over 40% of the fruits produced worldwide. They are soft, sweet, dessert bananas and are the main 'export cultivars' from banana-growing countries. The Dwarf Cavendish is a high yielding banana variety introduced to India from Israel and this low-priced fruit is widely grown in the country. Its bunch normally have 10 to12 hands with 175 - 225 fruits, which is higher than the other native varieties.

Banana is nutritionally a gold mine. From nutritional point of view, banana provides a balanced diet when compared to any other fruit. It is high in vitamin B6 that helps to fight infection and is essential for the synthesis of haeme, the iron containing part of hemoglobin. It is also rich in potassium and a great source of fibre. Banana has a calorific value ranging from 67 to 137 Calories per 100 g (Singh *et al*., 2016). The green-banana fruit (raw banana) consumed after cooking is referred to as plantain and the fruit consumed after ripening is referred to as dessert banana. The nutritive value of banana is very close to that of potato, but compared to potato, the energy in calories per 100 g is higher in banana pulp. When compared to an apple, a banana contains 4 times the proteins, twice the carbohydrates, 3 times the phosphorous, 5 times vitamin A and iron including twice of other minerals and vitamins (Nakirya, 2007). Several food products are manufactured from banana. Apart from the usage as food and for medicinal purposes, the whole plant is useful in many other ways (Anonymous, 2001). The prospects of banana processing in India are very bright.

Fruits and vegetables are source of many vitamins and antioxidants and they are too expensive. It is difficult to protect them for long time because it spoils too quickly. The banana is one of the highly consumed fruits and all over the world, it is being processed into a wide variety of products namely, banana chips, French fries, banana powder and flour, banana cocoa and coffee, alcohol, wine and vinegar. Green banana is perishable and deteriorate fast after harvesting.

Banana chips are one such value-added product with a crispy and unique taste. The chips are usually made from ripe green banana, consumed as a snack food and an ingredient in some breakfast cereals. It can also be further processed by coating with sweeteners, etc (Herrmann, 1997). Today, consumers are more interested in healthy products that taste good. Fried products are produced using non-hydrogenated oils and they contain no saturated fat and trans-fats. The technology is expected to improve the nation's nutrition and health by producing products that taste good, keep most of their nutritive values, have lower fat content than the conventionally fried snacks, are safer with little or no acryl amide formation and keep longer (Silva and Moreira, 2008).

Air drying or sun drying of raw banana chips is generally done before frying. It is important to control quality during drying as well as subsequent frying process. Deep fat frying is one of the oldest cooking methods for imparting the desired texture and flavour to a variety of food products. Though banana chips are available in the market for a long time, most of such chips are prepared by deep fat frying at high temperatures under normal atmospheric pressure. Currently, in traditional banana chips production process, the frying oil temperature and frying time are not standardized scientifically. Degradation of important nutritional compounds and the generation of toxic molecules like acrylamide in the foodstuff due to high frying temperatures and exposure to oxygen have led to the development of healthy and low-fat snack products.

Vacuum frying is alternative technology that might be an option for the production of novel snacks from fruits and vegetables with lower oil content and desired quality attributes. It is the frying process carried out under pressures well below atmospheric levels therefore, lowering the boiling point of oil, making possible to reduce substantially the frying temperature (Garayo and Moreira, 2002). The length of frying time and method of frying are important factors that affect phytochemical or nutraceuticals stability of fried products (Shirsat and Thaomas, 1998).

The main objective of this research was to study the effect of different frying process variables such as vacuum level, frying oil temperature and frying time on the quality of vacuum fried and atmospheric fried banana chips and also to optimize both atmospheric and vacuum frying process parameters for banana chips. It was desired to understand the difference between both frying technologies and study their impact on main quality attributes of the chips like oil absorption, moisture content, colour, flavor and the sensory quality. In this background, this research is a significant step to produce a healthier banana chips. This study is aimed to develop not only the healthy banana chips but also evolve a suitable package for preserving the above product.

The present study was carried with the following objectives:

- Study of physical and chemical properties of banana (var. *Dwarf Cavendish*).
- Optimization of atmospheric deep fat frying parameters for quality banana chips.
- Optimization of vacuum deep fat frying process parameters for quality banana chips.
- Storage study of atmospheric and vacuum deep fat fried banana chips.
- Cost economics of production of fried banana chips.

II REVIEW OF LITERATURE

In this chapter, all the past research works carried out on various aspects of banana, its processing into chips and storage were reviewed and presented under different sub-headings. Some other aspects relevant to the current research study were also reviewed and presented.

2.1 Banana fruit

Banana is one of the finest fruits produced in India. It is the second largest fruit produced after citrus, contributing about 16% of the world total fruit production. India is the biggest producer of banana, contributing to 27% of world banana production. Tamilnadu is the leading producer of banana, followed by Maharashtra (Mohapatra *et al.*, 2010). *Musa acuminata* (*Dwarf Cavendish)* is a popular commercial variety of banana and is extensively grown in this country.

Bananas are flexible plants and are suitable for all climates if best care is given. Bananas grow best in a uniformly warm environment and need 9 to 15 months of frost-free conditions to produce a flower stalk. In the subtropical region, the fruit ripens in 2-3 months. Banana is an evergreen perennial grown up to 3 m tall, with oblong leaves to 1.2 m long, drooping spikes of yellow flowers with purple bracts that open sporadically through the year, yielding edible yellow fruits (Anonymous, 2001).

Borah and Nayak (2013) reported that throughout the world, banana is processed into a wide variety of the products like banana chips, French fries, banana powder and flour, banana cocoa and espresso, liquor, wine and vinegar.

'Robusta' and 'Dwarf Cavendish' are the most popular banana varieties commonly grown in India and are the backbone of Indian banana industry for both internal and export trades (Oliveira, 2007).

Onyejegbu and Olarunda (1995) reported a gradual increase in the pulp to peel ratio in the banana cultivars and also in the cooking varieties of banana was noticed when ripening progresses and there was a widespread distinction in moisture contents among the varieties. The sugar content impacts on the texture of the fruit. As ripening progress, the increase in sugar content resulted in production of dark colored chips. Therefore the light colored crispy chips can be best created from stages 1^{st} and 2^{nd} day of ripening.

The starch content reduced as ripening advanced because of the hydrolysis of starch into sugar. Iodine testing on plantain samples may therefore look like a more precise method of differentiating the various ripeness stages, since the change in peel colour might not be too distinct or even suitable as a rapid check for this purpose during processing.

2.2 Physical Properties of Banana

Banana maturity has been measured by the amount of peel chlorophyll and its visual disappearance with ripening. Peel color charts are developed to help standardize banana maturity ratings for industry and research purposes (Blankenship *et al*., 1993).

Kachru *et al*. (1995) reported that, the pulp to peel ratio for Dwarf Cavendish variety of banana varies between1.39 to 2.32. The average pulp and peel moisture content were 264.17% (db) and 666.28 % (db), the maximum effective length and width of the banana pulp resting at its most stable position was observed to be 137.0 mm. The maximum diameter of fruit without peel was 23.34 mm.

Madamba *et al*. (1997) showed that the starch increased to a peak at the initial stages of ripening but decreased thereafter. Titratable acids increased, accompanied by a rapid decrease in starch, before the eating-ripe stage was reached. Total sugars and total soluble solids remained low until the final stages ripening.

Arkosova and Copikova (2000) reported that near-infrared (NIR) spectroscopy could be used to establish calibration equations to determine individual sugar content in Cavendish bananas that corresponded to the stage of ripeness.

Nair and Singh (2003) found that textural properties are the indicator for determination of maturity of the fruits during ripening and senescence. Texture plays a key role for processability of the fruits to a food processor and eating quality to the consumer.

Salvador *et al.* (2007) studied the changes in color and texture of banana during storage at 10 ºC and 20 ºC. They found that during storage, the change in peel color from green to yellow was gradual in the M. Cavendish samples.

The textural change, i.e., softening of the tissue in fruits, during ripening is caused by enzymatic degradation. The texture of the stored banana plays a major role in the preparation of processed products like banana figs, powder, jam, chips, etc. (Karthiayani *et al.*, 2013).

2.3 Biochemical Composition of Banana

Onyejegbu and Olarunda (1995) observed that moisture content among the varieties. There was also a gradual decrease in firmness of fruit as ripening advanced. Moisture content showed a positive correlation with sugar content in plantain is variety specific, because there was a significant difference in the sugar content among the varieties at stages of ripeness.

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The banana pulp contained 75 % water and was the most calorie-rich (with 90 kcal/100 g) of non-oil fresh fruits. It contained approximately 20 g of carbohydrates per 100 g of fresh pulp. Out of which fibre was 2 g per 100 g fresh weight that was useful for regulation of intestinal transit of foods. Potassium was the most abundant mineral present in banana with estimated values in the range of 4.10 - 5.55 mg per 100 g dry weight (Goswami and Borthakur, 1996).

Starch in the green fruit is converted into sugars (sucrose, glucose, fructose) and in very small quantities into maltose, the percentage of which rises from 1 or 2 % to nearly 20 % by the end of ripening. Total soluble solid contents in banana increased as fruit ripened (Bugaud *et al*., 2006).

Salvador *et al*. (2007) observed that increase in the moisture content of fruit, when the peel colour changes from green to yellow in *Musa Cavendish* banana sample during storage at 10 ºC and 20 ºC.

The skin of the cavendish subgroup fruits, which represents a major part of the fruit mass (30 %), is far richer than the pulp in antioxidant compounds (Aurore *et al.*, 2009).

Tapre and Jain (2012) reported that the increase in pulp moisture content during ripening may be due to carbohydrate breakdown and osmotic transfer from the peel to pulp. Compositional study of banana pulp of selected maturity levels was carried out. Results indicated that, a significant increase in moisture content of the pulp.

2.4 Frying of Food Products

Hawrysh *et al*. (1995) and Melton *et al.* (1993) studied that frying conditions and physicochemical changes that occur during frying which affect the quality parameters of the fried product. More specifically, oil temperature and processing time were critical factors. The frying medium i.e. the oil type, was another factor that mainly affected the degradation of the product after frying and also the quality properties of the fried products. To retard degradation, partial replacement of conventional oils by hydrogenated ones has been suggested.

Krokida *et al*. (2000) reported that during frying, heat was transferred from the oil to the food, water was evaporated from the food and oil is absorbed in it. During the frying process, the physical, chemical and sensorial characteristics of a food are modified. The quality of fried potatoes depended mainly on their structural, textural and optical properties.

Borah and Nayak (2013) reported that oil absorption was maximum (68.7 % w.b) in fresh banana slices. The diametrical shrinkage was not significant but the color and hardness of chips change considerably at some point of the frying period.

Bordin *et al*. (2013) observed the interactions among frying oil and fried food are of great relevance for nutritional quality of the final product. Foods are complicated and heterogeneous matrixes and all changes produced by frying occur simultaneously and contribute to the development of color, taste, texture and quality of fried product. Frying process relies on high temperatures and can change the structure of labile nutrients such as proteins, vitamins and antioxidants. Some water-soluble molecules such as ascorbic acid can be lost during the water evaporation. During frying, the product dehydrates from an initial moisture content of about 90 % (w.b) to less than 5 % (w.b) moisture content within few minutes of frying.

2.4.1 Deep fat frying

Crust is formed during most deep fat frying processes and is one of the most important characteristics of the fried foods (Keller *et al.*, 1986). Studies on deep fat frying have shown that oil uptake during frying of food is localized at the crust (Farkas *et al.*, 1996).

Deep fat frying is both heat and mass transfer process. The heat is transferred from the frying oil to the food material while moisture is evaporated and oil is absorbed by the food. Many factors that affect these processes are: the thermal and physical properties of the food, type of oil, the temperature of the oil, size and shape of the food and the processing conditions that lead to the degradation of the oil in the process (Moreira *et al.*, 1995).

Farkas *et al*. (1996) concluded that immersion or deep fat frying is the process of cooking foods by immersing them in edible oil at a temperature of 150–200 ºC, much above the boiling point of water.

Speek *et al*. (1998) investigated the effect of processing on carotenoids in vegetables, indicating an average loss of 14 and 24 % for vitamin - A activity in boiling and frying, respectively.

During deep fat frying process, undesirable changes may occur concurrently with desirable modifications, one such change being the loss of nutrients especially vitamins Fillion and Henry (1998).

Sahin *et al*. (1999) reported that deep fat frying process is one of the oldest and traditional method for frying food in which both frying and cooking of the food takes place simultaneously. While in conduction heat transfer takes place within the food material, convection heat transfer is the main transport process between food material and oil. During deep fat frying, the moisture content decreased with increase in temperature of frying, this leads to rapid dehydration of potato slices.

Hubbard and Farkas (2000) reported that the moisture present on the surface of the food was removed during deep fat frying, the crust formation begins and its thickness increases over the period of frying. The food can be viewed as a porous structure that serves as a conducting media for energy flow and vapor loss between surface of the food and its core region.

Bouchon *et al*. (2003) studied the frying process of food immersed in an oil bath at a temperature above the boiling point of water and observed that there was a counter flow of water vapour and oil at the surface of the produce.

Saguy and Dana (2003) concluded that deep fat frying is cheap and fast process of frying that changes the sensory and nutritional characteristics of food due to complex interaction between food and oil. This frying process with high temperature causes destruction of microorganisms, enzymes and reduces the water activity on the surface of the food. The change in the characteristics of the food depends on type of the oil, geometry of the food, temperature of the oil, duration of immersion. Exposure of the oil at high temperature for longer duration causes adverse reaction in the oil that leads to production of highly toxic compounds.

Bordin *et al*. (2013) reported that deep fat frying is a process of food and oil interaction at high temperatures in which the cooking and dehydration of food takes place that leads to physical and chemical changes in the product, such as starch gelatinization, protein denaturation and colour and flavor production by Millard reaction. Few components in the oil and food are lost during frying process and potential toxic compounds are formed in the oxidized oil. The study reported that many of these compounds have not been fully identified.

Borah and Nayak (2013) evaluated the quality of fried banana chips and oil absorption at different frying temperatures and oil absorption. The banana chips pre-dried to 200 % db at a temperature of 40 ºC and fried at 170 ºC for 180 s resulted in best quality banana chips. Pre-drying of banana chips before deep fat frying resulted in considerable reduction in oil uptake as compared to fresh fruit. The influence of moisture content, drying temperature and frying time on hardness of chips was significant. ANOVA of moisture loss and oil absorption during frying indicated that the pre-drying temperature did not have any significant effect on oil content or moisture content of chips after frying.

2.4.2 Vacuum frying

Shyu *et al.* (1998) stated that vacuum frying process carried out below atmosphere pressure level preferably less than 50 torr for fried snacks had more advantages over atmospheric frying. Fried products have less oil content, better preservation of natural colour, flavour and nutrient components in food and less adverse effect on frying oil quality are some of the advantages.

Moreira *et al.* (1999) observed that during frying, heat is transfer from the oil to the surface of the product by convection and then from the surface to the center of the product by conduction, which causes an increase in product temperature until the boiling temperature of water is attained and water starts evaporating.

The pressurization process plays an important role in the oil absorption mechanism. It can increase or decrease oil absorption depending on the amount of surface oil and free water present in the product (Garayo and Moreira, 2002).

Silva and Moria (2008) indicated that vacuum frying is a good option to achieve high quality fried products with better colours and flavours due to reduced oxidation, lower frying temperatures and much shorter processing times compared with other techniques. In case of high quality fruits and vegetable-based snacks production the products maintained their natural colour when fried under vacuum condition compared to traditional frying products where in excessive darkening of colour was noticed.

Vacuum frying is a deep fat frying process, which is carried out in a closed system below the atmospheric pressure, substantially reducing the boiling point of water and hence, the frying temperature. The low frying temperatures and minimal exposure to oxygen are responsible for most of the benefits of the vacuum fried products, which include nutrient preservation (Silva and Moreira, 2008), oil quality protection (Shyu *et al.* 1998) and reduction in toxic compound generation (Granda *et al.,* 2004).

Troncoso *et al*. (2009) found that oil absorption at the surface increased during vacuum frying process because of the higher heat and mass transfer rates and the existence of a pressurization step, thus increasing the final oil content compared to traditional frying for the same working temperature.

Maity *et al.* (2014) evaluated the effects of frying temperature and time on the quality characteristics of vacuum fried jackfruit chips. The frying time duration employed were 30, 25, and 20 minutes at 80, 90, and 100 ºC, respectively. They found that moisture content and breaking force of jack fruit chips decreased with increase in frying temperature and time during vacuum frying whereas the oil content increased. Moreover, sensory evaluation showed maximum acceptability for jack fruit chips fried at 90 ºC for 25 min.

Yamsaengsung *et al.* (2011) studied vacuum frying of banana chips. Banana slices with the cross sectional diameter of 0.25-0.30 cm and 0.35-0.45 cm thickness. Frying was done at three temperatures, viz., 100, 110 and 120 °C at 8 kPa of vacuum for 20 minutes to determine which temperature produced the highest degree of expansion. Sensory evaluation was conducted using a 7-point hedonic scale test to determine the effect of ripeness on acceptability of the product. Scanning electron microscopy (SEM) was used to analyze the structure of the vacuum fried banana chips. Results showed that the vacuum frying time, in general, affected the pore size of chips. The optimum conditions for best quality chips was 110 ºC under 8 kPa vacuum at which the highest degree of expansion was observed. Sensory evaluations did not unveil any significant difference ($p > 0.05$) in acceptability of the products based on ripeness. Results from SEM exhibited, a dramatic increase in the pore size of the banana chips as a function of frying time.

Diamante *et al.* (2015) stated that the vacuum frying process required first heating of oil to the required temperature. The sample to be processed was placed in the basket inside the frying chamber but suspended above the hot oil. The pressure inside the vacuum frying chamber was reduced and then the sample was lowered into the hot frying oil for the desired duration. After the frying, was raised above the oil and centrifuged within the chamber at optimum speed and time. Alternatively, the fried product can also be taken out of the chamber and centrifuged using a separate machine to drain the surface oil. The product was then cooled and packed.

Ruttanadech and Chungcharoen (2015) stated that, the vacuum frying is an alternative new technology to improve the quality of fried foods. The moisture could evaporate at the temperature below 100 ºC, leading to shorter frying time and it also reduce the oil oxidation because of low-temperature processing. The increase in frying temperature and time resulted in decrease in moisture content and breaking force.

Suryatman and Ahza (2016) studied vacuum frying of rice-straw mushroom stem chip. Three temperatures of 80, 90 and 100 ºC and five frying times of 3, 6, 9, 12 and 15 minutes were selected to determine the optimum frying condition with 2 mm thick slices. Results showed that the vacuum frying time, in general, affected the chips colour and oil uptake significantly ($p < 0.01$) and correlated with the moisture decrease. The chips moisture content declined significantly after vacuum frying at 90 and 100 ºC for 3 minutes. While for the 80 °C vacuum frying, the significant decrease of moisture occurred due to the increase of vacuum frying time from 3 to 6 minutes ($p < 0.01$). The optimum vacuum frying conditions for 2 mm slice thickness chips was 100 ºC for 3 minutes. The chips moisture loss generally followed a two-stage of falling rate pattern during vacuum frying and each could be well predicted by an exponential equation.

The vacuum pressure and temperature affect the rate of temperature change, evaporation of water and oil absorption during frying of jackfruit. The rate of oil absorption was affected by the rate of evaporation of water in accordance with the water content in solids. The temperature rise, decline in water content and oil absorption by chips changed the physical properties during frying. The rate of oil absorption seems to be influenced by temperature and vacuum pressure; higher the temperature and vacuum pressure, more oil the solids absorbed and *vice versa* (Jamaluddin*, et al*., 2016).

Segovia *et al.* (2016) suggested vacuum frying of pre-blanched cassava chips may be an alternative to atmospheric frying since it improved the color of the samples, reduced the oil gain and maintained crispness. Samples fried under vacuum conditions were exposed to lower temperatures. As a result, micro-structural changes/damage were inhibited (this is one of the main advantages of vacuum technology). The cassava slices fried under vacuum showed less bubbles and more uniform structure than those fried under traditional frying.

2.5 Quality Parameters of Fried Food Products

2.5.1 Oil uptake of fried chips

Gamble *et al.* (1987) indicated that the distribution of oil in fried food depended upon the structure of the food and the ease of moisture loss. Oil uptake was influenced by slice thickness, moisture content, its distribution and ease of transfer, the cutting edge, and degree of blistering during frying. Oil was associated with areas of moisture loss.

Fat content is determined by Soxhlet extraction (Anonymous, 1990). The dried samples are ground in a warning blender and extracted with petroleum ether (boiling point, 40-60°C) for 4 hours. Petroleum ether is removed under vacuum at 90ºC by a rotary evaporator. The recovered oil is left for 24 h in a vacuum oven at 70 ºC and weighted.

Pinthus and Saguy (1994) found that the frying oil quality influences the oil uptake. The interfacial tension between frying oil and potato surface was high in fresh oil. During repeated frying, the interfacial tension decreases therefore, the oil absorption increases during repeated potato frying.

The oil temperature had a negative effect on the moisture content of fried potatoes. As the temperature of frying increased, the moisture content of chips for the same frying time decreased (Krokida *et al*., 2000).

Shyu and Hwang (2001) observed that during frying, increase in oil-uptake was found to be related to the loss of moisture. This was because of the diffusion gradient created by the loss of moisture through the surface making the surface dry.

Budzaki and Seruga (2005) stated that the oil uptake and moisture loss were more intense at higher frying temperatures, which leads to faster oil uptake owing to faster moisture loss. The oil uptake was found to increase from an initial value of 0.0 kg/kg (db) to 0.6137 kg/kg (db), whereas the moisture content decreased from 0.4358 to 0.0489 kg/kg (db). Thus, the ratio of oil absorption to moisture loss was calculated to be 1.5:1. The oil content was higher for Krostula dough fried at 190ºC than for that fried at 160 ºC for the same frying time and the moisture loss rate increased as temperature increased.

Ziaiifar *et al*. (2008) suggested that oil uptake is a complex phenomenon resulting from interactions between oil and products that undergo numerous physical, chemical and structural transformations during frying.

Naz *et al.* (2009) reported that the high oleic sunflower oil with smaller value of linoleic acid content had higher frying stability than the oil with higher linoleic acid level. This indicating that the high oleic sunflower oil frying efficiency was depended mainly on oil linoleic acid content.

Moreira *et al*. (2009) reported that in vacuum frying process, the food is fried under reduced pressure and temperature this helped to reduce oil absorption by the product. De oiling mechanism was necessary to remove the excessive oil absorption at the surface of the product. Vacuum frying with a de-oiling step produced superior quality fried products with lower oil content. About 86% of the oil content in the chips can be easily removed by the centrifuge process without affecting the other quality attributes of the product and breaking of the chips. The final oil content of potato chips was significantly different for the samples fried under vacuum conditions for 360 s, de-oiled at 750 rpm for 40 sec and different oil temperatures. Vacuum fried snacks were found to absorb lower oil content and as low as 27 % less than that of atmospherically fried samples and also they were lighter in color. The atmospherically fried sample absorbed more oil and they have large open structure due to high temperature compared to vacuum fried sample fried at lower oil temperature.

Sothornvit *et al*. (2011) reported that oil centrifugation speed in the vacuum frying process reduces significant and substantial reductions in the oil absorption without affecting the sensory perceptions and maintaining the high quality of chips. Edible coating helped to maintain the banana chips quality with low oil content. Reduction of oil absorption in fried products would benefit by adding value to the snack market as a healthy food product.

Oil uptake during frying is needed to be considered during frying because the fat content of a product will also affect its flavour, odour and general organoleptic properties. The frying oil not only acts as heat transfer medium, because they are heated to high temperatures of approximately 170-180 ºC, it will start to degrade through hydrolysis and oxidation of fatty acids. One of the alternative methods used to reduce fat content in chips is by doing a pre-treatment before frying (Aida, *et al*., 2016).

2.5.2 Moisture content

Gamble and Rice (1987 & 1988) and Rice and Gamble (1989) noted that the free water present in the surface of potato chips evaporated rapidly, the surface became dry and the inner moisture was converted to vapour, creating a vapour gradient. Moisture content and time of frying had a significant effect on color of chips. The colour changes from lightness to darkness was observed during deep fat frying of banana chips and concluded that the pre-dried chips had darker color after frying when compared to fresh chips.

Molla *et al.* (2008) observed that the rate of water removal depends on frying time and temperature. Obtaining of 4% moisture content in banana chips required frying time of 3 minutes at 170 °C. During frying, most of the water is removed from the matrices resulting in textural changes. Higher oil temperature involved in atmospheric frying caused faster moisture loss and accelerated process of crust formation. At higher temperature of frying, the rate of water evaporation increased that lead to expansion resulting in formation of concave structure. The more concave structure helps to reduce oil uptake of the fried matrices.

2.5.3 Colour

Toma *et al.* (1986) studied the effect of surface freezing pre-treatment on colour changes during deep fat frying and they reported that surface freezing treatment was an effective way of decreasing oil adsorption and improving the colour of french fries.

Krokida *et al*. (2001) reported that as the oil temperature and duration of frying increased the colour of the final product significantly gets affected due to osmotic dehydration and browning reaction that takes place during frying. This resulted in more dark coloured products. The replacement of the frying oil by hydrogenated oil may reduce the formation of dark colour of the chips. In case of deep fat frying, the lower oil temperatures up to 170 ºC results in lighter (less red and more yellow) and more acceptable product. The pretreated products have more acceptable color.

Dueik *et al*. (2010) studied the effect of frying temperature and time on colour of vacuum fried banana chips. They found that when the frying time was extended longer, the L* value decreased at all the frying temperatures. At the same frying time, the higher frying temperature resulted in lower *L** value.

Tristimulus colour of a sample is expressed in three coordinate system L*a*b*. The L* coordinate of an object is the lightness intensity as measured on a scale from 0 to 100, where 0 represents black and 100 represents white. The a* coordinate of an object represents the position of the object's color on a pure green and pure red scale, where -127 represents pure green and +127 represents pure red. The b* coordinate represents the position of the object's color on a pure blue and pure yellow scale, where -127 represents pure blue and +127 represents pure yellow (Soltani *et al*., 2011).

2.5.4 Crispiness

Crispness is a salient textural characteristic for most fresh dry cereal and starch-based snack food products and its loss due to the adsorption of moisture is a major cause of snack food product rejection by consumers (Nielsen, 1979).

Crispiness is highly valued and universally liked textural characteristic that indicates freshness and high quality of the product. It stimulates to active eating due to good appearance (Jose *et al*. 1996).

Jose *et al*. (1996) attempted blanching of whole green bananas in water at 50, 60, 70, 80, 90 and 100 ºC for 2, 15 and 30 min and then peeled, sliced and fried in oil to make chips. Significant interactions were found between blanching time, temperature and crispness of chips. Response surface analysis predicted that crispiest chips could be produced at blanching conditions of 69 ºC for 22 min.

Costa *et al.* (2001) reported that the crispy surface is developed due to the migration of oil into the intracellular spaces formed during frying as a result of cell-wall shrinkage and water evaporation.

2.5.5 Texture

Badui (1993) reported that the pectic enzymes affected the internal tissues of carrot and thus the overall texture. For most of the fruits and vegetables, texture depends on the presence of pectic substances which are part of the intercellular material.

Shyu and Hwang (2001) stated that the texture of a fried product determined its eating quality. Increase in crispiness positively affected the acceptability of product. Temperature and time of frying greatly affected the breaking force. The breaking force of chips as a measurement of crispness of chips was measured using texture analyzer. In case of fried apple chips, lower values of breaking force indicated higher crispy texture of chips. High breaking force during frying may be due to soft texture of apple slices which in turn was a result of high moisture content. Lower values of breaking force indicated higher crispy texture of vacuum fried apple. High breaking force required during initial frying may be due to the high moisture content in banana that results in soft texture.

Soltani *et al*. (2011) observed a decrease in firmness, rupture energy and hardness as the fruit ripened. The firmness degraded from 75.1 N at stage one to 27 N at stage seven.

Maity *et al.* (2014) studied textural properties of vacuum fried jackfruit chips. The breaking force required was less for chips fried at 80 ºC which decreased significantly in the chips fried at 100 ºC. This may be due to the development of dehydrated crust. After 20 min of frying, there was very little change observed in the texture values. Further frying would not be necessary for increasing the crispiness in the product. This would help to reduce the cost of the frying process while minimizing nutritional loss. Hence, crispy texture in jackfruit chips was achieved at 30, 25 and 20 minutes at 80, 90 and 100 ºC, respectively.

Satishkumar (2014) reported that the quality of jackfruit chips mainly crispiness depended on frying temperature and time.

Nagarathna (2017) measured crispiness of jack fruit chips using texture analyzer and reported that the jackfruit chips losing their crispiness during storage due to moisture absorption and the chips become soggy. The decrease in crispiness was found to be generally less in jack chips packed in MMP pouches with N_2 gas flushing.

2.6 Packaging and Storage of Fried Chips

Packaging and storage are important to control quality of fried chips. Storage stability depended on packaging. Good packaging and storage condition extend the shelf life. Chips can be packed in packages of various dimensions and materials (Ahmed, 1977).

Ammawath *et al.* (2002) stored deep-fat fried banana chips for 8 weeks at ambient temperature (27 ºC) using four types of packaging material *viz*., laminated aluminium foil (LAF), oriented polypropylene (OPP), polypropylene (PP) and low-density polyethylene (LDPE). The moisture content, water activity and breaking force values of all samples increased during storage. The Hunter colour values (L = lightness, a = redness/greenness

& b = yellowness/blueness) showed higher L and lower ‘a’ and ‘b’ values during storage. The most notable sensory change that occurred during storage was decrease in crispness. Samples packed in LAF exhibited higher scores, whilst LDPE gave the lowest scores for crispness and odor than any other sample during storage.

Borah and Nayak (2013) stored banana chips and the most notable changes during storage were with samples packed in LDPE which gave the lowest score in crispness and product colour.

Satishkumar (2014) tested three packages such as polyethylene; polypropylene and aluminium laminate pouches for storing deep fat fried jackfruit chips at ambient conditions for two months. The aluminium laminate was found to be best for jackfruit chips since the chips in this package had least moisture content, free fatty acids, peroxide value and thiobarbituric acids value.

Nagarathna (2017) tested three different packages namely, polyethylene, polypropylene and aluminium laminate pouches for storing both atmospheric and vacuum deep fat fried jackfruit chips with and without nitrogen gas flushing at ambient conditions for two months. The chips stored in laminated pouches with N_2 gas flushing obtained higher overall acceptability scores of 7.5 for vacuum fried and 5.03 for atmospheric fried.

III MATERIAL AND METHODS

In this chapter, the material used and the techniques adopted for various experiments during the present study, conducted in AICRP on Post-Harvest Engineering and Technology, University of Agricultural Sciences (UAS), Gandhi Krishi Vignana Kendra (GKVK), Bengaluru, during the year 2017-2018 are described. The methods used for physical and biochemical analysis of raw banana and chips, production and storage of chips in different packaging materials are presented systematically.

3.1 Material

3.1.1 Ingredients for banana chips

For the present study, *Dwarf Cavendish* variety banana fruits (Plate 3.1) were collected from local Bangalore market. Care was taken to select fresh, mature and unripe fruits for chips production. Criteria for selection of fruits for chips production were: size, maturity level and fruit colour. Refined sunflower oil (Gemini Brand), salt and chilly powder were also procured from the local market. Different packaging materials used were procured from Bangalore City Market. The chemicals used for analysis in this study were of analytical grade.

3.1.2 Preparation of raw banana slices for chips

The green thick fruit peel was removed manually using sharp stainless steel knife. Since it was difficult to peel raw green bananas, care was taken to handle the fruit pulp with minimum damage. The freshly peeled fruits were cut into slices of about 2.5 mm thick with the help of sharp circular stainless steel blade (Plate 3.2) in which the slice thickness could be adjusted. The raw banana slices were then used for chips production.

3.2 Physical Characteristics of Raw Banana Fruit

3.2.1 Size and skin thickness

Fruit size of selected variety was determined by measuring the dimensions (length and diameter) using a Digital Vernier caliper (Make: Mitutoyo Corporation, Japan). The number of fruits used for measuring the size was 15. The mean value of length and diameter of the fruit without peel were used to express the fruit size. The thickness of peel was measured after carefully separating the peel from the fruit. The deskinned raw banana was sliced using circular cutting blade and the slice thickness was measured.

3.2.2 Tristimulus colour

Tristimulus colour measurements of the banana fruit were made using a Spectrophotometer (Make: Konica Minolta Instrument, Osaka, Japan, Model - CM5). It is a light weight, compact tristimulus colour analyzer for measuring reflected-light colour. It combines advanced electronic and optical technology to provide high accuracy and complete portability. Using an 8 mm diameter (measuring area) diffused illumination and 0^{o} viewing angle, the instrument takes accurate colour measurements instantaneously and the readings are displayed. The colour of the sample was measured in CIELAB (L*a* b*) coordinate system where L* indicate lightness of the sample; a* value indicate greenness (-) or redness (+) of the sample; and b* value indicate blueness (-) or yellowness (+) of the sample. Three readings were taken for each sample and the mean value was reported.

3.2.3 Pulp to skin ratio

Twenty fruits were deskinned and the pulp to skin ratio was determined by weighing the pulp and peel separately and the ratio was computed.

3.2.4 Textural studies of banana fruit

Textural properties of banana fruit were studied using a Texture Analyzer (Make: Stable Microsystems Ltd, UK; Model - HDi) which was linked to a computer that recorded the data *via* Texture Expert Exceed Software supplied along with the instrument. The texture analyzer does three dimensional product analyses. The texture of fruit is expressed by measuring the hardness during cutting test using the Warner Bratzler blade set. The test procedure included the cutting of slices using blade set and measuring the force of cutting in real time. During cutting test, a single blade having 90 mm length and 0.7 mm width (sharp edged) was used to cut/shear through the samples under specified conditions. The heavy duty platform was secured to the base of the machine and the slotted base plate was placed on the platform. The banana fruits were held horizontally against the slotted base plate and the cutting test was conducted.

3.3 Biochemical Characteristics of Banana Fruit

3.3.1 Moisture content and dry matter content

Banana slices were subjected to moisture and dry matter analysis as per AOAC (2005) protocols. The moisture content was determined for triplicate samples by measuring weight loss of measured sample in a moisture box by desiccation in an oven maintained at 105 °C until constant weight. The dry matter content was estimated as the difference of sample weight and moisture content.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \qquad \text{Eq...3.1}$$

3.3.2 Total soluble solids (TSS)

A pocket Refractometer (Make: ATAGO; Model: PAL-1) was used to measure the (TSS) of banana fruit. The juice squeezed from homogenized fruit pulp through muslin cloth was used for TSS measurement and the reading after temperature correction were in ° Brix. Measurements obtained were made for 3 samples and the average value is reported.

3.3.3 Titrable acidity

The titrable acidity of banana fruit samples was determined by the visual titration method (Ranganna, 1986). The pulp was taken in a blender and mixed thoroughly. The pulped material was weighed, water added and boiled for 1 h replacing the water lost by evaporation, cooled, transferred to a volumetric flask and made up to the volume. It was then filtered, the filtrate was diluted with boiled distilled water and titrated with 0.1 N NaOH using a few drops of 1% phenolphthalein solution as indicator. The titre value was noted down and titrable acidity was calculated by using the following formula:

$$\text{Titreable acidity (\%)} = \frac{\text{Titre value} \times \text{N NaOH made up} \times \text{Volume of Citric acid} \times \text{Equivalent Weight}}{\text{Aliquot taken for titration x Weight of the sample x 1000}} \text{ x } 100$$

Eq...3.2

3.3.4 Reducing sugars

Determination of reducing sugars was done by the Nelson-Somogyi method (Sadasivam and Manickam, 1992). 10 g of pulp was placed in a 250 ml beaker and 80 ml of distilled water was added. This solution was neutralized with 1 N NaOH using phenolphthalein indicator and boiled gently in a water bath for 1 h with occasional stirring. Boiling distilled water was added to maintain the original level. The sample was cooled, transferred to 250 ml volumetric flask and the volume was made up. Then the solution was filtered through Whatsman No. 4 filter paper. 50 ml of the filtrate obtained was pipetted out to a 250 ml volumetric flask. To which 2 ml of 45% lead acetate and 100 ml distilled water were added and left to stand for 10 minutes. Excess lead was precipitated with 1.8 ml of 22% potassium oxalate solution. The volume was then made up with distilled water and filtered to obtain the clarified solution. Four ml Fehling's solution [Fehling's No.1 (2 ml) + Fehling's No.2 (2 ml)] with 10 ml of distilled water was taken in a conical flask. The clarified solution in the burette was titrated against the boiling Fehling's solution in the conical flask. Titration value was taken at the end point when the boiling liquid turns brick red colour of precipitated Cu_2O. The reducing sugars of the banana pulp expressed in percentage were calculated using the following formula:

$$\text{Reducing sugars (\%)} = \frac{0.05 \times \text{Volume made up}}{\text{Titre value} \times \text{Weight of Sample}}\ 100 \qquad \text{Eq ... 3.3}$$

3.3.5 Total sugar

During analysis of reducing sugars (Sec. 3.3.4), a portion of the clarified solution that remained was used for estimation of total sugars. 50 ml of clarified solution was transferred to 250 ml volumetric flask, 2 spatulas full of citric acid was added and left for 24 hours at room temperature for hydrolysis. The hydrolyzed sample was neutralized with 40% NaOH and the volume was made up to 250 ml using distilled water to produce invert sugar solution. Fehling's solution [Fehling's No.1 (2 ml) + Fehling's No.2 (2 ml)] with 10 ml of distilled water was boiled and titrated against invert sugar solution taken in the burette till rust brown precipitation was observed. Then 2 drops of methylene blue indicator were added and titration was continued until complete discoloration of the indicator colour (Sadasivam and Manickam, 1992). The total sugar (%) was estimated using the following equation:

$$\text{Total sugars (\%)} = \frac{\text{mg of sugar} \times \text{Dilution} \times 100}{\text{Titre value} \times \text{Weight of sample (g)}} \times 100 \qquad \text{Eq…3.4}$$

3.3.6 Estimation of starch content of banana fruit (Anthrone method)

Starch content of banana fruit was estimated by Anthrone method. The starch was hydrolyzed into simple sugars in hot dilute acid medium and the quantity of simple sugars was measured colorimetrically. The weighed samples (0.1 - 0.5 g) were homogenized with 80% ethanol to remove sugars and centrifuged to retain the residue. The residue was washed repeatedly with hot 80% ethanol till the washings did not give colour with anthrone reagent. The sugar free residue was dried over a water bath and 5.0 ml of water and 6.5 ml of 52% perchloric acid were added and kept for hydrolysis at 0°C for 20 min to form glucose followed by centrifuging and collection of supernatant. The extraction was repeated using fresh perchloric acid, centrifuged; the supernatants pooled and made up to 100 ml. About 0.1 or 0.2 ml of the supernatant was pipette out and made up the volume to 1 ml with water. The standards were prepared by taking 0.2, 0.4, 0.6, 0.8 and 1 ml of the working standard (Standard glucose: Stock-100 mg in 100 ml water and Working standard - 10 ml of stock diluted to 100 ml with water) and made up the volume to 1 ml in each tube with water. About 4 ml of anthrone reagent (200 mg anthrone dissolved in 100 ml of ice-cold 95% sulphuric acid) was added to each tube and dehydrated for eight min in a boiling water bath to form hydroxymethyl furfural followed by rapid cooling. This compound formed a green coloured product with anthrone and the intensity of green to dark green colour was measured at 630 nm using colorimeter (Make: Jenway Ltd; Model: 6051). The glucose content in the samples was measured with the help of standard graph and using following equation:

$$\text{Glucose content (\%)} = \frac{\text{Concentration of glucose from standard graph} \times 100 \times 100 \times 1}{\text{Aliquot taken for estimation} \times \text{Weight of sample} \times 10^{6}} \times 100$$

Eq…3.5

$$\text{Starch content (\%)} = \text{Glucose content (\%)} \times 0.90 \qquad \text{Eq…3.6}$$

3.4 Production of Deep Fat Fried Banana Chips

Conventional atmospheric deep fat fried banana chips were produced using an electrical Deep fat fryer.

3.4.1 Electrical Deep fat fryer

The Electrical Deep fryer (Make: Bakers Shoppee Pvt Ltd; Model: Deluxe), used in this study, was a commercial batch processing equipment, completely made up of stainless steel (Plate 3.3) It mainly consisted of frying chamber and frying basket. The frying chamber was a rectangular stainless steel trough that could hold a maximum of about 8 litres of frying oil. At the bottom of frying chamber, electrical heating coils were fixed and a thermostat sensor was suitably positioned in the chamber to measure the temperature of the oil continuously. From the control panel of the equipment, the frying oil temperature could be set to a desired value. There was a lid to cover the frying chamber especially during frying operation. A rectangular frying sample basket made up of stainless steel mesh was used to introduce and hold the sample inside the frying oil. It had a capacity to hold about 300 - 500 g of sample. The Bakelite handle of the basket helped to hold the basket (without burning our hand due to heat) and lift the sample batch up and down.

3.4.2 Operation of deep fat fryer

The frying chamber was first filled with 5 l (maximum 8 l) of frying oil. The required frying temperature was set and the equipment was switched on to heat the oil using the heating coils controlled by thermostat. After reaching the set frying temperature, the basket with preweighed banana slices sample was introduced into the frying oil and the lid was closed. At the end of frying (for set time), the frying basket was taken out from oil, allowed to cool for 3 - 4 minutes and then the final weight of fried chips was measured. Immediately salt (@ 2%) and chilly powder (@1%) were added to fried chips, mixed thoroughly and stored in LDPE bags (Plate 3.3). The same frying oil was used for further trials after making up the volume with fresh oil. The process flow chart of preparation of banana chips was presented Fig 3.1. The freshly peeled raw bananas were sliced to obtain approx. 2.5 mm thickness by using a cutting blade. The cut slices were blanched in hot water @ 60 °C containing 1% KMS for 5 minutes followed by air drying at room

Plate 3.1 Banana Fruit (cv. Dwarf Cavendish)

Plate 3.2 Cutting Blade and Freshly Cut Banana Slices

Plate 3.3 Electric Deep Fat Fryer

temperature for 15 min to remove surface moisture. Then the slices were atmospheric deep fat fried using refined sunflower oil. The frying was done at 3 different temperatures: 160, 180 and 200 °C for frying times of 8, 9 and 10 minutes in factorial combinations.

Table 3.1: Details of atmospheric deep fat frying treatments employed for the production of banana chips

Frying temperature (°C)	Frying time (min)		
	t_1=8	t_2=9	t_3=10
T1 - 160	T_1t_1	T_1t_2	T_1t_3
T2 - 180	T_2t_1	T_2t_2	T_2t_3
T3 - 200	T_3t_1	T_3t_2	T_3t_3

Independent variables:

Frying Temperature : 3 levels (160, 180 & 200 °C)

Frying Time : 3 levels (8, 9 & 10 min)

Dependent variables:

Chips out-turn;

Oil absorption by chips;

Chips physical characteristics - Crispiness, Tristimulus colour

Chips sensory quality: Colour, flavour, texture, taste and overall acceptability

Chips biochemical characteristics - moisture, free fatty acids, peroxide value

Statistical design - Factorial CRD

Number of treatments - 3×3

Replication - 2

3.4.2 Optimization of atmospheric deep fat frying process parameters

There are two independent parameters that affect the quality of deep fat fried chips: (1) frying temperature and (2) frying time. These two parameters were varied as per the scheme below and the resultant chips were tested for sensory quality, biochemical characteristics and physical parameters. Chips out-turn and oil absorption by fried chips were also studied.

3.5 Production of Vacuum Deep Fat Fried Banana Chips

This study mainly involved in use of a Vacuum fryer for the production of banana chips.

3.5.1 Vacuum fryer

The Vacuum fryer (Make: Viet Nam; Model: VF 400 VT) used in this study was a commercial batch processing equipment (Plate 3.10), completely made up of stainless steel. It consisted of mainly the following:

a) Vacuum frying chamber
b) Water jet operated vacuum pump with vapour condenser
c) Control panel
d) Sample loading basket with Pneumatic control
e) Basket centrifuge (for removal of oil from fried chips)

a) Vacuum frying chamber

It is the major component of the vacuum fryer in which the banana slices were fried into chips. This chamber was a large vat (vessel) that could hold approximately 75 litres of frying oil. The oil could be heated to a set frying temperature with the help of submerged electrical heating coils which were controlled by a Thermostat. The frying sample placed in the basket could be introduced into the frying chamber through the sample door. The sample basket was actually suspended from a top hook that could be moved up and down using pneumatic control mechanism assisted by using an external compressor. The frying chamber needs to be closed air-tight to create vacuum inside the frying chamber. There was an illuminated glass viewing window on one side of the frying chamber wall to monitor the frying operation. The frying chamber was provided with vacuum pressure gauge, pressure purge valve and also a safety valve.

Fully mature, unripe banana

↓

Washing and Peeling

↓

Cutting into slices using cutting blade

↓

Banana slices of 2.5 mm thickness

↓

Blanching in water @ 60 °C having 1% KMS for 5 min

↓

Air drying for 15 min

↓

Atmospheric deep fat frying in electrical deep fryer

↓

Hot fried banana chips

↓

Addition of salt (@ 2%) & chilly powder (@ 1%)

↓

Mixing & Packaging

↓

Atmospheric fried banana chips

Fig. 3.1: Process flow chart for production of banana chips by atmospheric deep fat frying

b) Water jet operated vacuum pump with vapour condenser

To create vacuum inside the frying chamber, an external vacuum pump operated by a water jet was provided. It will suck out the air/ vapour present in the frying chamber through a water cooled condenser. Water for the operation of vacuum pump and also for the condenser was supplied from a large cold water reservoir. Since water was recirculated, there was a simple cooling water tower (electric fan) was provided on the top of the water reservoir in order to cool the warm water from the condenser.

c) Control panel

The control panel was provided to control all the sub systems of the vacuum fryer. It is incorporated with all electricals like main power switch, control switches for vacuum pump, frying oil heaters, water pump and cooling fan. PLC controller for setting frying oil temperature was additionally mounted on the control panel.

d) Sample loading basket

The cylindrical sample loading basket with a lid was made up of stainless steel perforated sheet metal in which sample to be fried was loaded. The basket had a capacity to hold above 2-3 kg of frying material. A circular ring at the top of basket was provided to hang the basket from pneumatic control hook with which the basket could be drawn into the frying oil medium or lifted up with using compressed air.

e) Basket centrifuge

It is a separate unit in the vacuum fryer set up where the sample basket with vacuum fried chips could be subjected to centrifugation (@ 500 rpm) for the purpose of removal of residual surface oil from the fried chips. The basket was rotated at high speed to create required centrifugal force to expel out the excess oil from the fried sample. During centrifugation hot air (approx. 50 ºC) was blown through the fried sample loaded in the basket. To aid oil separation, the PLC temperature controller helps to control the temperature of the hot air generated inside the unit.

3.5.1.1 Operation of vacuum fryer

At the beginning, the frying chamber was filled with 60 litres of frying oil and the same oil level was maintained for all frying experiments. Initially, the frying oil temperature was set 5ºC above the desired value and the necessary air pressure (≈ 4 kg/cm^2) was created in the external air compressor for working of pneumatic cylinder which actually helps to lift or lower the sample basket hanged inside the vacuum frying chamber. When the temperature of the frying oil reached to desired level, the sample basket with prepared raw banana slices (sample size - 500 g) was hanged inside the vacuum frying chamber. The chamber door was closed air-tight and pressure purge valve was closed. The vacuum pump and cooling water pump were switched on to create desire vacuum inside the frying chamber. When the desired vacuum was created inside the chamber, the sample basket was immersed into frying oil medium using pneumatic control cylinder lever. Generally, the frying oil temperature dropped by 3-4 ºC at the beginning of frying operation and that is the reason for setting slightly higher frying oil temperature at the beginning of the operation. However, the frying oil temperature was reset to the desired value using temperature controller when the sample was loaded. At the beginning of the frying operation, lot of water gets evaporated from the sample that fog the chamber can be seen through viewing glass. The vapours meanwhile were sucked away by the vacuum pump and the frying process could be early seen through the illuminated viewing glass window. Frying was done for the set duration and at the end of the frying time, the sample basket was lifted up from the frying oil with the help of pneumatic control lever and allow to cool for about 5 minutes inside the frying chamber. The vacuum pump was shut down before taking out the sample basket, the purge valve was opened to normalize the pressure inside the chamber with atmosphere and the sample door was opened. The removed sample basket was immediately placed inside the centrifuge for residual surface oil removal from the fried banana chips. Circulation of hot air at about 50°C inside the centrifugation chamber helped to expel more oil from the fried chips. The fried chips were removed and weighed to compute chips out-turn. Salt (@ 2%) and chilly powder (@1%) were added to hot fried chips, mixed thoroughly and stored in LDPE bags for future analysis. Meanwhile, a second sample basket was readied for loading into vacuum fryer in order to reduce the loss of heat energy. Care was taken to maintain the same oil level in the frying camber during all experiments. Also, the required water level was maintained in the water reservoir for smooth functioning of vacuum pump and supply of cooling water to the condenser. Since the frying oil was reused, the oil condition was monitored using a Frying oil monitor (make: ATAGO; model: DOM- 24) which actually measures Total Polar Molecules (TPM) and Acid Value (AV) of oil.

3.5.2 Process of preparation of vacuum fried banana chips

The process flow chart of preparation of vacuum fried banana chips is presented Fig 3.2. The freshly peeled raw bananas were sliced to obtain approximately 2.5 mm thick slices using a cutting blade. The cut slices were blanched in hot water (@ 60 °C) containing 1% KMS for 5 minutes followed by air drying at room temperature for 15 min to remove surface moisture. Then the slices were vacuum fried at different frying conditions. After frying, the fried chips were de oiled by centrifugation at 500 rpm for 5 minutes. Frying was done under 2 different vacuum levels such as 640 and 400 mm Hg, at these pressures pure water will boil at 56 and 80 °C, resectively. Three different frying temperatures of 80, 90 and 100 °C and frying times of 15, 20, 25 and 30 min in factorial combinations were employed for banana chips production (Table 3.2).

3.5.3 Optimization of vacuum frying process parameters

There are three independent parameters that influenced the quality of vacuum fried chips: (i) Vacuum level (ii) Frying temperature and (iii) Frying time. These three parameters were varied as per the scheme below and the resultant chips were tested for sensory quality, biochemical characteristics and physical parameters. Chips out-turn and oil absorption by fried chips were also studied.

3.5.6 Frying oil monitor

Frying oil monitor is a device (Make: ATOGO Model: DOM-24) (Plate 3.10) used to periodically check and monitor the frying oil quality. This instrument is capable of measuring both TPM (Total Polar Molecules), an indicator of overall quality of frying oil, as well as AV (Acid Value), which indicates breakdown and changes in cooking oil parameter. The measurement range for TPM was 0.5 to 40% and 0.00 to 9.99 for AV.

Table 3.2: Details of vacuum frying treatments employed for the production of banana chips

Frying Vacuum Level	Frying Temperature	Frying Time (min)			
		t_1=15	t_2=20	t_3=25	t_4=30
640 mm Hg	T_1= 80 °C	$V_1T_1t_1$	$V_1T_1t_2$	$V_1T_1t_3$	$V_1T_1t_4$
	T_2= 90 °C	$V_1T_2t_1$	$V_1T_2t_2$	$V_1T_2t_3$	$V_1T_2t_4$
	T_3= 100 °C	$V_1T_3t_1$	$V_1T_3t_2$	$V_1T_3t_3$	$V_1T_3t_4$
400 mm Hg	T_1= 80 °C	$V_2T_1t_1$	$V_2T_1t_2$	$V_2T_1t_3$	$V_2T_1t_4$
	T_2= 90 °C	$V_2T_2t_1$	$V_2T_2t_2$	$V_2T_2t_3$	$V_2T_2t_4$
	T_3= 100 °C	$V_2T_3t_1$	$V_2T_3t_2$	$V_2T_3t_3$	$V_2T_3t_4$

Independent variables:

Frying Vacuum : 2 levels (640 & 400 mm Hg)

Frying Temperature : 3 levels (80, 90 & 100 °C)

Frying Time : 4 levels (15, 20, 25 & 30min)

Dependent variables:

Chips out-turn;

Oil absorption by chips

Chips physical characteristics - Crispiness, Tristimulus colour

Chips sensory quality - Colour, flavour, texture, taste and overall acceptability

Chips biochemical characteristics - moisture, free fatty acids, peroxide value

Statistical Design - Factorial CRD

Number of treatments - 2*3*4 = 24

Replications - 2

Fully mature, unripe banana

↓

Washing and Peeling

↓

Cutting into slice cutting blade

↓

Banana slices of 2.5 mm thickness

↓

Blanching for 5 min water @ 60 °C having 1% KMS for 5 min

↓

Air drying for 15 min

↓

Vacuum frying

↓

Centrifugation for de-oiling fried chips (500 rpm @ 5 min) & Cooling (@RT)

↓

Addition of salt (@2%) & chilly powder (@1%)

↓

Mixing & Packaging

↓

Vacuum fried banana chips

Fig. 3.2: Process flow chart for production of vacuum fried banana chips

1. **Vacuum fryer control panel**
2. **Vacuum frying chamber**
3. **Glass viewing window**
4. **Pneumatic cylinder control lever**
5. **Pneumatic cylinder with lift hook**
6. **Water/vapour condenser**
7. **Vacuum pump (water jet operated)**
8. **Water reservoir**
9. **Cooling tower (with fan)**
10. **Basket centrifuge**
11. **Control panel for centrifuge**
12. **Sample basket**
13. **Vacuum pressure guage**
14. **Pressure purge value**
15. **Thermostat**

Plate 3.4 Vacuum Fryer

Plate 3.5 Atmospheric Fried Banana Chips

640 mm Hg **400 mm Hg**

Plate 3.6 Vacuum Fried Banana Chips

Operation

1) Submerge the frying oil monitor in the frying oil below the marked line on the device.
2) Press start button for 1 s, the instrument will switch on and TPM (or) AV will be the displayed depending on selections.
3) The SW1 and SW2 settings were provided for TPM and AV measurement.

This instrument was used during vacuum frying of banana chips to check the quality of oil. The TPC and AV values were recorded periodically to know if the frying oil was fit for frying or not. The TPC value of frying oil should be below 25 and AV value should be below 3.0 to use it for frying.

3.6 Banana Chips Parameters

3.6.1 Chips out-turn

Chips out-turn indicate the yield per unit weight of raw materials (raw banana slices) used. It was calculated by using the formula:

$$Chips\ out\ turn = \frac{Weight\ of\ the\ fried\ chips}{Initial\ weight\ of\ raw\ slices} \times 100 \qquad \text{Eq ... 3.6}$$

3.6.2 Oil absorption by chips

Moisture free chips of 1- 2 g of sample was weighed in moisture free thimble and the crude fat of chips was extracted out by refluxing in Soxhlet apparatus (Plate 3.7) by using petroleum ether as solvent. The residual solvent was decanted from the chips and the weight of fat free chips sample was again determined. Then, the oil absorption by moisture free chips was calculated from weight difference (Anonymous, 1990) as:

$$\text{Oil absorption by banana chips (\%)} = \frac{\left(\begin{array}{c}\text{Initial weight of moisture free chips} \\ \text{- Weight of chips after fat extraction}\end{array}\right)}{\text{Initial weight of chips}} \times 100 \qquad \text{Eq…3.7}$$

3.6.3 Physical characteristics

The physical characteristics of chips measured in this study included tristimulus colour and crispiness.

3.6.3.1 Tristimulus colour

Tristimulus colour measurements of the vacuum and atmospheric fried banana chips were made using a Spectrophotometer (Make: Konica Minolta Instrument, Osaka, Japan; Model-CM5) (Plate 3.9). The instrument is a light weight, compact tristimulus colour analyzer for measuring reflected-light colour. It combines advanced electronic and optical technology to provide high accuracy and complete portability. Using an 8 mm diameter (measuring area) diffused illumination and 0° viewing angle, the instrument takes accurate colour measurements instantaneously and the readings are instantly displayed. In the present study, the colour of the sample was measured in L* a* b* coordinate system where L* indicate lightness of the sample; a* value indicate greenness (-) or redness (+) of the sample and b* value indicate blueness (-) or yellowness (+) of the sample. Three readings were taken for each sample and the mean value was reported.

3.6.3.2 Crispiness

Crispiness is most important textural property of fried chips. Crispiness is the characteristics of a product by which it resists compression force until it fractures into small pieces. It actually relates to the ease of fracture or fracturability and brittleness of the product. Crispiness of banana chips was studied using a Texture Analyzer (Make: Stable Microsystems Ltd, UK; Model – Hdi) and it was linked to a computer to record the data *via* Texture Expert Exceed software supplied along with the instrument. The Texture Analyzer measures force and distance in real time thus providing three dimensional product analyses. The texture of chips was expressed in terms of crispiness measured by conducting cutting test using blade set with knife supplied with texture analyzer. The test procedure included the cutting of chips using the blade set with knife and measuring the force of cutting in real time. During cutting test, a single blade having 70 mm width and 90 mm length was used to cut through the samples under specified conditions as shown in Plate 3.8. The heavy duty platform was secured to the base of the machine and slotted plate was placed on the platform. The banana chip 3 mm thickness were held manually against slotted base plate individually and the cutting test was conducted according to TA Settings mentioned in Table 3.3. The maximum force was recorded in real time by the texture analyzer and the data were transferred to a computer. Texture Expert Exceed software supplied with texture analyzer was used to analyze the force/time data to identify the absolute peak force required for cutting. Each measurement was taken in two replicates and the mean, maximum force of cutting was used to express the crispiness of the chips in grams 'g_f' (gram force)

Table 3.3: Texture analyzer settings for cutting test to measure crispiness of banana chips

Texture Analyzer Settings	
Mode	Measuring force in compression
Option	Return to start
Pre-test speed	2 mm/s
Test speed	2.0 mm/s
Post-test speed	5 mm/s
Distance (Compression)	4 mm/s for chips; 10 mm/s for raw fruit
Data acquisition	400 pps

3.6.4 Biochemical characteristics of banana chips

3.6.4.1 Moisture content of chips

Banana chips were analyzed for moisture content as per AOAC (1980) protocols. The moisture content was determined (for duplicate samples) by measuring weight loss of sample kept in moisture cup for desiccation in a hot air oven maintained at 105 ºC for 2 hours. The sample was taken out, weighed and again dried in the oven for half-an-hour to measure the weight once again. The procedure was repeated till two consecutive weights were same. The moisture content was estimated by using the formula:

$$\text{Moisture content \%} = \frac{\text{Initial weight of chips} - \text{Final weight of chips}}{\text{Initial weight of chips}} \times 100$$

Eq...3.8

3.6.4.2 Free fatty acids

Two grams of sample was dissolved in 50 ml of neutral solvent (25 ml ether, 25 ml 95% alcohol and 1 ml of 1% phenolphthalein indicator and neutralized by 0.1 N KOH). A few drops of phenolphthalein indicator were added to it and titrated against 0.1 N KOH till pink colour was obtained which persisted for 15 seconds (Sadasivam and Manickam, 2008)

$$\text{Free fatty acid } \left(\frac{\text{mg of KOH}}{\text{g}}\right) = \frac{\text{Titre value } \times \text{N. of KOH } \times 56.1}{\text{Weight of sample (g)}} \times 100$$

Eq…3.9

3.6.4.3 Peroxide value

Peroxide value of the banana chips was determined according to American Oil Chemists Society (AOCS, 2006) Official Methods. About 2 g of the chip sample was taken in a 250 ml conical flask and 30 ml of acetic acid-chloroform (3:2) mixture was added to it. The flask was swirled and then 0.5 ml of saturated potassium iodide was added. Then, the solution was mixed again for 1 minute and few drops of starch solution (1%) was added. The solution was titrated against previously standardized 0.05 N sodium thiosulphate solution, until the blue colour disappeared. The peroxide value was expressed in milli equivalents of peroxide per kg of the sample.

$$Peroxide\ value\ \left(\frac{meq}{kg\ of\ fat}\right) = \frac{S \times N \times 1000}{Weight\ of\ sample\ (g)} \times 100$$

Eq. …3.10

Where,

S= Sodium thiosulphate solution (Test-Blank)

N= Normality of sodium thiosulphate solution

Plate 3.7 Soxhlet Extraction Unit

Plate 3.8 Texture Analyzer

Plate 3.9 Spectrophotometer for Colour Measurement

Plate 3.10 Frying Oil Monitor

3.7 Sensory Quality of Banana Chips

The sensory evaluation of banana chips was carried out using 9-point hedonic scale (Amerine *et al.,* 1980) and the Performa used is given in Appendix-I. Banana chips of each treatment were judged for the sensory quality attributes such as colour /appearance, crispiness/texture, taste, flavour and overall acceptability by a panel of 10 judges. The average score given by all the judges for different quality characteristics were recorded and mean scores were computed.

3.8 Storage Study of Atmospheric and Vacuum Deep Fat Fried Banana Chips

Storage study of best adjudged atmospheric and vacuum deep fat fried banana chips was conducted. The banana chips were packed in 3 different types of packages namely, low density polyethylene (LDPE, 300 gauge), polypropylene (PP, 300 gauges) and metalized multilayer polyethylene (MMP) of 4 layers (viz., polyethylene, polyester, aluminium, polyethylene) with and without nitrogen flushing. The nitrogen gas was flushed in a Vacuum Packaging Machine (Make: Reepack, Italy; Made: RV 50) attached with a Gas Mixer. Vacuum level of 95% was first created in the package (vacuum chamber) and then nitrogen gas was flushed at a pressure of 2 kg/cm^2 for a set time of about 10 seconds and thermally sealed to make them air-tight. The packages were stored at ambient conditions of Bangalore for two months to study the shelf life of the Banana chips. The quality parameters such as moisture content, free fatty acids, peroxide value, tristimulus colour and crispiness of stored chips were analyzed at regular intervals of 15 days. The procedures adopted were already described in previous sub-sections.

Independent variables:

Types of banana chips	: 2 (Atmospheric and Vacuum fried)
Type of package	: 3 (LDPE, PE and MMP)
Gas flushing	: 2 (Nitrogen, No gas flushing)
Duration of storage	: 60 days (@15 days interval)

Dependent variables:

Chips moisture content

Free fatty acid

Peroxide value

Tristimulus colour

Crispiness

Sensory parameters

3.8 Statistical Analysis

Statistical analysis of experimental data was done using UAS, Bangalore Computer Facility. The data of the atmospheric and vacuum frying experiments were analyzed using Factorial Completely Randomized Design to determine the significant differences among treatments.

3.9 Cost-Economics of Banana Chips Production

Based on the cost of raw materials, processing, packaging and storage cost of banana chips, the Cost : Benefit Ratio of banana chips production was computed following standard procedures.

IV RESULTS AND DISCUSSION

The results of the present study entitled "Comparative Study of Atmospheric and Vacuum Deep Fat Frying of Banana Chips (var. *Dwarf Cavendish*)" conducted at the AICRP on Post-Harvest Engineering and Technology, Division of Agricultural Engineering, University of Agricultural Sciences, GKVK, Bangalore, are presented under the following major headings.

4.1 Physical and Chemical Properties of Banana (var. *Dwarf Cavendish*)

4.2 Optimization of Atmospheric Deep Fat Frying Parameters for Quality Banana Chips

4.3 Optimization of Vacuum Deep Fat Frying Process Parameters for Quality Banana chips

4.4 Storage Study of Atmospheric and Vacuum Deep Fat Fried Banana Chips

4.5 Cost Economics of Production of Fried Banana Chips

4.1 Physical and Chemical Properties of Banana

4.1.1 Physical properties of banana fruit

The Physical properties of unripe, fully matured raw banana of variety *Dwarf Cavendish* are presented in Table 4.1

4.1.1 Size

The length of fruit ranged from 140 to 180 mm with the average fruit length of 170 ± 2 mm. The diameter of the fruit was less at the ends, maximum at the middle of the fruit and the average diameter was 26.42 ± 2 mm. Kachru *et al*. (1995) reported that the maximum effective length and width of the banana fruit varied between 130 and 137 mm.

4.1.2 Pulp to skin ratio

The ratio of pulp to peel ranged from 1.37 to 1.51 with an average value of 1.45 ± 0.25. Kachru *et al.* (1995) reported a value of 1.18 for pulp to peel ratio for Dwarf Cavendish variety of banana.

4.1.3 Peel thickness

The average skin thickness of Dwarf Cavendish raw banana fruit was 4.71 ± 0.2 mm and it is well known that the skin thickness varies with ripening. Salvador *et al.* (2007) reported that during storage, the peel thickness decreased with colour changes from green to yellow.

4.1.4 Colour

The colour of banana fruit skin on second day of ripening (L*a*b*) was presented in the Table 4.1. The L* value of banana peel ranged from 56.11 to 56.23 with a mean value of 56.16; a* value ranged from 9.81 to 9.92 with a mean value of 9.84; and b* value ranged from 33.60 to 34.12 with a mean value of 33.80. The colour of the peel varies at different ripening stages. Maximum colour variation was reported to be observed after the 5th day of ripening. Salvador *et al*. (2007) reported that peel colour of Musa Cavendish banana varied from green to yellow during storage.

Table 4.1: Physical characteristics of banana (var. *Dwarf Cavendish*)

Physical parameters	Values		Mean Values
	Min	Max	
Length of the fruit (mm)	150	190	170
Peel thickness (mm)	4.45	4.95	4.71
Pulp to peel ratio	1.30	1.81	1.51
Cutting strength (g_f)	16,040	16,092	16,084.
Average weight of the fruit (g)	110	135	116
Skin colour of fruit (L* a* b*)	L* 51.22 a* 8.05 b* 31.20	L* 59.27 a* 11.31 b* 36.14	L* 56.11 a* 9.81 b* 33.60
Fruit diameter (mm)	22.24	30.40	26.42 ± 2

4.1.5 Cutting strength

Hardness is a characteristic of a product by which it resists compressive failure. It is determined by measuring the maximum force to compress the given layer of the product.

During compression of the product, the number of peaks or total length of the Force-Deformation (Time) curve will give a measure of this property. The cutting strength of deskinned banana pulp was recorded to be 16,084 (g_f).

4.1.2 Biochemical characteristics of raw banana fruit

The chemical characteristics of fully matured, unripe raw banana fruit pulp of selected variety *Dwarf Cavendish* are presented in Table 4.2. The moisture content of raw banana pulp was 70.75%; Total soluble solids was 3.1 °Brix; Acidity was 1.62%; Total sugars was 1.24%; Reducing sugar was 0.6%; the dry matter content was 29.25% and the starch content was 21.24%.

Table 4.2: Biochemical characteristics of banana fruit (var. *Dwarf Cavendish*)

Parameters	Values
Moisture content (%)	70.75
TSS (°B)	3.1
Acidity (%)	1.62
Total sugar (%)	1.24
Reducing sugar (%)	0.61
Dry matter content (%)	29.25
Starch (%)	21.24

4.2 Optimization of Atmospheric Deep Fat Frying Parameters for Quality Banana Chips

Trials were conducted to optimize the atmospheric deep fat frying process variables for production of banana chips using mature unripe banana fruits. Three atmospheric frying temperature levels (160, 180 and 200 ºC) and frying times (8, 9 and 10 min) were employed to produce quality banana chips. The chips out-turn, oil absorption, crispiness, tristimulus (instrumental) colour, sensory and biochemical characteristics of banana chips were studied and the results are presented below.

4.2.1 Fried chips out-turn under atmospheric deep fat frying

The out-turn or yield of banana chips fried under two different combinations of processing parameters namely, frying temperature and frying time is presented in Table 4.3. The fried banana chips out-turn was about 39.24 - 34.83%. A significant variation was noticed in chips out-turn at different processing conditions. The mean chips out-turn under atmospheric frying temperature of 160, 180 and 200 ºC were 39.64, 41.82 and 43.46%, respectively. Statistically significant difference was observed in the out-turn of atmospheric fried banana chips fried at different temperatures. Under atmospheric frying, banana chips out-turn were 41.29, 41.68 and 41.95% respectively for frying duration of 8, 9 and 10 minutes. Statistical analysis showed that there was significant difference between out-turn of atmospheric fried banana chips with respect to frying time. In case of atmospheric frying, the interaction effect of frying temperature and frying time was not significant as for as chips out-turn was concerned. Increased chips out-turn was noticed at higher frying temperatures as well as for longer frying duration perhaps due to increased oil absorption by the chips (Sagay and Dana, 2003; Budzaki and Seruga, 2005) under the above condition.

4.2.2 Oil absorption by atmospheric deep fat fried banana chips

The oil absorption by banana chips fried under different combinations of processing parameters namely, frying temperature and frying time are presented in Table 4.4. The mean oil absorption of atmospheric fried chips at 160, 180 and 200 ºC were 41.74, 46.53 and 48.61%, respectively. Statistical analysis indicated that there was significant difference between oil absorption by banana chips fried at different frying temperatures. The oil absorption of atmospheric fried chips was 44.76, 45.80 and 46.31% respectively for frying duration of 8, 9 and 10 minutes. Statistical analysis showed that within the experimental range, there was no significant difference between oil absorption by banana chips fried for different frying time periods. The interaction effect of frying temperature and frying time was also not significant for oil absorption by banana chips. The frying oil actually occupied the pores left behind by the evaporated moisture. Saguy and Dana (2003) reported that more oil was absorbed by the chips in deep fat frying since higher oil temperature were used for frying and that caused faster removal of moisture from the chips. Budzaki and

Table 4.3: Banana chips out-turn at different atmospheric frying conditions

Frying temperature (ºC)	Out turn of Banana chips (%)			
	Frying time (min)			Mean
	8	9	10	
160	39.24	39.24	39.98	39.64
180	41.62	41.80	42.12	41.82
200	43.01	43.54	43.83	43.46
Mean	41.29	41.68	41.95	**41.65**
	F - value	**SEM**	**CD (@5%)**	
T	*	0.03	0.09	
t	*	0.03	0.09	
T × t	NS	0.05	NS	

Note: *= Significant NS= Not significant

Table 4.4: Oil absorption by atmospheric fried banana chips processed at various frying conditions

Frying temperature (ºC)	Oil absorption by banana chips (%)			
	Frying time (min)			Mean
	8	9	10	
160	40.05	41.98	43.17	41.74
180	43.17	46.62	46.85	46.53
200	48.11	48.79	48.91	48.61
Mean	44.76	45.80	46.31	**45.29**
	F - value	**SEM**	**CD (@5%)**	
T	*	0.150	0.150	
t	NS	0.150	NS	
T × t	NS	0.260	NS	

Note: *= Significant NS= Not significant

Seruga (2005) also reports that the oil uptake and moisture loss were move initially at higher frying temperatures.

4.2.3 Physical characteristics of atmospheric fried banana chips

The two physical characteristics of atmospheric fried banana chips namely, (instrumental) tristimulus colour and crispiness were studied for the experiment are presented below.

4.2.3.1 Tri-stimulus colour

The tristimulus colour of atmospheric fried banana chips in terms of L*a*b* values are presented in Table 4.5. At three different frying oil temperatures of 160, 180 and 200 ºC, the colour of banana chips varied as: lightness L*- 57.69 to 57.98, 61.80 to 62.12 and 61.94 and 62.78; a* - 11.72 to 11.50, 12.80 to 12.69 and 13.05 to 13.69; b* - 35.49 to 35.34, 34.12 to 34.03 and 31.85 to 31.69, respectively. The colour change during frying was mainly due to biochemical changes that takes place in the fried chips. Most of the moisture gets evaporated and there was a formation of thin crust on the surface of the chips. Lot of frying oil also finds entry into the banana chips. All the above contribute to change in colour of fried chips (Farkas *et al*. 1995; Keller *et al*., 1986). The frying temperature had a negative effect on lightness of product. Krokida *et al.* (2001) also reported that increase in temperature of frying oil and frying duration highly influenced in colour of potato chips due to interaction of product and frying oil during frying. Avoiding, browning of food during frying is most important since it may lead to significant loses of nutrients also.

4.2.3.2 Crispiness

Crispiness is the common textural property possessed by snack food. It is usually associated with many small fracture peaks. The crispiness also related to brittleness or fracturability of the product structure. In case of fried chips, the cutting strength of chips can also give a measure of the crispiness. The breaking force of atmospheric fried banana chips obtained from different frying temperatures and frying times is presented in Table 4.6. It was observed that the frying temperature and frying time had significant effect on the breaking force of chips. The breaking force decreased when the frying temperature and

Table 4.5: Tristimulus colour of atmospheric fried banana chips processed at various frying conditions

Frying Conditions		Tristimulus Colour		
Temperature (ºC)	**Time (min)**	L*	a*	b*
160	8	57.69	11.72	35.49
	9	57.81	11.66	35.40
	10	57.98	11.50	35.34
180	8	61.80	12.80	34.12
	9	61.92	12.74	34.08
	10	62.12	12.69	34.03
200	8	57.98	13.05	31.85
	9	59.97	13.12	31.80
	10	62.78	13.17	31.69

Table 4.6: Crispiness (Cutting strength) of atmospheric fried banana chips processed at various frying conditions

Frying temperature (ºC)	Crispiness (Cutting strength) of Banana Chips (g_f)			
	Frying time (min)			Mean
	8	**9**	**10**	
160	2284.16	2028.26	1890.55	2085.65
180	2025.84	2575.24	2436.12	2345.23
200	2357.09	2099.54	1985.89	2131.00
Mean	2222.53	2252.34	2087.02	**2186.57**
	F – value	**SEM**	**CD (@5%)**	
T	*	8.82	28.63	
t	*	8.82	28.63	
T × t	*	15.28	49.59	

Note: *= Significant NS= Not significant

frying time increased. The crispiness atmospheric fried chips were 2085.65, 2345.23 and 2131 g_f respectively for chips fried at 160, 180 and 200 ºC. Statistically significant difference was observed in crispiness of banana chips fried at different temperatures. The mean value of crispiness of atmospheric fried chips were, 2222.53, 2252.34 and 2087.02 g_f respectively for frying duration of 8, 9 and 10 minutes. The crispiness was significantly different when fried for different durations. The interaction effect between frying temperature and frying time on crispiness of chips was also significant. Shyu and Hwang (2001) measured crispiness of banana chips in terms of breaking force in the texture analyzer and reported that the crispiness of chips varied due to moisture variation, is influenced by frying temperature and time. Lower breaking force (better crispiness) was observed for chips fried at higher temperatures.

4.2.4 Biochemical characteristics of atmospheric fried banana chips

The biochemical characteristics namely, moisture content, free fatty acids and peroxide value of atmospheric fried banana chips were studied are presented below.

4.2.4.1 Moisture content

The moisture content of banana chips fried under different combinations of frying temperature and frying time at atmospheric pressure are presented in Table 4.7. The mean moisture content of atmospheric fried banana chips fried at 160, 180 and 200 ºC were 5.21, 4.19 and 3.81%, respectively. Statistical analysis showed that there was a significant difference between moisture content of fried banana chips with respect to frying temperature. For atmospheric fried chips, the mean moisture contents were 4.48, 4.46 and 4.27% respectively for frying time periods of 8, 9 and 10 minutes. There was no significant variation in moisture content of fried chips was observed with respect to frying duration. Further the interaction effect was also not significant.

Molla *et al.* (2008) observed that the rate of water removal depended on frying time and temperature. Getting 4% moisture content in banana chips required frying time of 3 minutes at 170 ºC. Many studies indicated that the chips fried at higher frying temperatures relatively had lower moisture content (Sahin *et al.*, 1999; Satishkumar, 2014). This was mainly attributed to higher heat transfer rate from the frying medium to chips surface owing to higher heat transfer potential that quickly evaporated the moisture present in the banana chips.

4.2.4.2 Free fatty acids

The free fatty acids of banana chips fried under different combinations of processing parameters namely, frying temperature and frying time are presented in Table 4.8. The mean free fatty acids (mg of KOH/g) of atmospheric fried banana chips were 0.43, 0.78 and 0.91 (mg of KOH/g) respectively for frying under 160, 180 and 200 ºC temperature. Statistical analysis showed that there was significant difference between free fatty acids content of banana chips with respect to frying temperature employed. The mean free fatty acids content of atmospheric fried chips fried for different durations of 8, 9 and 10 minutes were 0.68, 0.71 and 0.74 (mg of KOH/g), respectively. Statistically there was no significant difference observed in free fatty acids content of atmospheric fried banana chips with respect to frying durations. Aida *et al*. (2016) reported that oil heated to higher temperature for longer time during frying lead to degradation of oil and also free fatty acids content of banana chips. At similar frying conditions, an increase in FFA of jack fruit chips was observed by Satishkumar (2014).

4.2.4.3 Peroxide value

The peroxide value of banana chips fried under different combinations of frying temperature and frying time are presented in Table 4.9. The mean peroxide value (meq / kg of fat) of atmospheric fried banana chips at 160, 180 and 200 ºC frying temperatures were 16.06, 19.11 and 20.41 (meq / kg of fat), respectively. Statistically there was a significant difference observed in peroxide value of chips fried at different temperatures. The mean peroxide value of atmospheric fried chips for frying durations of 8, 9 and 10 minutes were 17.97, 18.46 and 19.14 (meq / kg of fat) respectively. With respect atmospheric frying time period, there was a significant difference between peroxide value of banana chips. The interaction effect of frying temperature and frying time was also significant as far as peroxide value of chips was concerned.

The main reason for increase in peroxide value of banana chips with respect to increase in frying temperature and frying time were due to: (i) Enhanced degradation of frying oil as well as biochemical modification of chips constituents producing free fatty acids and peroxides that increased the peroxide value and (ii) Increased oil absorption by chips. Amany *et al*. (2012) reported that deep fat fried potato chips were higher peroxide value (45.13 meq / kg) at higher frying temperature and frying time. Satishkumar (2014) for jack fruit chips also reported increase in peroxide value of fried chips at higher frying temperature.

The main source of FFA in fried banana chips was the observed oil by the chips during frying process. The cooking oil when heated to high temperatures was known to break down (depending on the type of the oil) and produce free fatty acids due to oxidation: At higher temperatures of frying, the chips actually were found to absorb more oil as explained earlier in Sec 4.2.2 which ultimately increased the FFA content of the chips.

4.2.5 Sensory quality of atmospheric fried banana chips

The sensory characteristics of banana chips such as colour, crispiness, taste, flavour and overall acceptability were tested by the sensory panel of 10 judges and the mean sensory scores of various atmospheric frying treatments are presented in the Tables 4.10.

4.2.5.1 Colour

The mean sensory scores for "colour" of atmospheric fried banana chips fried under different combinations of process parameters namely, temperature and time are presented in Fig 4.1. The mean sensory colour scores of fried chips were 7.58, 7.66 and 7.40 respectively for frying 160, 180 and 200 $^{\circ}$C frying temperature. Statistical analysis (Appendix- IV) showed that there was no significant difference between colour scores of fried chips with respect to frying temperature employed in this study. The mean sensory colour scores of chips were 7.43, 7.75 and 7.46 respectively for frying durations of 8, 9 and 10 minutes shows statistically significant effect. The interaction effect of frying time and frying temperature was also significant. Generally, for longer frying times especially at

Table 4.7: Moisture content of atmospheric fried banana chips at various frying conditions

Frying temperature (˚C)	Moisture content of Banana chips (% w.b)			
	Frying time (min)			Mean
	8	9	10	
160	5.28	5.20	5.14	5.21
180	4.11	4.34	4.12	4.19
200	4.05	3.84	3.55	3.81
Mean	4.48	4.46	4.27	**4.40**
	F - value	**SEM**	**CD (@5%)**	
T	*	0.04	0.14	
t	NS	0.04	NS	
T × t	NS	0.07	NS	

Note: *= Significant NS= Not significant

Table 4.8: Free fatty acids value of atmospheric fried banana chips for different frying conditions

Frying temperature (˚C)	Free fatty acid value of banana chips (mg of KOH/g)			
	Frying time (min)			Mean
	8	9	10	
160	0.34	0.45	0.51	0.43
180	0.86	0.75	0.75	0.78
200	0.84	0.92	0.97	0.91
Mean	0.68	0.71	0.74	**0.71**
	F - value	**SEM**	**CD (@5%)**	
T	*	0.01	0.03	
t	NS	0.01	NS	
T × t	NS	0.02	NS	

Note: *= Significant NS= Not significant

Table 4.9: Peroxide value of atmospheric fried banana chips at various frying conditions

Frying temperature (°C)	Peroxide Value of Banana Chips (meq / kg of fat)			
	Frying time (min)			Mean
	8	9	10	
160	14.31	16.50	17.37	16.02
180	19.73	18.31	19.28	19.11
200	19.88	20.56	20.78	20.41
Mean	17.97	18.46	19.14	**18.52**
	F - value	**SEM**	**CD (@5%)**	
T	*	0.04	0.13	
t	*	0.04	0.13	
T x t	*	0.07	0.23	

Note: *= Significant NS= Not significant

Table 4.10: Mean sensory scores of atmospheric fried banana chips fried at various frying conditions

	Colour	Flavour	Texture	Taste	Overall acceptability
T_1t_1	7.21	7.525	7.050	7.075	7.100
T_1t_2	7.77	7.825	7.225	7.175	7.275
T_1t_3	7.76	7.700	7.575	7.675	7.850
T_2t_1	7.54	7.475	8.000	7.585	7.475
T_2t_2	7.83	7.710	8.125	8.125	8.100
T_2t_3	7.61	7.700	8.025	7.925	7.860
T_3t_1	7.54	7.700	7.745	7.640	7.655
T_3t_2	7.66	7.520	7.590	7.555	7.765
T_3t_3	7.01	6.695	7.635	6.955	7.080

Frying temperature: T_1 - 160 °C; T_2 - 180 °C; T_3 - 200 °C
Frying duration : t_1 - 8 min ; t_2 - 9 min; t_3 - 10 min

high frying temperatures, the chips tend to turn darker due to complex biochemical reaction including enzymatic browning that take place in the fried material. Krokida *et al*. (2001) reported that frying time and frying temperature of oil directly affected the color of the potato chips. Moyano *et al*. (2002) also observed colour changes in impregnated French fries due to variation in deep fat frying condition.

4.2.5.2 Flavour

The mean sensory "flavour" scores of atmospheric fried banana chips fried under different frying temperature and time combinations are presented in Fig 4.1. The mean sensory scores for flavour of atmospheric fried chips were 7.68, 7.62 and 7.30 respectively for frying temperature of 180, 190 and 200 ˚C. Statistical analysis (Appendix IV showed that there was significant difference between flavour of banana chips with respect to different atmospheric frying temperature employed. The mean sensory flavor scores of fried chips for frying durations of 8, 9 and 10 minutes were 7.56, 7.68 and 7.36, respectively. Atmospheric frying time within the experimental range did not influence the flavour of fried chips. The interaction effect between of frying time and frying temperature was also not significant.

4.2.5.3 Texture (Crispiness)

The mean sensory "texture" scores of atmospheric fried banana chips fried under different combinations of frying temperature and time are presented in Fig 4.1. The mean sensory texture scores of fried chips processed at 160, 180 and 200 °C were 7.28, 8.05 and 7.65, respectively. Statistically significant difference was observed in sensory texture scores of chips fried at different temperatures (Appendix IV). The mean sensory texture scores of fried chips were 7.59, 7.64 and 7.74 respectively for various frying durations of 8, 9 and 10 minutes. Atmospheric frying time within the experimental range did not influence the texture of fried chips. The interaction effect between frying temperature and frying time was also not significant. Any deep fat fried product has a characteristic texture, more closely associated with crispiness. The banana slices when fried at high temperatures especially for longer durations will results in chips of low moisture contents (< 4%) which get better sensory scores due to their crispiness. Satishkumar (2014) reported better sensory texture scores for jackfruit chips when fried at higher temperatures.

4.2.5.4 Taste

The mean sensory “taste” scores of atmospheric fried banana chips fried under different combinations of frying process parameters namely, temperature and time are presented in Fig 4.1. The mean sensory taste scores of fried chips processed at 160, 180 and 200 °C were 7.30, 7.87 and 7.38, respectively and for various frying durations of 8, 9 and 10 minutes the scores were 7.43, 7.61 and 7.51, respectively. Both, the frying time did not significantly influence the fried chips. The interaction effect of frying temperature and frying temperature was also found to be significant (Appendix IV). The taste of the chips mainly depends on composition of the food material and interaction between the food materials with frying oil during frying process. Optimally fried chips especially with good colour are generally perceived to be tastier.

4.2.5.5 Overall acceptability

The mean sensory scores for “overall acceptability” of atmospheric fried banana chips fried at different temperature and time combinations are presented in Fig 4.1. The mean overall acceptability scores of chips fried at 160, 180 and 200 °C were 7.40, 7.81 and 7.51, respectively and statistically no significant difference was observed in sensory overall acceptability scores of chips fried at different temperatures. The mean sensory scores for overall acceptability of atmospheric fried chips were 7.41, 7.71 and 7.59 respectively for frying durations of 15, 20 and 25 minutes and the frying time significantly influenced the taste of fried chips. The interaction effect between frying temperature and time was also found to be significant (Appendix IV). The overall acceptability is basically a comprehensive assessment of fried chips encompassing various sensory attributes like coloue, flavor, texture and taste. As discussed earlier, the frying condition significantly affected all the above four attributes and therefore, the overall acceptability also.

4.2.2.6 Selection of optimum atmospheric frying conditions for banana chips

Trials were conducted to optimize the atmospheric fried banana chips production process parameters using matured unripe banana fruit slices. Three frying temperatures (160, 180 and 200 °C) and frying durations (8, 9 and 10 minutes) were employed to produce banana chips of better acceptability and with relatively lower fat content. The experimental

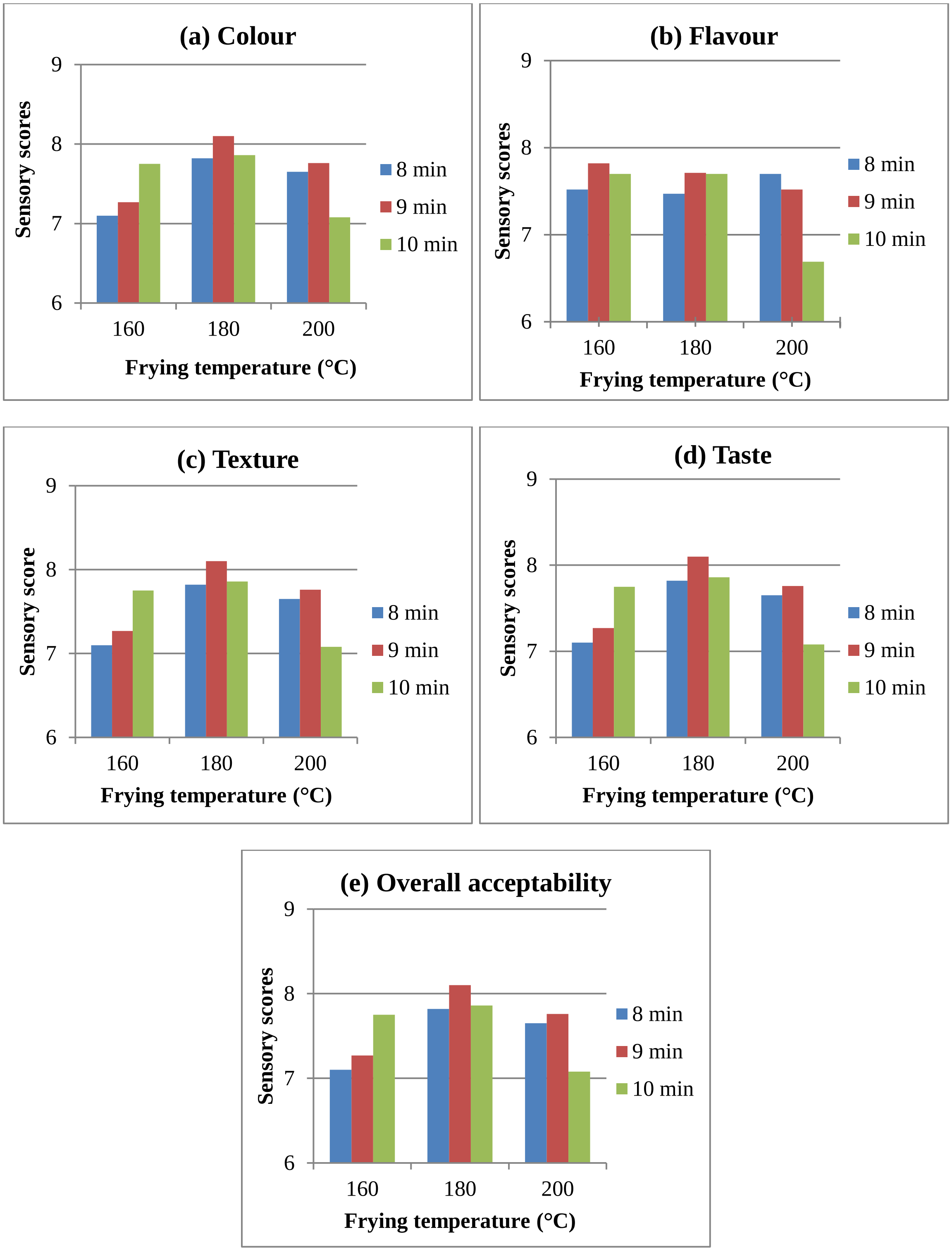


Fig. 4.1: Effect of frying temperature and time on sensory qualities of atmospheric fried banana chips

banana chips samples were tested for sensory characteristics by using 9-point hedonic scale. The organoleptic qualities of the banana chips such as colour, crispiness, taste, flavour and overall acceptability were tested by a sensory panel of 10 judges. From the sensory scores of banana chips of various frying treatments, it could be seen that banana chips fried at 180 ˚C frying temperature for 9 minutes showed highest sensory scores with respect to colour (7.83), texture (7.71), flavour (8.12), taste (8.12) and overall acceptability (8.10). The crispiness, colour and overall acceptability scores were the main criteria for the selection of optimum frying conditions. Hence, the frying process combination of 180 °C frying temperature and 9 minutes of frying time was selected as optimum to obtain good quality banana chips (from var. Dwarf Cavendish) by atmospheric frying techniques.

4.3 Optimization of Vacuum Frying Process Parameters for Quality banana chips

The trials were conducted to optimize vacuum frying process parameters for banana chips using mature, unripe *Dwarf Cavendish* banana fruit. Two vacuum levels (640 and 400 mm Hg), three frying temperatures (80, 90 and 100 ˚C) and four frying times (15, 20, 25 and 30 min) were employed to produce low fat banana chips. The chips out-turn, oil absorption, crispiness, tristimulus (instrumental) colour, sensory and biochemical characteristics of vacuum fried banana chips were studied and the results are presented below.

4.3.1 Fried chips out-turn under vacuum frying

The chips out-turn or yield of banana chips fried under different combinations of vacuum level, frying temperature and frying time are presented in Table 4.11. The fried banana chips out-turn in case of vacuum frying ranged from 36.24 to 45.53 % and the mean value was 40.02. The significant variation was noticed in chips out-turn at different processing conditions. The mean chips out-turn under 640 and 400 mm Hg vacuum were 37.26% and 42.79, respectively. Statistically significant difference was observed in out-turn of vacuum fried banana chips fried at different vacuum levels. The banana chips out-turn under vacuum frying temperatures of 80, 90 and 100 ˚C and for frying duration of 15, 20, 25 and 30 minutes were 39.46, 40.03, 40.14 and 40.46 %, respectively. Statistical analysis showed that there was significant difference between out-turn of vacuum fried

Table 4.11: Out-turn of banana chips processed at different vacuum frying conditions

Frying Conditions			Fried Chips Out-turn (%)
Vacuum (mm Hg)	**Temperature (ºC)**	**Time (min)**	
640	80	15	37.20
		20	36.24
		25	36.40
		30	36.54
	90	15	36.30
		20	36.88
		25	36.91
		30	37.03
	100	15	37.49
		20	38.47
		25	38.56
		30	39.12
400	80	15	40.37
		20	40.54
		25	40.96
		30	41.36
	90	15	42.23
		20	42.63
		25	42.76
		30	43.19
	100	15	44.14
		20	44.48
		25	45.28
		30	45.53
		Grand Mean	**40.02**

ANOVA

Vacuum (V)	**640 mm Hg**		**400 mm Hg**	
Mean	37.26		42.79	
Temperature (T)	**80 ºC**		**90 ºC**	**100 ºC**
Mean	38.70		39.74	41.63
Time (t)	**15 min**	**20 min**	**25 min**	**30 min**
Mean	39.46	40.03	40.14	40.46

	F value	SEM	CD (@5%)
V	*	0.010	0.030
T	*	0.012	0.036
T	*	0.014	0.042
V x T	*	0.018	0.051
V x t	*	0.020	0.059
T x t	*	0.025	0.072
V x T x t	*	0.035	0.102

banana chips fried at different time duration and temperature. It could be observed that all the interaction effects of frying parameters namely, vacuum levels, temperature and time were also significant.

The variation in fried banana chips out-turn was mainly attributed to different oil absorption by the chips due to the influence of vacuum frying parameters. As explained in previous section, the oil absorption was related to loss of moisture by chips during frying, increased oil absorption when moisture loss was more. Jamaluddin *et al* (2016) found that higher the frying temperature and vacuum the jack fruit chips absorbed more oil and *vice versa*. Nagarathna (2017) also reported that chips out-turn in case of jackfruit was significantly influenced by frying temperature and frying time.

4.3.2 Oil absorption by vacuum fried banana chips

The oil absorption of banana chips fried under different combinations of processing parameters namely, vacuum level, frying temperature and frying time are presented in Table 4.12. The mean oil absorption of vacuum fried chips at 640 and 400 mm Hg were 25.33 and 24.59 %, respectively. Statistical analysis indicated that there was a significant difference in the oil absorption of banana chips fried at different vacuum levels. The mean oil absorption of vacuum fried chips was 23.76, 24.97 and 26.15% respectively for frying temperature of 80, 90 and 100 ˚C and 24.44, 24.77, 25.17 and 25.46 for frying duration of 15, 20, 25 and 30 minutes. Statistical analysis showed that there was significant difference in oil absorption by banana chips fried under different temperatures for different time periods. The interaction effects of vacuum, frying temperature and frying time was also significant. Moreira *et al*. (2009) absorbed that vacuum fried snacks absorbed 27% less oil compared to atmospheric frying, mainly because vacuum frying carried at low frying oil temperature. Ruttanadech and Chungcharoen (2015) reported that oil uptake by vacuum fried chips was affected by frying temperature and time and it increased with increase in both frying temperature and frying time. The oil uptake was 11.19, 15.45 and 20.23 for 15 min vacuum frying at 80, 90 and 100 °C which increased respectively to 27.91, 32.77 and 38.12 for 30 min frying. The increase in oil uptake was stated to be related to the loss of moisture during frying.

Table 4.12: Oil absorption of banana chips processed at different vacuum frying condition

Frying Conditions			Oil Absorption by Fried Chips (%)
Vacuum (mm Hg)	**Temperature (ºC)**	**Time (min)**	
640	80	15	23.92
		20	24.10
		25	24.53
		30	24.74
	90	15	24.96
		20	25.27
		25	25.45
		30	25.64
	100	15	25.82
		20	26.01
		25	26.57
		30	26.94
400	80	15	22.42
		20	22.84
		25	23.68
		30	23.87
	90	15	24.05
		20	24.50
		25	24.82
		30	25.12
	100	15	25.50
		20	25.89
		25	26.02
		30	26.46
Grand Mean			**24.96**

ANOVA				
Vacuum (V)	**640 mm Hg**		**400 mm Hg**	
Mean	25.33		24.59	
Temperature (T)	80 ºC	90 ºC		100 ºC
Mean	**23.76**	**24.97**		**26.15**
Time (t)	**15 min**	**20 min**	**25 min**	**30 min**
Mean	24.44	24.77	25.17	25.46
	F value	**SEM**		**CD (@5%)**
V	*	0.012		0.035
T	*	0.015		0.043
t	*	0.017		0.050
V x T	*	0.021		0.061
V x t	*	0.024		0.070
T x t	*	0.029		0.086
V x T x t	*	0.042		0.121

4.3.3 Physical characteristics of vacuum fried banana chips

Physical characteristics of banana chips namely, (instrumental) tristimulus colour and crispiness were studied for the experimental vacuum fried banana chips samples and are presented below.

4.3.3.1 Tristimulus colour

The tristimulus colour of vacuum fried banana chips in terms of L*a*b* values are presented in Table 4.13. For chips fried under vacuum level of 640 mm Hg the lightness L* value ranged from 58.24 to 64.02; a* value ranged from 5.08 to 6.89; and b* value ranged from 30.23 to 33.99. Similarly for the chips fried under 400 mm Hg, the L*, a* and b* values are ranged from 52.53 to 61.56, 6.54 to 8.98, 27.31 to 37.07 respectively. Generally, chips fried at higher temperatures were slightly darker for the same vacuum and frying durations. Da Silva and Moriera (2008) reported that vacuum fried vegetable based snacks were of much better quality with good retention of colour due to reduced oxidation oil under lower frying temperature employed in vacuum frying when compared to atmospheric frying. Amany *et al.* (2012) stated that there was a significant effect on colour of fried potato chips, a lower extent of browning in case of vacuum frying.

4.3.3.2 Crispiness

Crispiness is the unique textural property of all fried chips. It is usually associated with micro fractures when crushed or munched. The crispiness also related to brittleness or fracturability of the product structure. In case of fried chips, the cutting strength may also give a measure of the crispiness. The breaking force of vacuum fried banana chips obtained from different vacuum levels, frying temperatures and frying times was presented in Table 4.14. It was observed that the frying temperature and frying time had significant effect on the breaking force. Generally, the breaking strength of chips decreased when the frying temperature and frying time increased. The mean values of crispiness of chips were 1381.37 and 2133.53 g_f respectively for chips fried under 640 and 400 mm Hg. The crispiness of vacuum fried chips was 1750.07, 1878.68 and 1794.54 gf respectively for frying temperature of 80, 90 and 100 $^{\circ}$C. The crispiness of vacuum fried chips was 1700.42, 1819.91, 1741.26 and 1753.86 g_f respectively for 15, 20, 25 and 30 minutes of frying time.

Table 4.13: Tristimulus colour of vacuum fried banana chips processed at various frying condition

Frying Conditions			Tristimulus Colour		
Vacuum (mm Hg)	**Temperature (ºC)**	**Time (min)**	**L***	**a***	**b***
640	80	15	64.02	5.08	30.23
		20	63.75	5.24	33.99
		25	63.02	5.40	33.30
		30	62.69	5.59	32.05
	90	15	63.27	5.72	32.46
		20	62.88	5.89	32.25
		25	62.10	6.01	32.04
		30	61.95	6.14	31.84
	100	15	61.78	6.34	31.72
		20	61.22	6.50	31.57
		25	59.95	6.65	31.42
		30	58.24	6.89	31.28
400	80	15	61.56	6.54	31.07
		20	59.02	6.87	29.85
		25	57.91	7.04	29.62
		30	55.26	7.36	29.35
	90	15	60.08	7.54	29.10
		20	58.48	7.70	28.74
		25	58.03	7.92	28.42
		30	56.12	8.05	28.21
	100	15	54.87	8.26	28.01
		20	54.30	8.42	27.84
		25	53.09	8.67	27.65
		30	52.53	8.98	27.31

Table 4.14: Crispiness (Cutting strength) of vacuum fried banana chips processed at various frying conditions

Frying Conditions			Crispiness of Fried Chips (g_f)
Vacuum (mm Hg)	Temperature (ºC)	Time (min)	
640	80	15	1852.74
		20	1921.64
		25	1626.16
		30	1798.33
	90	15	2082.07
		20	1904.01
		25	1989.16
		30	1824.07
	100	15	2182.67
		20	1958.41
		25	1725.58
		30	1524.61
400	80	15	1757.59
		20	1695.78
		25	1745.64
		30	1602.20
	90	15	1892.11
		20	2123.29
		25	1339.13
		30	1927.63
	100	15	2012.09
		20	1829.83
		25	1495.13
		30	1627.50
		Grand Mean	**1809.89**

ANOVA

Vacuum (V)	640 mm Hg		400 mm Hg	
Mean	1381.37		2133.53	
Temperature (T)	**80 ºC**	**90 ºC**		**100 ºC**
Mean	1750.07	1878.68		1794.54
Time (t)	**15 min**	**20 min**	**25 min**	**30 min**
Mean	1700.42	1819.91	1741.26	1753.86

	F-value	SEM	CD (@5%)
V	*	3.208	9.365
T	*	3.929	11.470
t	*	4.536	13.244
V x T	NS	5.556	NS
V x t	*	6.415	18.730
T x t	*	7.857	22.939
V x T x t	*	11.112	32.441

Statistically significant difference was observed in crispiness of chips fried at different vacuum level, frying temperature and time. The interaction effects between vacuum level, frying temperature and frying time were significant. Tinako *et al.* (2008) reported that frying temperature had significant effect on crispiness of pineapple chips in which hardness decreased with increase in temperature.

4.3.4 Biochemical characteristics of vacuum fried chips

The biochemical characteristics of vacuum fried banana chips namely, moisture content, free fatty acids and peroxide value were studied and are presented below.

4.3.4.1 Moisture content

The moisture content of banana chips fried under three different combinations of processing parameters namely, vacuum level, frying temperature and frying time are presented in Table 4.15. The mean moisture content of banana chips fried under 640 and 400 mm Hg vacuum levels were 5.88 and 3.88%, respectively. The mean moisture content of chips fried at temperature levels of 80, 90 and 100 ˚C were 5.54, 4.86 and 4.24 %, respectively and for the different frying durations of 15, 20, 25 and 30 minutes, it was 5.12, 4.98, 4.80 and 4.63%, respectively. Statistical analysis showed that there was significant difference between moisture content of banana chips with respect to vacuum level, frying temperature and frying time. The interaction effect of vacuum level, frying time and frying temperature were not significant. Under vacuum, the boiling points of both frying oil as well as water present in the banana slices were lowered that helped to achieve frying much lower temperature in vacuum frying when compared to atmospheric frying (Silva and Moreira, 2008). With increasing frying temperature and time, the moisture content of vacuum fried banana chips decreased (Ruttanadech and Chungcharoen, 2015). Tinako *et al.* (2008) reported that moisture content of vacuum fried pineapple chips decreased with increase in frying time and temperature.

4.3.4.2 Free fatty acids

The free fatty acids of banana chips fried under three different combinations of processing parameters namely, vacuum level, frying temperature and frying time are

Table 4.15: Moisture content of vacuum fried banana chips processed at various frying conditions

Frying Conditions			Moisture Content (%)
Vacuum (mm Hg)	Temperature (ºC)	Time (min)	
640	80	15	6.51
		20	6.45
		25	6.32
		30	6.18
	90	15	6.04
		20	5.95
		25	5.84
		30	5.73
	100	15	5.62
		20	5.51
		25	5.34
		30	5.10
400	80	15	4.99
		20	4.82
		25	4.60
		30	4.45
	90	15	4.22
		20	3.94
		25	3.71
		30	3.52
	100	15	3.34
		20	3.22
		25	3.01
		30	2.84
		Grand Mean	**4.88**

ANOVA

Vacuum (V)	**640 mm Hg**		**400 mm Hg**	
Mean	5.88		3.88	
Temperature (T)	**80 ºC**	**90 ºC**	**100 ºC**	
Mean	5.54	4.86	4.24	
Time (t)	**15 min**	**20 min**	**25 min**	**30 min**
Mean	5.12	4.98	4.80	4.63

	F-value	SEM	CD (@5%)
V	*	0.012	0.034
T	*	0.014	0.042
T	*	0.016	0.048
V x T	*	0.020	0.059
V x t	NS	0.023	NS
T x t	NS	0.028	NS
V x T x t	NS	0.040	NS

presented in Table 4.16. The mean free fatty acids (mg of KOH/g) of vacuum fried banana chips were 0.557 and 0.694 respectively for frying under 640 and 400 mm Hg vacuum levels. The mean free fatty acids content of vacuum fried chips fried under different temperatures of 80, 90 and 100 ˚C were 0.564, 0.598 and 0.714, respectively. Statistical analysis showed that there was significant difference between free fatty acids content of banana chips with respect to vacuum level and frying temperature. The mean free fatty acids content of chips for frying duration of 15, 20, 25 and 30 minutes were respectively 0.583, 0.609, 0.652 and 0.658 and within the experimental range there was no significant difference observed in free fatty acids content of vacuum fried banana chips fried at different frying durations. As explained in Sec 4.2.4.2, the source of FFA in fried chips was mainly the absorbed oil which actually undergo oxidation under the vacuum frying condition apart from oil hydrolysis. The primary oxidation products of oil and fats were hydroperoxides can decompose further to form secondary oxidation products such as alcohols, ketones, aldehydes and acids (Amany *et al*., 2012). Hydrolysis of oil also produce free fatty acids (Shyu *et al.*, 1998). The vacuum frying conditions especially higher frying temperature and lower vacuum may likely to enhance both oxidation hydrolysis resulting in more FFA in frying oil and thus the fried banana chips. Nagarathna (2017) also reported increased amount of FFA in jackfruit chips at higher vacuum frying temperatures.

4.2.4.3 Peroxide value

The peroxide value of banana chips fried under different combinations of three processing parameters namely, vacuum level, frying temperature and frying time are presented in Table 4.17. The mean peroxide value (meq / kg of fat) of vacuum fried banana chips under 640 and 400 mm Hg were 6.51 and 7.91, respectively. The mean peroxide value of vacuum fried chips for different frying temperatures of 80, 90 and 100 °C was 6.59, 7.19 and 7.85, respectively and for different frying durations of 15, 20, 25 and 30 minutes it was 6.91, 7.09, 7.37 and 7.48, respectively. Statistically there was a significant difference observed in peroxide value of banana chips fried under different vacuum levels, frying temperatures and frying time periods. The interaction effect of these three combinations were also found to be significant. The peroxide content in vacuum fried banana chips was mainly due to oxidation of frying oil and lipids present in the banana

Table 4.16: Free fatty acids content of vacuum fried banana chips processed at various frying conditions

Frying Conditions			Free Fatty Acids (mg of KOH/g)
Vacuum (mm Hg)	**Temperature (ºC)**	**Time (min)**	
640	80	15	0.500
		20	0.500
		25	0.530
		30	0.530
	90	15	0.550
		20	0.550
		25	0.570
		30	0.570
	100	15	0.590
		20	0.590
		25	0.600
		30	0.600
400	80	15	0.595
		20	0.600
		25	0.630
		30	0.630
	90	15	0.530
		20	0.595
		25	0.690
		30	0.730
	100	15	0.730
		20	0.820
		25	0.890
		30	0.890
		Grand Mean	**0.625**

ANOVA

Vacuum (V)	**640 mm Hg**		**400 mm Hg**	
Mean	0.557		0.694	
Temperature (T)	**80 ºC**	**90 ºC**	**100 ºC**	
Mean	0.564	0.598	0.714	
Time (t)	**15 min**	**20 min**	**25 min**	**30 min**
Mean	0.583	0.609	0.652	0.658
	F-value	**SEM**	**CD (@5%)**	
V	*	0.011	0.033	
T	*	0.014	0.040	
t	NS	0.016	NS	
V x T	NS	0.019	NS	
V x t	NS	0.022	NS	
T x t	NS	0.028	NS	
V x T x t	NS	0.039	NS	

Table 4.17: Peroxide value of vacuum fried banana chips at various frying conditions

Frying Conditions			Peroxide Value (meq / kg of fat)
Vacuum (mm Hg)	Temperature (ºC)	Time (min)	
640	80	15	5.320
		20	5.320
		25	6.470
		30	6.470
	90	15	6.630
		20	6.600
		25	6.820
		30	6.820
	100	15	6.720
		20	6.950
		25	7.070
		30	7.000
400	80	15	7.180
		20	7.180
		25	7.380
		30	7.420
	90	15	7.420
		20	7.685
		25	7.685
		30	7.930
	100	15	8.210
		20	8.820
		25	8.820
		30	9.270
		Grand Mean	**7.216**

ANOVA

Vacuum (V)	640 mm Hg	400 mm Hg
Mean	6.51	7.91

Temperature (T)	80 ºC	90 ºC	100 ºC
Mean	6.59	7.19	7.85

Time (t)	15 min	20 min	25 min	30 min
Mean	6.91	7.09	7.37	7.48

	F-value	SEM	CD (@5%)
V	*	0.011	0.033
T	*	0.014	0.041
t	*	0.016	0.047
V x T	*	0.020	0.057
V x t	*	0.023	0.066
T x t	*	0.028	0.081
V x T x t	*	0.039	0.115

slices forming primary hydro peroxides. Vacuum though inhibit oxidation by reducing the availability of oxygen still it may not arrest the oxidation completely. Higher vacuum level (640 mm Hg) would obviously reduce the oxidation reaction better than lower vacuum level of 400 mm Hg. Further the temperature of frying was major factor responsible for the formation of peroxides as stated by many researches (Moreira *et al*., 2009; Amany *et al*., 2012) and increase in frying temperature caused enhanced production of peroxides when fried under 640 mm Hg vacuum (Nagarathna, 2017).

4.2.4.4 Total polar molecules of frying oil during vacuum frying

The Total polar molecules of frying oil were monitored during vacuum frying experiments to observe if it exceeded the critical value of 25 and during all trials, the TPM was within 15. The TPM measured during one experimental frying cycle is presented in Fig. 4.2. The TPM was found to increase slightly during vacuum frying at all temperatures employed and the higher value was noticed at higher temperatures (100°C).

4.2.4.5 Acid value of frying oil during vacuum frying

During vacuum frying experiments, the Acid value (AV) of frying oil was monitored to observe if it exceeded the critical value of 6.0 and during all trials, the AV was within 3.0. The AV measured during one experimental frying cycle is presented in Fig. 4.3. The AV was found to increase slightly during vacuum frying at all temperatures tested and the higher value was noticed at higher temperatures (100°C).

4.3.5 Sensory quality of vacuum fried banana chips

The sensory characteristics of vacuum fried banana chips such as colour, crispiness, taste, flavour and overall acceptability were tested by the sensory panel of 10 judges and the mean sensory scores of chips for various vacuum frying treatments are presented in the Tables 4.18.

4.3.5.1 Colour

The mean sensory scores for “colour” of vacuum fried banana chips fried under different combinations of process parameters namely, vacuum, temperature and time are presented in the Table 4.18 and Appendix VI. The mean sensory scores for colour of vacuum fried chips were 6.35 and 6.63 respectively for 640 and 400 mm Hg frying vacuum levels. The mean sensory colour scores of vacuum fried chips were 5.56, 6.99 and 6.83 respectively for different frying temperature of 80, 90 and 100 ˚C. The mean sensory colour scores of vacuum fried chips were 6.29, 6.59, 6.64 and 6.45 respectively for frying durations of 15, 20, 25 and 30 minutes. Statistical analysis showed that there was significant difference between colour of vacuum fried chips with respect to vacuum level, frying temperature and time employed during frying. The interaction effect of vacuum level, frying time and frying temperature were also significant. Potato chips fried under vacuum exhibit a lower extent of browning and mere golden yellow colour in comparison to atmospheric fried chips (Amany *et al.*, 2012). Dueik *et al*. (2010) also reported change in colour of vacuum fried banana chips reduction of L* value and darker colour with increase in frying temperature and time. Pan *et al*. (2015) reported about the effect of temperature and time on colour of breaded shrimps during vacuum frying. Vacuum-fried samples had higher L* values and lower a* and b* values compared to atmospheric fried samples due to lower frying temperature and frying time. Vacuum frying absolutely reduced degradation of colour as it lowered the rate of Millard reaction compared to atmospheric frying.

4.2.5.2 Flavour

The mean sensory scores for "flavour" of vacuum fried banana chips fried under different combinations of process parameters namely, vacuum, temperature and time are presented in the Table 4.18 and Appendix VI. For frying under 640 and 400 mm Hg, the mean sensory scores for flavour of vacuum fried chips were 6.32 and 6.24, respectively. The vacuum levels and frying time within the experimental range did not influence the flavour of fried chips. The mean sensory flavour scores for were 5.59, 6.61 and 6.63 respectively for 80, 90 and 100 ˚C frying temperatures. The mean sensory flavor scores of vacuum fried chips were 6.10, 6.61 6.08 and 6.33 respectively for frying durations of 15, 20, 25 and 30 minutes. Statistical analysis showed that there was significant difference between flavour of banana chips with respect to frying temperature and frying time employed during frying. Flavour plays an important role in acceptability of the product but

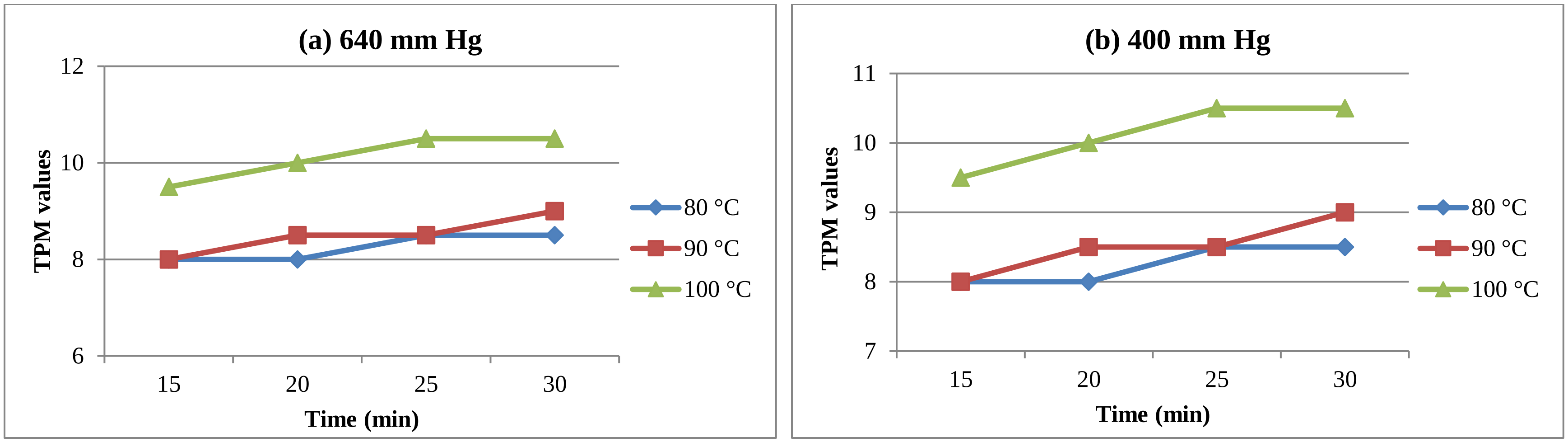


Fig. 4.2: Effect of temperature and time on Total Polar Molecules (TPM) of vacuum frying oil

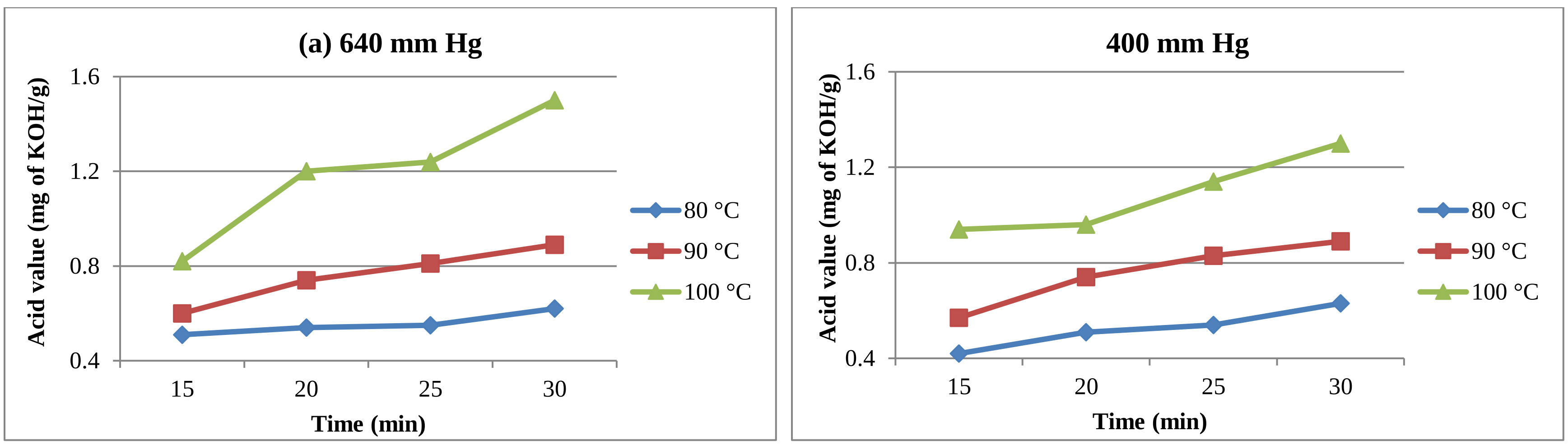


Fig. 4.3: Effect of temperature and time on Acid Value of vacuum frying oil

Table 4.18: Mean sensory scores of vacuum fried banana chips processed at different frying temperature-time combinations under 640 and 400 mm Hg vacuum

Treatments	640 mm Hg (V_1)					400 mm Hg (V_2)				
	Colour	Flavour	Texture	Taste	Overall acceptability	Colour	Flavour	Texture	Taste	Overall acceptability
T_1t_1	6.24	6.09	5.52	5.80	6.00	4.35	4.73	5.00	4.07	4.32
T_1t_2	6.15	6.20	6.11	6.02	6.05	5.43	5.67	5.35	4.70	4.80
T_1t_3	5.78	6.07	6.20	6.06	6.04	5.80	5.53	5.38	5.12	5.02
T_1t_4	6.10	6.50	6.00	5.50	5.80	5.50	4.00	5.55	5.00	5.00
T_2t_1	6.87	6.40	6.10	6.00	6.35	6.50	6.25	6.08	6.00	6.00
T_2t_2	6.88	6.75	6.67	6.13	6.35	7.52	7.42	7.35	7.33	7.23
T_2t_3	7.12	6.65	6.47	6.18	6.60	7.80	5.96	7.15	7.53	7.57
T_2t_4	6.20	6.50	6.50	6.00	6.20	7.05	7.00	6.45	6.47	6.50
T_3t_1	6.32	6.12	6.02	6.00	6.20	7.50	7.05	7.32	7.05	7.20
T_3t_2	6.31	6.45	6.05	6.08	6.36	7.25	7.17	7.22	7.00	7.09
T_3t_3	5.83	5.15	6.17	6.14	6.21	7.56	7.15	7.60	7.50	7.80
T_3t_4	6.50	7.00	6.00	6.00	6.50	7.40	7.02	7.42	7.20	7.40

Frying Temperature (°C) : T_1 – 80; T_2 – 90; T_3 – 100
Frying Duration (min) : t_1 – 15; t_2 – 20; t_3 – 25; t_4 – 30

compounds present in the food materials are lost easily during processing. Yamsaengsung, *et al*. (2011) reported that vacuum frying diminishes most of the oxidative reactions and that helps to preserve the flavour of banana chips. The frying oil temperature and frying time play important role in preserving the natural flavour of food material during frying and also frying in low pressure helps to retain more volatile compounds.

4.2.5.3 Texture (Crispiness)

The mean sensory scores for "texture" of vacuum fried banana chips fried under different combinations of namely vacuum, temperature and time combinations are presented in the Table. 4.18 and Appendix VI. The mean sensory texture scores of fried chips processed under the vacuum of 640 and 400 mm Hg were respectively 6.15 and 6.49. The mean sensory texture scores of fried chips processed at 80, 90 and 100 °C were 5.64, 6.59 and 6.72, respectively. The mean sensory texture scores of vacuum fried chips were 6.00, 6.45, 6.49 and 6.32 respectively for various frying durations of 15, 20, 25 and 30 minutes. Statistically significant difference was observed in sensory texture scores of chips fried at different vacuum, frying temperatures and frying time. All interaction effects of vacuum, frying temperature and frying time were also significant. The sensory score for texture of vacuum fried banana chips was mainly related to "crispiness". The porous structure of chips was due to fast moisture evaporation that leave vacuoles in the product matrix. The snapping and crumbling of fried chips was attributed to this porous structure. Frying temperature and duration most probably affect the as well as level of moisture loss during frying and therefore the product structure and sensory texture scores. Ruttanadech and Chungcharoen (2015) observed crispier banana chips relatively at higher frying temperature of 100 and 120 °C than at 80 °C under vacuum frying.

4.2.5.4 Taste

The mean sensory scores for "taste" of vacuum fried banana chips fried under different combinations of process parameters namely, vacuum, temperature and time are presented in Table 4.18 and Appendix VI. The mean sensory taste scores of fried chips processed under 640 and 400 mm Hg were 5.99 and 6.24, respectively. The mean sensory taste scores of fried chips processed at 80, 90 and 100 °C were 5.28, 6.45 and 6.62, respectively. The mean sensory taste scores of vacuum fried chips for various frying durations of 15, 20, 25 and 30 minutes were 5.82, 6.21, 6.42 and 6.02, respectively. Statistically significant difference was observed in sensory taste scores of chips fried at different vacuum levels, frying temperature and times. The interaction effects between of frying vacuum level, frying time and frying temperature were also found to be significant. It was interacting to note that the vacuum fried banana chips produced under lower vacuum level at higher temperature and for longer frying duration tend to receive better taste scores. The variation in taste scores may be attributed to variation in level of oil and moisture present in the fried chips owing to vacuum frying conditions. Nagarathna (2017) also reported variation in texture scores at different vacuum frying conditions for jackfruit chips.

4.2.5.5 Overall acceptability

The mean sensory scores for “overall acceptability” of vacuum fried banana chips fried under different combinations of process parameters namely, vacuum; temperature and time are presented in Table 4.18 and Appendix VI. The overall acceptability scores of vacuum fried chips processed under 640 and 400 mm Hg were 6.22 and 6.32, respectively. Statistically significant difference was observed in sensory overall acceptability scores of chips fried at different vacuum levels. The mean sensory overall acceptability scores of fried chips at 80, 90 and 100 ˚C were 5.37, 6.60 and 6.84, respectively and for the frying durations of 15, 20, 25 and 30 minutes were 6.01,6.31, 6.54 and 6.23, respectively. Statistically significant difference was observed in sensory overall acceptability scores of chips fried at different frying temperatures and time durations. The interaction effects between vacuum level, frying time and frying temperature were also found to be significant.

The sensory parameter ‘overall acceptability’, is an important chips characteristic to make final decision to accept or reject the product. It intrinsically encompasses all the other sensory characteristics like colour, flavor, texture and taste to arrive at the comprehensive value. As discussed earlier (sec. 4.2.5), the vacuum frying process parameters affected all the sensory attributes which obviously influence” overall acceptability" of vacuum fried banana chips. The chips fried under 400 mm Hg vacuum at relatively at higher frying temperatures for longer time obtained better acceptability scores. Amany *et al*. (2012) reported better sensory scores for vacuum fried potato chips when compared to atmospheric frying (overall quality).

4.2.5.6 Selection of optimum vacuum frying conditions for banana chips

Trials were conducted to optimize the vacuum fried banana chips production process parameters using matured unripe banana fruit slices. The vacuum levels of 640 and 400 mm Hg, frying temperatures (80, 90 and 100 ˚C) and frying durations (15, 20, 25 and 30 minutes) were employed to produce banana chips of better acceptability and with relatively lower fat content. The experimental banana chips samples were tested for sensory characteristics by using 9-point hedonic scale. The organoleptic qualities of the banana chips such as colour, crispiness, taste, flavour and overall acceptability were tested by a sensory panel of 10 judges. From the sensory scores of banana chips of various frying treatments, it could be seen that banana chips fried at 90 ˚C frying temperature for 25 minutes under 400 mm Hg vacuum showed highest sensory scores with respect to colour (7.80), texture (8.40), flavour (8.10), taste (8.00) and overall acceptability (8.51). The crispiness, colour and overall acceptability scores were the main criteria for the selection of optimum frying conditions. Hence, the frying process combination of 90 °C frying temperature and 25 minutes of frying time was selected as optimum to obtain good quality banana chips (from var. Dwarf Cavendish) by vacuum frying techniques.

4.4 Packaging and Storage Study of Vacuum and Atmospheric Fried Chips

Banana chips were processed by two different frying methods such as atmospheric and vacuum deep fat frying. The conventional atmospheric deep fat fried banana chips were prepared at the optimized frying temperature of 180 ˚C for 9 minutes while the vacuum fried chips were prepared at optimized frying condition of 400 mm Hg vacuum at 90 ˚C for 25 minutes. Both the products (chips) were kept for further storage studies by packaging the chips in different packaging materials with and without N_2 gas flushing for two months. Periodically the chips were analyzed for various biochemical and sensory quality and the results are presented below.

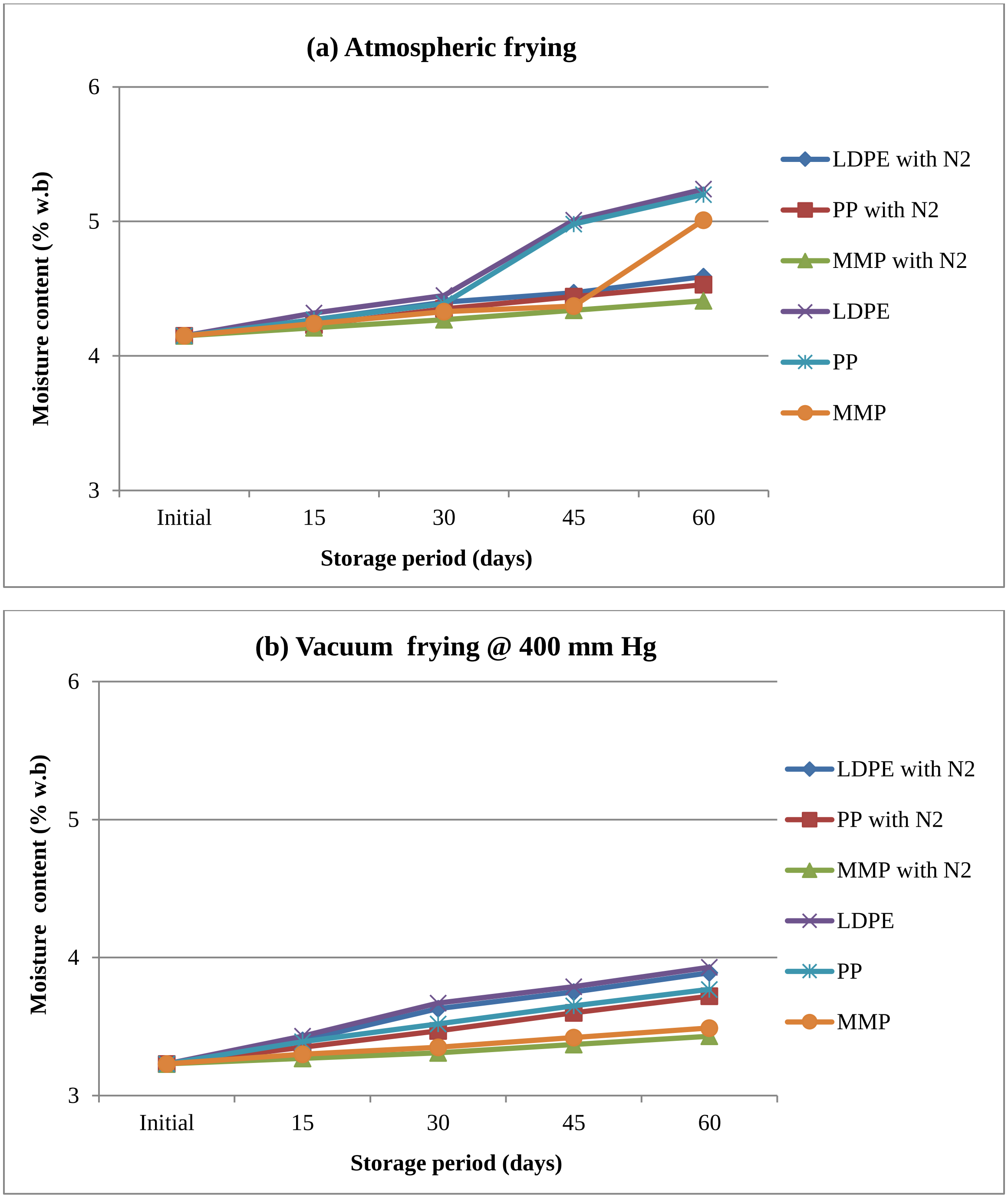
4.4.1 Effect of storage on moisture content of banana chips

During storage, the variation observed in moisture contents of both atmospheric and vacuum deep fried banana chips kept in three different packaging materials with and without N_2 gas flushing is shown in Fig. 4.5. The initial moisture content of vacuum fried chips (3.23%) was found to be lower when compared to atmospheric fried chips (4.15%). As the storage period increased, the moisture content of vacuum fried chips with nitrogen flushing increased from the initial value of 3.23% to 3.40, 3.63, 3.75 and 3.89% in LDPE; 3.35, 3.47, 3.60 and 3.72% in polypropylene (PP); and 3.27, 3.31, 3.37 and 3.43% in metalized multilayer polyethylene (MMP), respectively for 15, 30, 45 and 60 days of storage. In case of atmospheric fried chips also the moisture content increased from the initial value of 4.15% to 4.27, 4.40, 4.47 and 4.59% in LDPE; 4.23, 4.35, 4.44 and 4.53% in PP; and 4.21, 4.27, 4.34 and 4.41% in MMP, respectively for 15, 30, 45 and 60 days of storage. In case of vacuum fried chips packed without nitrogen flushing, the amount of increase in moisture content was 3.43, 3.67, 3.79 and 3.93% in LDPE; 3.39, 3.52, 3.65 and 3.77% in PP; and 3.30, 3.35, 3.42 and 3.49% in MMP for 15, 30, 45 and 60 days of storage, respectively. While in atmospheric fried chips, the moisture content increased from the initial value of 4.15% to 4.32, 4.45, 5.01 and 5.24% in LDPE; 4.27, 4.39, 4.98 and 5.20 % in PP; 4.24, 4.33, 4.37 and 5.01 % in MMP for 15, 30, 45 and 60 days of storage, respectively. It could be observed that the increase in moisture content of banana chips was more in case of atmospheric fried chips than vacuum fried chips during storage. However, the increase in moisture content of banana chips in all packages was low till about 30 days of storage and beyond that the accumulation of moisture in the chips was much faster. Increase in moisture content of the banana chips was noted to be lower in packages flushed with nitrogen gas. Further, the chips stored in MMP gained relatively lesser moisture compare to other packages. The moisture content of banana chips during storage was found to vary with respect to type of packaging material, gas environment, type of frying and as well as duration of storage. Ammavath *et al*. (2002) reported increase in moisture content of deep fat fried banana chips during 8 weeks of storage. Fan *et al*. (2007) reported that the storage time and temperature had significant effect on moisture content of vacuum fried carrot chips. The increase in moisture content depends on permeability of packaging material for moisture and length of storage. MMP package relatively being less permeable to moisture could reduce the moisture gain by stored banana chips.

4.4.2 Effect of storage on free fatty acids (FFA) of banana chips

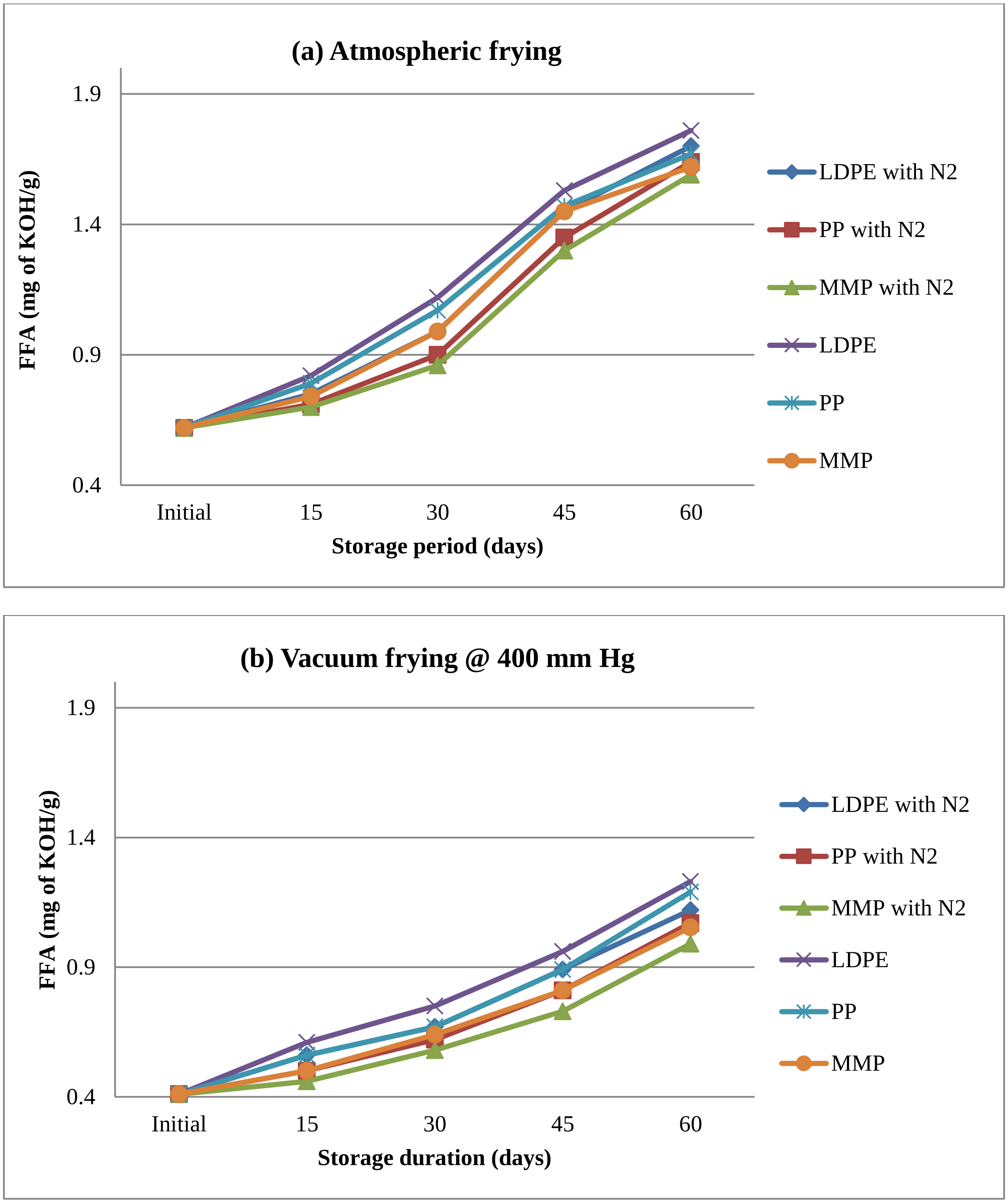
The free fatty acids content of banana chips stored for 2 months at ambient conditions in different packaging materials with and without N_2 gas flushing is presented in Fig. 4.6. As the storage period increased, the FFA content (mg of KOH/g) of both vacuum and atmospheric fried chips packed with nitrogen flushing increased from the initial value of 0.412 to 0.561, 0.676, 0.894 and 1.125 in LDPE; 0.503, 0.627, 0.815 and 1.072 in PP; 0.460, 0.581, 0.734 and 0.991 in MMP for 15, 30, 45 and 60 days of storage, respectively. The FFA content of atmospheric fried chips increased from the initial value of 0.621 to 0.754, 0.990, 1.425 and 1.709) in LDPE; 0.714, 0.905, 1.351 and 1.642 PP; 0.709, 0.862, 1.301 and 1.598 in MMP respectively for 15, 30, 45 and 60 days of storage. In case of vacuum fried chips packed without nitrogen flushing, the FFA increased from the initial value of 0.412 to 0.617, 0.754, 0.962 and 1.231 in LDPE; 0.561, 0.677, 0.891 and 1.199 in PP; 0.502, 0.641, 0.810 and 1.053 in MMP for 15, 30, 45 and 60 days of storage, respectively. Similarly, in atmospheric fried chips, the FFA content increased from the initial value of 0.621 to 0.821, 1.125, 1.532 and 1.764 in LDPE; 0.794, 1.075, 1.475 and 1.675 in PP; 0.742, 0.994, 1.453 and 1.621 in MMP for 15, 30, 45 and 60 days of storage, respectively. It could be seen that The FFA content of banana chips prepared under both frying methods consistently increased during storage regardless of type of package and with or without N_2 gas flushing. However, it was noticed that the increase in free fatty acids content of banana chips was observed to be less in MMP pouches when compared to other two packages especially when stored with N_2 gas flushing. The FFA of banana chips significantly varied with respect to N_2 gas flushing, packaging materials and frying method as well as storage period.

During storage, the oil and fat in the fried chips might be broken down into FFA and other organic compounds due to oxidative rancidity which of course was known to be progressive reactions with storage period. This could be the main reason for increase in FFA in banana chips during storage. When packages were flushed with N_2, the available



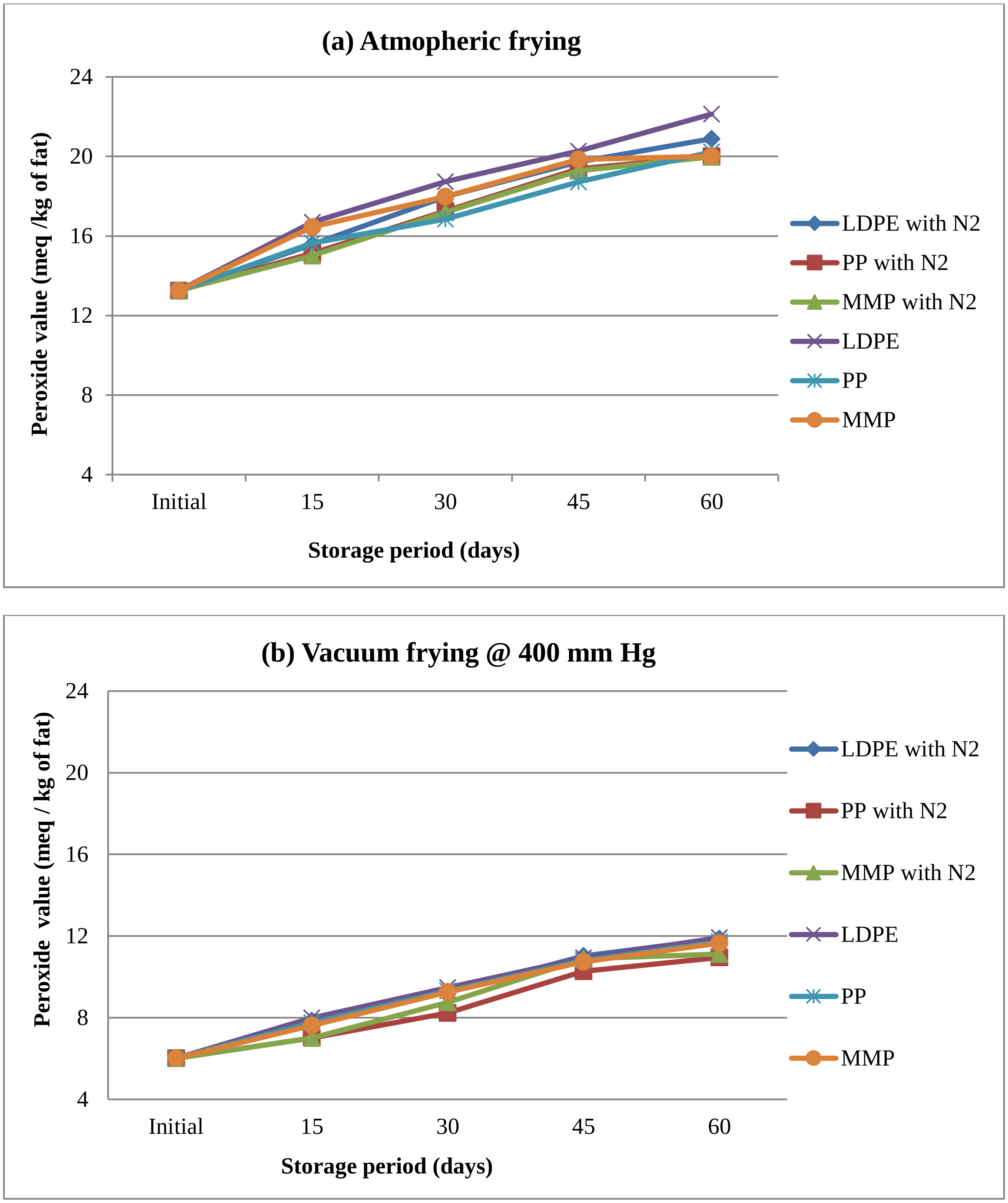
LDPE =Low density polyethylene
PP = Polypropylene
MMP = Metalized multilayer polyethylene

Fig. 4.4: Effect of storage in different packages with and without nitrogen flushing on moisture content of atmospheric and vacuum deep fat fried banana chips



LDPE =Low density polyethylene
PP = Polypropylene
MMP = Metalized multilayer polyethylene

Fig 4.5: Effect of storage in different packages with and without nitrogen flushing on free fatty acids (FFA) of atmospheric and vacuum deep fat fried banana chips



LDPE =Low density polyethylene

PP = Polypropylene

MMP = Metalized multilayer polyethylene

Fig. 4.6: Effect of storage in different packages with and without nitrogen flushing on peroxide value of atmospheric and vacuum deep fat fried banana chips

oxygen to effect rancidity reaction in chips got reduced greatly and that probably was the reason for lower lever of FFA in chips flushed with nitrogen. Among the three packages used, the MMP film was relatively more impervious to oxygen (also moisture) migration from outside atmosphere into the package where the banana chips were stored. The metallic layer in the film probably blocks the oxygen movement entirely. This may be the reason that chips in MMP had lower FFA. It may be noted that the initial level of fat content (46.62 %) in atmospheric fried chips before storage was much higher than vacuum fried chips (24.82 %). More fat obviously encouraged rancidity and therefore the atmospheric fried chips had always more FFA content than vacuum fried chips. Further the repeated use of frying oil for multiple times might have increased the FFA content of oil. Satishkumar *et al.* (2016) and Nagarathna (2017) also reported increase of FFA content respectively for atmospheric and vacuum fried jackfruit chips during storage.

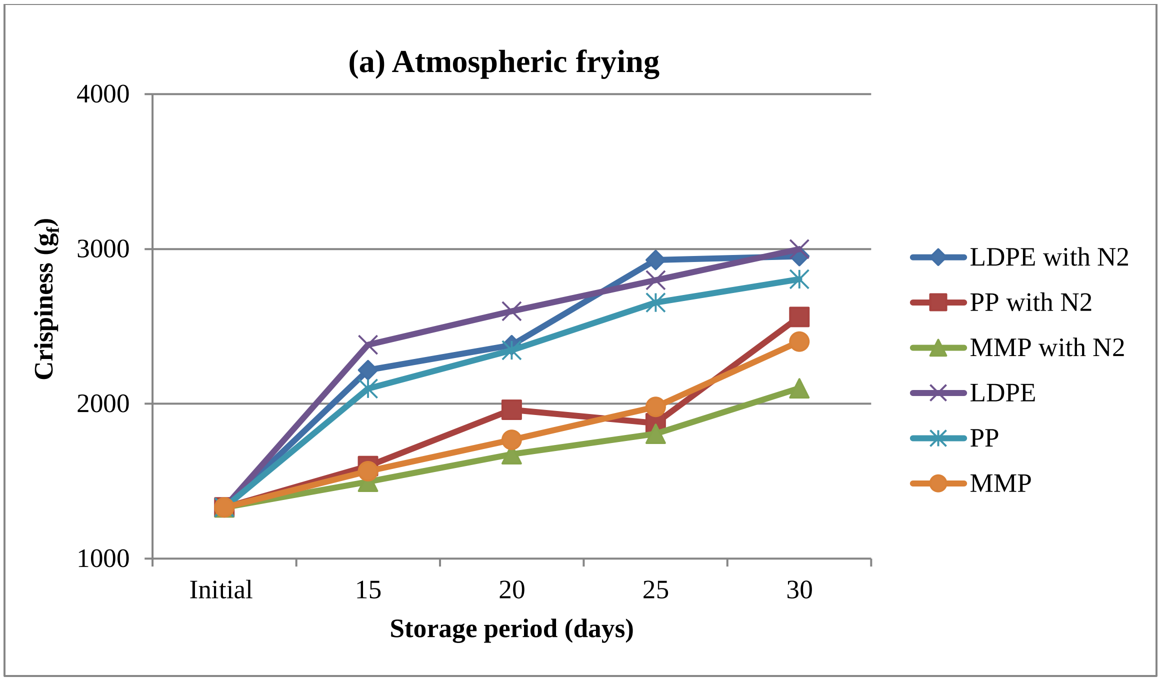
4.4.3 Effect of storage on peroxide value of banana chips

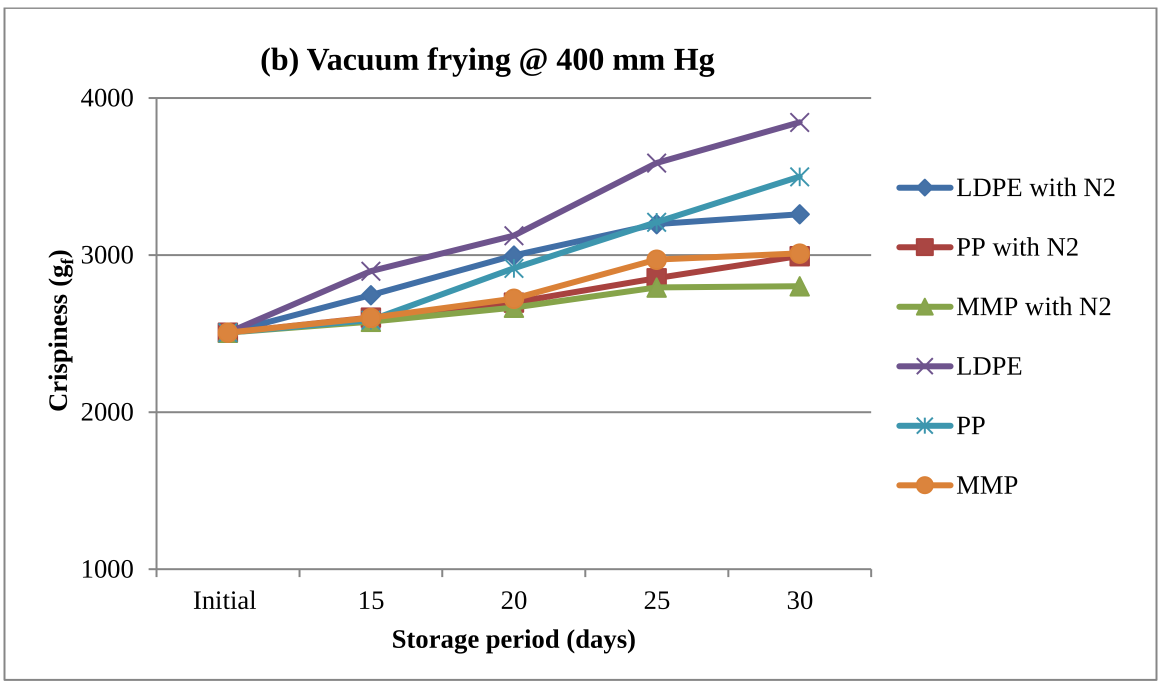
During storage, the peroxide value of banana chips prepared by two frying methods and packed in three different packaging materials with and without N_2 gas flushing is shown in Fig. 4.7. The initial peroxide value (meq / kg of fat) of freshly prepared vacuum fried chips 6.01 was relatively lower than the atmospheric fried chips 13.26 As the storage period increased, the peroxide value increased from the initial value of 6.01 to 7.85, 9.24, 11.02 and 11.87 in LDPE; 7.01, 8.23, 10.27 and 10.95 in PP; and 7.01, 8.75, 10.89 and 11.12 in MMP for 15, 30, 45 and 60 days of storage, respectively for vacuum fried chips with nitrogen flushing. In atmospheric fried chips, packed with N_2 flushing, the peroxide value increased from 13.26 to 15.57, 17.98, 19.73 and 20.89 in LDPE; 15.12, 17.25, 19.37 and 20.01 in PP; and 15.01, 17.19, 19.28 and 19.98 in MMP for 15, 30, 45 and 60 days of storage, respectively. In case of vacuum fried chips packed without N_2 flushing, the peroxide value increased from the initial value of 6.01 to 7.98, 9.47, 10.92 and 11.92 in LDPE; 7.75, 9.30, 10.80 and 11.71 in PP; and 7.62, 9.25, 10.74 and 11.65 in MMP for 15, 30, 45 and 60 days of storage, respectively. Similarly, in atmospheric fried chips without N_2 gas flushing, the peroxide value is increased from the initial value of 13.26 to 16.69, 18.73, 20.27 and 22.13 in LDPE; 15.65, 16.85, 18.72 and 20.23 in PP; and 16.45, 17.98, 19.85, and 20.01 in MMP for 15, 30, 45 and 60 days of storage, respectively. The peroxide value was different in both vacuum and atmospheric fried banana chips with storage period in all package materials irrespective of (with and without) N_2 gas flushing. Also, the peroxide value was found to be less in banana chips packed in MMP with N_2 gas flushing when compared to other two packaging materials. The peroxide value of banana chips considerably varied with respect to gas flushing, type of frying and packaging materials as well as storage period.

An increase in peroxide and also FFA values with storage was reported by Nagarathna (2017) for vacuum fried jackfruit chips while Satishkumar *et al*. (2016) observed the same trend with atmospheric fried jack chips during storage.

4.4.4 Effect of storage on crispiness of banana chips

The cutting strength, a measure of crispiness /hardness of stored banana chips, measured using a Textural Analyzer is shown in Fig. 4.8. Increase in cutting force required indicated decrease in crispiness of chips. It was observed that the crispiness of banana chips decreased in all packaging materials with or without N_2 gas flushing as the storage period increased. The decrease in crispiness of banana chips with storage was steeper in atmospheric fried chips in comparison to vacuum fried chips. The crispiness of chips decreased from an initial value of 1330.1 g_f to 2217.3, 2379.7, 2927.9 and 2952.8 g_f in LDPE; 1598.5, 1961.5, 1875.2 and 2560.7 g_f in PP; and 1496.4, 1673.6, 1806.1 and 2100.9 g_f in MMP for 15, 30, 45 and 60 days of storage, respectively for vacuum fried chips with nitrogen flushing. For atmospheric fried chips packaged with N_2 flushing also the crispiness decreased from the initial value of 2506.2 g_f to 2745.1, 2997.3, 3198.4 and 3259.80 g_f in LDPE; 2602.2, 2698.5, 2853.5 and 2994.7 gf in PP; and 2575.6, 2666.5, 2795.1 and 2801.7 g_f in MMP respectively for 15, 30, 45 and 60 days of storage. In vacuum fried chips packed without nitrogen flushing the crispiness decreased from the initial value of 1330.1 g_f to 2380.4, 2597.3, 2798.4 and 2998.6 g_f in LDPE; 2098.2, 2345.6, 2654.5 and 2804.7 g_f in PP; and 1564.9, 1766.5, 1979.10 and 2401.7 g_f in MMP respectively for 15, 30, 45 and 60 days of storage 60, respectively. For atmospheric fried chips packaged without N_2 gas flushing the crispiness decreased from the initial value of 2506.2 g_f to 2898.7, 3123.5, 3586.5 and 38451.7 g_f in LDPE; 2585.4, 2915.7, 3210.1 and 3499.74 g_f in





LDPE =Low density polyethylene
PP = Polypropylene
MMP = Metalized multilayer polyethylene

Fig. 4.7: Effect of storage in different packages with and without nitrogen flushing on crispiness of atmospheric and vacuum deep fat fried banana chips

PP; and 2599.9, 2723.1, 2971.8 and 3010.9 g_f in MMP for 15, 30, 45 and 60 days of storage, respectively. The decrease in crispiness was found to be generally less in banana chips packed in MMP pouches with N_2 gas flushing. In general, the crispiness of banana chips was considerably varied with respect to gas flushing, type of frying and packaging materials as well as storage period.

The crispiness of banana chips is intimately associated with moisture content of chips. During storage, generally the moisture content of banana chips increased due to moisture migration from surrounding atmospheric air, the degree of moisture gain however depended on permeability of the package material to moisture. Since, in all packages, moisture gain was observed (Sec 4.4.1) in stored banana chips, the crispiness invariably of chips came down. It could be observed that in chips packed in MMP, the moisture gain was relatively less compare to other two packages that helped to preserve crispiness better in that package. Furthermore, the same argument goes with chips flushed with N_2 where the moisture gain was relatively observed to be lower. Nagarathna (2017) also observed the reduction in crispiness of vacuum fried jackfruit chips stored in three packaging materials both with and without N_2 flushing.

4.4.5 Effect of storage on tristimulus colour banana chips

The variation in tristimulus colour of banana chips, an instrumental measurement in terms of L*a*b* values, with storage is presented in the Table 4.19 and 4.20. As the storage period increased, the L* value of banana chips stored in all the packaging materials decreased indicating dulling of colour. The luminosity (L*) value of vacuum fried banana chips decreased from initial value of 57.23 to 57.01, 56.95, 56.80 and 56.69 in LDPE; 57.05, 57.00, 56.85 and 56.76 in PP; and 57.08, 57.03, 56.92 and 56.80 in MMP for 15, 30, 45 and 60 days of storage, respectively for chips packed with nitrogen flushing. The a* value of vacuum fried chips with nitrogen flushing decreased from an initial value of 7.92 to 7.85, 7.76, 7.24 and 7.13 and b* value decreased from 28.42 to 28.31, 28.19, 27.94 and 27.87 in LDPE, PP and MMP, respectively. Similarly, in case of atmospheric fried chips with gas flushing, the L* is decreased from the initial value of 65.69 to 65.25, 64.95, 64.35 and 63.95 in LDPE; 65.35, 65.05, 64.25 and 63.98 in PP; and 65.45, 65.15, 64.13 and 64.02

Table 4.19: Effect of storage at ambient conditions in different packaging materials with and with without nitrogen flushing on tristimulus colour of vacuum fried banana chips

Type of package	Tristimulus Colour parameter	Nitrogen gas flushing					Without Nitrogen gas flushing				
		Storage period (days)					Storage period (days)				
		0	15	30	45	60	0	15	30	45	60
LDPE	L*	57.23	57.01	56.95	56.80	56.69	57.23	56.94	56.82	55.99	55.85
	a*	7.92	7.85	7.76	7.24	7.13	7.92	7.80	7.71	6.92	6.80
	b*	28.42	28.31	28.19	27.94	27.87	28.42	28.26	28.18	27.87	27.75
PP	L*	57.23	57.05	57.00	56.85	56.76	57.23	57.02	56.92	56.25	56.03
	a*	7.92	7.87	7.81	7.30	7.24	7.92	7.81	7.76	7.01	6.94
	b*	28.42	28.26	28.15	27.80	27.84	28.42	28.19	28.09	27.02	26.91
MMP	L*	57.23	57.08	57.03	56.92	56.80	57.23	57.05	56.97	56.00	59.87
	a*	7.92	7.90	7.85	7.40	7.36	7.92	7.84	7.79	7.01	6.81
	b*	28.42	28.20	28.17	27.61	27.59	28.42	28.10	28.01	27.75	27.66

Table 4.20: Effect of storage at ambient conditions in different packaging materials with and with without nitrogen flushing on tristimulus colour of atmospheric fried banana chips

Type of package	Tristimulus Colour parameter	Nitrogen gas flushing					Without Nitrogen gas flushing				
		Storage period (days)					Storage period (days)				
		0	15	30	45	60	0	15	30	45	60
LDPE	L*	65.69	65.59	65.52	64.70	64.56	65.69	65.47	65.39	64.42	64.10
	a*	9.24	9.12	9.06	8.41	8.39	9.24	9.01	8.86	7.92	7.80
	b*	26.85	26.78	26.71	25.62	25.48	26.85	26.70	26.59	25.01	24.62
PP	L*	65.69	65.61	65.57	64.81	64.62	65.69	65.46	65.38	64.59	64.48
	a*	9.24	9.17	9.10	8.85	8.79	9.24	9.09	8.94	8.54	8.40
	b*	26.85	26.81	26.78	25.72	25.61	26.85	26.60	26.54	25.35	24.98
MMP	L*	65.69	65.64	65.60	64.98	64.75	65.69	65.55	65.47	64.70	64.61
	a*	9.24	9.21	9.18	8.95	8.86	9.24	9.15	9.09	8.71	8.59
	b*	26.85	26.83	26.80	25.94	25.90	26.85	26.62	26.59	25.47	25.09

LDPE = low density polyethylene
PP = poly propylene
MMP = metalized multilayer polyethylene

in MMP for 15, 30, 45 and 60 days of storage, respectively. The a* value of atmospheric deep fat fried chips with nitrogen flushing decreased from the initial value of 9.24 to 9.17, 9.42 and 9.58 and b* value decreased from 26.85 to 25.680, 25.780 and 25.120 in LDPE, PP and metalized multilayer polyethylene, respectively at 60 days of storage. The L* value of atmospheric fried chips without nitrogen flushing also decreased from the initial value of 68.26 to 68.05, 67.99, 67.78 and 66.72 in LDPE; 68, 67.98, 67.89 and 66.92 in PP; 68.11, 68.10, 67.95 and 67.80 in MMP for 15, 30, 45 and 60 days of storage, respectively.

The colour of banana chips was influenced by many factors that were intrinsic in nature. Change or modification in the composition of chips which might be caused by storage factors would obviously affect the colour of the product. For example, increase in moisture content of chips might result in dullness of chips (reduction in L* value). During storage of banana chips, change in moisture, FFA, peroxide value, etc, were observed, the degree of which of course were dictated by type of packaging, gas flushing and the product itself. Since all the above parameters varied during storage of banana chips, the colour of chips measured also varied considerably. Nagarathna (2017) and Satishkumar (2014) also observed variations in colour of vacuum fried and atmospheric fried jack chips, respectively during storage.

4.4.6 Effect of storage on sensory quality of banana chips

Both atmospheric and vacuum fried banana chips, packed with and without nitrogen flushing, in three distinct packaging materials namely, LDPE, PP and MMP and stored for 60 days at Bangalore ambient conditions were subjected to sensory evaluation by trained panel of judges at every 15 days interval to evaluate 5 organoleptic parameters namely, colour, flavour, texture/crispiness, taste and overall acceptability. The results are presented in Tables 4.21 and 4.22.

4.4.6.1 Colour

The mean sensory score recorded for “colour” of banana chips fried under atmospheric as well as vacuum pressure, stored in different packages for different storage periods are presented in Tables 4.21 and 4.22. The initial mean sensory colour score for the fresh chips was 7.80 for vacuum fried chips and 7.83 for atmospheric fried chips. The colour scores generally decreased with storage period. In case of vacuum fried chips (Table 4.21) packed with nitrogen flushing, the colour score decreased from initial value of 7.80 to 7.68, 7.62, 6.98 and 6.80 in LDPE; 7.71, 7.66, 7.13 and 6.95 in PP; and 7.77, 7.70, 7.40 and 7.32 in MMP respectively after 15, 30, 45 and 60 days of storage. For vacuum fried chips (Table 4.21) packed without nitrogen flushing, the colour score decreased from initial value of 7.80 to 7.60, 7.56, 6.78 and 6.68 in LDPE; 7.66, 7.60, 7.02 and 6.84 in PP; and 7.74, 7.64, 7.26 and 7.20 in MMP respectively after 15, 30, 45 and 60 days of storage. The chips stored in MMP showed highest sensory score with more acceptable colour of 7.32 (with gas flushing) and 7.20 (without gas flushing) even after 60 days of storage. The vacuum fried chips packed without nitrogen flushing obtained relatively. lower colour scores when compared to chips packaged with nitrogen flushing. In case of atmospheric deep fat fried chips (Table 4.22) packed with nitrogen flushing the colour score decreased from initial value of 7.83 to 7.64, 7.50, 6.84 and 6.70 in LDPE; 7.72, 7.66, 6.98 and 6.88 in PP; and 7.80, 7.70, 7.0 and 6.96 in MMP, respectively after 15,30,45 and 60 days of storage. In case of atmospheric deep fat banana chips packed without nitrogen flushing, the colour scores decreased from 7.83 to 7.60, 7.48, 6.42 and 6.32 in LDPE; 7.64 7.54,6.72 and 6.64 in PP; and 7.68, 7.64, 7.01 and 6.62 in MMP. The atmospheric fried chips packed in MMP with nitrogen flushing recorded relatively higher values when compared to chips packed without nitrogen flushing. After 60 days of storage, the banana chips stored only in MMP with gas flushing obtained highest colour scores of 7.32 for vacuum fried and 6.96 for atmospheric fried chips. The decrease in sensory scores for colour of banana chips with increase in storage period might be due to oxidation and bleaching of carotenoids in the presence of oxygen (Ammawath, 2002). Borah and Nayak (2013) also noticed change in colour of banana chips during storage. Gain in moisture by stored banana chips might be one of the strong reason for the change in colour of chips apart from other biochemical reasons.

4.4.6.2 Flavour

The sensory score for “flavour” of banana chips stored in different packages for different storage periods (Tables 4.21 and 4.22) generally varies with storage period. The mean sensory flavour score for the fresh chips was 8.40 for vacuum fried chips and 7.71 for atmospheric fried chips. In case of vacuum fried chips (Table 4.21) packed with nitrogen flushing, the flavour score decreased from initial value of 8.40 to 8.20, 8.06, 7.62 and 7.40 in LDPE; 8.28, 8.22, 7.76 and 7.68 in PP; and 8.36, 8.30, 7.88 and 7.76 in MMP after 15, 30, 45 and 60 days of storage, respectively. The vacuum fried banana chips stored without nitrogen flushing obtained relatively lower flavour scores when compared to chips packaged with nitrogen flushing. In case of atmospheric deep fat fried chips (Table 4.22) packed with nitrogen flushing, the flavour score decreased from initial value of 7.71 to 7.58, 7.50,6.80 and 6.56 in LDPE; 7.62, 7.56, 6.98 and 6.74 in PP; and 7.68, 7.62, 7.04 and 6.94 in MMP, respectively after 15, 30, 45 and 60 days of storage. The vacuum fried banana chips packed with and without nitrogen flushing obtained relatively higher flavour scores when compared atmospheric deep fat fried chips packaged with nitrogen flushing. After 60 days of storage, the banana chips stored in MMP with gas flushing obtained higher flavour scores of 7.76 for vacuum fried and 6.94 for atmospheric fried. In case of banana chips, flavor scores generally decrease with storage since, the rancidity sets in and progressively increased due to the presence of high amount of oil in the fried chips. Some packages like MMP tend to control the rate of increase in rancidity of chips that may be the reason for better flavour sensory score for chips stored in MMP even after 60 days of storage. Similar trend was reported by Nagarathna (2017) for jackfruit chips during storage.

4.4.6.3 Texture

The sensory score for “texture” of banana chips stored in various packages for different storage periods (Tables 4.21 and 4.22) generally decreased with storage period. The mean sensory texture score for the fresh chips was 8.10 for vacuum fried chips and 8.12 for atmospheric fried chips. In case of vacuum fried chips (Table 4.21) packed with nitrogen flushing, the texture score decreased from initial value of 8.10 to 7.92, 7.80, 7.56 and 7.22 in LDPE; 7.98, 7.96, 7.70 and 7.62 in PP; and 8.04, 8.0, 7.94 and 7.86 in MMP after 15, 30, 45 and 60 days of storage, respectively. For vacuum fried chips packed without nitrogen flushing, the texture score decreased from initial value of 8.10 to 7.86, 7.72, 7.24 and 6.96 in LDPE; 7.90, 7.82, 7.46 and 7.08 in PP; and 7.92, 7.88, 7.58 and 7.12 in MMP, respectively after 15, 30, 45 and 60 days of storage. The vacuum fried chips packed without nitrogen flushing obtained relatively lower texture scores when compared to chips packaged with nitrogen flushing. In case of atmospheric deep fat fried chips (Table 4.22) packed with nitrogen flushing, the texture score decreased from initial value of 8.12 to 7.80, 7.66, 6.71 and 6.52 in LDPE; 7.86, 7.70 ,6.80 and 6.62 in PP; and 7.94, 7.86, 7.06 and 6.96 in MMP respectively after 15, 30, 45 and 60 days of storage. The atmospheric fried banana chips with and without nitrogen flushing obtained relatively lower textural scores when compared to vacuum fried chips packaged with nitrogen flushing. After 60 days of storage, the banana chips stored only in MMP with gas flushing obtained higher texture scores of 7.86 for vacuum fried and 6.96 for atmospheric fried chips. Texture of a fried product determines its eating quality. Decrease in textural quality of banana chips observed during storage period might be due moisture absorption by the chips that tend to soften the product. Jackson *et al.* (1996) studied the sensory texture of banana chips during storage and noted that chips become chewy and softer as the storage period increased. The crispiness can be retained over the storage period by pretreating the banana chips before frying. Fan *et al.* (2007) investigated on textural properties of the carrot chips during storage and noted that the breaking force of the chips increased reduction in crispiness with increase in storage time.

4.4.6.4 Taste

The sensory score for “taste” of banana chips stored in various packages for different storage periods are presented below Tables 4.21 and 4.22. The mean sensory taste score for the fresh chips was 8.10 for vacuum fried chips and 7.80 for atmospheric fried chips. The taste scores of banana chips generally decreased with storage period in all packages. In case of vacuum fried chips packed with nitrogen flushing, the taste score decreased from initial value of 8.10 to 7.94, 7.86, 7.26 and 7.14 in LDPE; 7.98, 7.90, 7.40 and 7.32 in PP; and 8.06, 8.0, 7.72 and 7.65 in MMP after 15, 30, 45 and 60 days of storage, respectively. For vacuum fried chips (Table 4.21) packed without nitrogen flushing, the taste score decreased from initial value of 8.10 to 7.84, 7.56, 7.02 and 6.64 in LDPE; 7.90, 7.64, 7.08 and 6.80 in PP; and 7.94, 7.70, 7.16 and 6.88 in MMP respectively after 15, 30, 45 and 60 days of storage. The vacuum fried chips packed without nitrogen flushing obtained relatively lower taste scores when compared to chips packaged with nitrogen flushing. In case of atmospheric deep fat fried chips (Table 4.22) packed with nitrogen flushing, the taste score decreased from initial value of 7.80 to 7.62, 7.50, 6.86 and 6.50 in LDPE; 7.70, 7.56, 6.90 and 6.54 in PP; and 7.78, 7.66,7.00 and 6.60 in MMP respectively after 15, 30, 45 and 60 days of storage. The atmospheric deep fat fried banana chips with and without nitrogen flushing obtained relatively lower taste scores when compared to vacuum fried chips packaged with nitrogen flushing. After 60 days of storage, the banana chips stored in MMP with gas flushing obtained higher taste scores of 7.65 for vacuum fried and 6.60 for atmospheric fried chips. The taste of the chips was influenced by the salt level, biochemical constitution of the genotype, amount of oil absorbed and rancidity caused during storage. As discussed earlier, the level of rancidity of banana chips considerably varied with type of package used and duration of storage. Where the rancidity was less like in MMP stored chips, the taste scores were high.

4.4.6.5 Overall acceptability

The sensory score for "overall acceptability" of jackfruit chips stored in various packages for different storage periods are presented below Table 4.21 and 4.22. The mean sensory score for overall acceptability of fresh banana chips was 8.51 for vacuum fried chips and 8.10 for atmospheric fried chips. It may be noted that vacuum fried chips, in general, obtained better sensory scores than atmospheric fried chips except for texture. The overall acceptability scores generally decreased with storage period. In case of vacuum fried chips packed with nitrogen flushing, the overall acceptability score decreased from initial value of 8.51 to 8.42, 8.30, 7.50 and 7.26 in LDPE; 8.46, 8.38, 7.74 and 7.60 in PP; and 8.48, 8.40, 7.84 and 7.76 in MMP after 15, 30, 45 and 60 days of storage, respectively. For vacuum fried chips (Table 4.21) packed without nitrogen flushing, the overall acceptability score decreased from initial value of 8.51 to 8.40, 8.18, 7.06 and 6.62 in LDPE; 8.42, 8.22, 7.10 and 6.80 in PP; and 8.42, 8.30, 7.54 and 7.02 in MMP respectively after 15, 30, 45 and 60 days of storage. The vacuum fried chips packed with nitrogen flushing obtained relatively higher overall acceptability scores when compared to chips packaged without nitrogen flushing. In case of atmospheric deep fat fried chips (Table 4.22) packed with nitrogen flushing, the overall acceptability score decreased from initial value of 8.10 to 7.70, 7.52, 6.62 and 6.00 in LDPE; 7.74, 7.58, 6.70 and 6.08 in PP; and

Table 4.21: Mean sensory scores of vacuum fried banana chips stored in different packages with and without nitrogen flushing at ambient conditions

Type of package	Sensory parameters	Nitrogen flushing					Without nitrogen flushing				
		Storage period (days)					Storage period (days)				
		0	15	30	45	60	0	15	30	45	60
LDPE	Colour	7.80	7.68	7.62	6.98	6.80	7.80	7.60	7.56	6.78	6.68
	Flavour	8.40	8.20	8.06	7.62	7.40	8.40	8.00	7.80	7.54	7.26
	Texture	8.10	7.92	7.80	7.56	7.22	8.10	7.86	7.72	7.24	6.96
	Taste	8.10	7.94	7.86	7.26	7.14	8.10	7.84	7.56	7.02	6.64
	Overall acceptability	8.51	8.42	8.30	7.50	7.26	8.51	8.40	8.18	7.06	6.62
PP	Colour	7.80	7.71	7.66	7.13	6.95	7.80	7.66	7.60	7.02	6.84
	Flavour	8.40	8.28	8.22	7.76	7.68	8.40	8.16	8.04	7.60	7.34
	Texture	8.10	7.98	7.96	7.70	7.62	8.10	7.90	7.82	7.46	7.08
	Taste	8.10	7.98	7.90	7.40	7.32	8.10	8.42	8.22	7.10	6.80
	Overall acceptability	8.51	8.46	8.38	7.74	7.60	8.51	8.42	8.22	7.10	6.80
MMP	Colour	7.80	7.77	7.70	7.40	7.32	7.80	7.74	7.64	7.26	7.20
	Flavour	8.40	8.36	8.30	7.88	7.76	8.40	8.24	8.16	7.78	7.56
	Texture	8.10	8.04	8.0	7.94	7.86	8.10	7.92	7.88	7.58	7.12
	Taste	8.10	8.06	8.0	7.72	7.65	8.10	7.94	7.70	7.16	6.88
	Overall acceptability	8.51	8.48	8.40	7.84	7.76	8.51	8.42	8.30	7.54	7.02

LDPE = Low density polyethylene
PP = Polypropylene
MMP = Metalized multilayer polyethylene

Table 4.22: Mean sensory scores of atmospheric fried banana chips stored in different packages with and without nitrogen flushing at ambient condition

Type of package	Sensory parameters	Nitrogen flushing					Without nitrogen flushing				
		Storage period (days)					Storage period (days)				
		0	15	30	45	60	0	15	30	45	60
LDPE	Colour	7.83	7.64	7.50	6.84	6.70	7.83	7.60	7.48	6.42	6.32
	Flavour	7.71	7.58	7.50	6.80	6.56	7.71	7.42	7.30	6.42	6.00
	Texture	8.12	7.80	7.66	6.71	6.52	8.12	7.68	7.40	6.50	6.36
	Taste	7.80	7.62	7.50	6.86	6.50	7.80	7.52	7.36	6.62	6.03
	Overall acceptability	8.10	7.70	7.52	6.62	6.00	8.10	7.60	7.42	6.40	5.50
PP	Colour	7.83	7.72	7.66	6.98	6.88	7.83	7.64	7.54	6.72	6.64
	Flavour	7.71	7.62	7.56	6.98	6.74	7.71	7.54	7.42	6.60	6.50
	Texture	8.12	7.86	7.70	6.80	6.62	8.12	7.76	7.58	6.70	6.50
	Taste	7.80	7.70	7.56	6.90	6.54	7.80	7.60	7.44	6.74	6.40
	Overall acceptability	8.10	7.74	7.58	6.70	6.08	8.10	7.66	7.54	6.54	5.76
MMP	Colour	7.83	6.88	7.70	7.0	6.96	7.83	7.68	7.64	7.01	6.62
	Flavour	7.71	7.68	7.62	7.04	6.94	7.71	7.60	7.54	6.82	6.86
	Texture	8.12	7.94	7.86	7.06	6.96	8.12	7.80	7.76	6.88	6.62
	Taste	7.80	7.78	7.66	7.00	6.60	7.80	7.64	7.50	6.86	6.48
	Overall acceptability	8.10	7.84	7.70	6.76	6.12	8.10	7.72	7.62	6.72	6.00

LDPE = Low density polyethylene
PP = Polypropylene
MMP = Metalized multilayer polyethylene

7.84, 7.70, 6.76 and 6.12 in MMP, respectively after 15, 30, 45 and 60 days of storage. The atmospheric deep fat fried chips with and without nitrogen flushing obtained relatively lower overall acceptability scores when compared to vacuum fried chips packaged with nitrogen flushing. After 60 days of storage, the banana chips stored in MMP with N_2 gas flushing obtained higher overall acceptability scores of 7.76 in case of vacuum fried and 6.12 in case of atmospheric fried chips.

Sensory quality of banana chips though subjective in nature but still indicate the general trend of product acceptability by consumers. High score for various sensory attributes of banana chips stored in MMP package with N_2 flushing especially for vacuum fried chips indicated that this package was most suitable. From two months of storage study of both atmospheric and vacuum fried banana chips in different packages with and without N_2 flushing, it could be clearly seen that banana chips stored in MMP package with N_2 flushing obtained high scores for various sensory attributes even after 60 days of storage. Therefore, from this study, it could be concluded that the MMP package with N_2 flushing was ideal for storing both atmospheric and vacuum fried banana chips.

4.5 Cost-Economics of Banana Chips Production

The cost of production was worked out to be Rs 237.06/ kg and Rs 295.03/ kg of atmospheric and vacuum fried chips, respectively (Appendix II). The Cost:Benefit ratio for the production of atmospheric fried chips was 1:1.26 for that of vacuum fried chips, it was 1:1.69.

V SUMMARY

Banana, belonging to the family *Musaceae*, is perhaps the most popular fruit in the world and is a major fruit in the international trade. India produced about 26.5 million tonnes of banana during the year 2015 and its share was highest @33.41% of the total fruits production in the country. Dwarf Cavendish banana is the most popular and valuable edible variety of triploid banana and it constitutes over 40% of the fruits produced worldwide. It is being processed into a wide variety of products namely, banana chips, French fries, banana powder and flour, banana cocoa and coffee, alcohol, wine and vinegar.

Banana chips are one such value-added product with a crispy and unique taste. The chips are usually made from ripe green banana, consumed as a snack food and an ingredient in some breakfast cereals. Though banana chips are available in the market for a long time, most of such chips are prepared by deep fat frying at high temperatures under normal atmospheric pressure. Currently, in traditional banana chips production process, the frying oil temperature and frying time are not standardized scientifically. Degradation of important nutritional compounds and the generation of toxic molecules like acrylamide in the foodstuff due to high frying temperatures and exposure to oxygen have led to the development of healthy and low-fat snack products.

Vacuum frying is alternative technology that might be an option for the production of novel snacks from fruits and vegetables with lower oil content and desired quality attributes. It is the frying process carried out under pressures well below atmospheric levels therefore, lowering the boiling point of oil, making possible to reduce substantially the frying temperature. An attempt was made to optimize the atmospheric and vacuum deep fat frying process parameters for quality banana chips and also to study the storage stability of atmospheric and vacuum deep fat fried banana chips.

Well matured, unripe banana (var. Dwarf Cavendish) was selected for the preparation of banana chips. The banana was manually peeled and sliced using cutting blade to obtain the dimension of 2.5 mm thick slices. The cut slices were blanched in hot water (@60 $^{\circ}$C) with 1% KMS for 5 minutes and air dried at room temperature for 10-15 minutes to remove surface moisture. Then the slices were atmospheric and vacuum fried using refined sunflower oil. Atmospheric frying was done using electric deep fryer at frying temperature at 160, 180 and 200 ˚C for 8, 9 and 10 minutes of frying duration. Vacuum fried banana chips were made using a vacuum fryer having separate centrifugation unit for de oiling the chips. Vacuum frying process parameters namely, vacuum level (640 & 400 mm Hg), frying temperature (80, 90 & 100 °C) and frying duration (15, 20, 25 and 30min) After frying the chips were subjected to centrifugation for 5 min at 500 rpm in the basket centrifuge for the removal of excess surface oil from the chips. Immediately after frying, the chips were cooled for 5 min and then the chilly powder (@1%) and salt (@2%) were added to the chips and packed. For different combinations in frying parameters, the oil absorption by the chips, chips out-turn, crispiness, tristimulus colour, biochemical characteristics like peroxide value and FFA and sensory quality of the chips were studied. Optimum process parameter for both atmospheric and vacuum frying were determined based on quality characteristics of fried chips.

Storage study of atmospheric and vacuum fried chips prepared at optimized process parameters was done. The banana chips were packed in three packages LDPE, PP and MMP packages with and without nitrogen gas flushing at ambient conditions of Bangalore for two months. The stored chips were tested at 15 days interval for moisture content, FFA, peroxide value, tristimulus colour, crispiness and sensory quality.

Based on the results obtained in different experiments, the following conclusion could be drawn:

- ❖ Under atmospheric deep fat frying, among different combinations of frying temperature and time periods tried, the best quality banana chips could be obtained at frying temperature of 180 ˚C for 9 minutes of frying duration.
- ❖ Under vacuum frying, among various combinations of vacuum frying parameters tried, the banana chips fried under 400 mm Hg vacuum at 90 ˚C frying temperature for 25 min of frying time was found to be best in terms of various quality parameters.

- The vacuum fried banana chips contained much less fat (24.82%) when compared to atmospheric fried chips (46.62%) and therefore was considered better from health point of view.
- Both atmospheric and vacuum fried chips could be stored for at least 2 months and among the three tested packages, the Metalized Multilayer Polyethylene package with N_2 gas flushing was found to be ideal for banana chips storage.
- The cost of production for atmospheric and vacuum fried chips was Rs 237.06/ kg and Rs 295.0/ kg, respectively. The Cost : Benefit ratio for the production of atmospheric fried chips was 1:1.26 for that of vacuum fried chips, it was 1:1.69

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APPPENDIX – I

SENSORY SCORE CARD FOR ATMOAPHERIC AND VACUUM FRIED BANANA CHIPS

Name of judge: **Date:**

SCORE SYSTEM

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

Product	**Quality characteristics**				
	Colour	**Flavour**	**Texture**	**Taste**	**Overall acceptability**
A					
B					
C					
D					
E					
F					

Signature

APPPENDIX – II

COST ECONOMICS OF BANANA CHIPS PRODUCTION

Cost economics of vacuum fried banana chips

Assumption made:

1) Cost of the banana chips slicing machine (C1) = Rs. 500
2) Cost of vacuum fryer machine (C2) = Rs. 4.50,000
3) Cost of banana fruit per kg = Rs 28/ kg
4) Salvage value of equipment (S) = 10%
5) Annual use (U) expected operational hour = 2000h
6) Expected life (L) = 10 years
7) Product out turn per kg of raw material = 400 g

1) Fixed cost

a) Depreciation cost (D)

$$D = \frac{C-S}{UL} \quad = \frac{500-0.1}{20,000} \quad = 22.5/h$$

b) Interest on capital investment @ 12 % per annum on fixed price (I)

$$I = \frac{C+S}{2U} \times 0.12$$

$$= Rs.13.51/h$$

c) Repair and maintenance cost @ 2 % (R)

$$R = \frac{C}{UL} \times 0.02$$

$$= Rs.\ 0.450$$

Total fixed cost (D + I + R) = (22.5 + 13.51 + 0.450) = Rs. 36.47/h

2. Operational cost/Variable cost

i) Power consumption	= 5.5 kW/h
(Energy cost @ 3.40/units)	= Rs. 17.6/h
ii) Labour cost @ Rs. 300 per day (8 hours) per person	= Rs. 75.50/h
iii) Raw material cost (Rs. 28/kg fruit @40% pulp per kg fruit)	=Rs. 28/ kg
iv) Raw material cost for frying 1 kg chips	= Rs. 130
Oil cost per kg (980 ml)	= Rs.97
Oil consumption/kg of chips	= (80 ml)
Oil cost for frying 1 kg chips	= Rs. 7.76
Cost of packaging material per kg	= Rs.8.5
Chilli/Salt / miscellaneous per kg	= Rs. 20
Total variable cost	= (17.6+75.50+ 130+ 9.7+ 8.5 +20)/h
	= Rs. 259.36/h
Total cost of production	= TFC + TVC
	= (259.36 + 1.168)/h
	= Rs. 295.03/ kg
Revenue by selling chips	= Rs 500/ kg
Cost : Benefit Ratio	**= 1: 1.69**

Cost Economics of Atmospheric Fried Banana Chips

Assumption made:

Cost of the banana chips slicing blade (C1)	= Rs. 500
Cost of Electrical atmospheric fryer (C2)	= Rs. 13,990
Cost of banana per kg	= Rs 28
Salvage value of equipment (S)	= 10%
Annual use (U) expected operational hour	= 2000h
Expected life (L)	= 10 years
Product out turn per kg of raw material	= 350 g

1) Fixed cost

a) Depreciation cost (D)

$$D = \frac{C-S}{UL} = \frac{500-0.1}{20,000}$$

= RS 0.724/h

b) Interest on capital investment @ 12 % per annum on fixed price (I)

$$I = \frac{C+S}{2U} \times 0.12$$

=Rs.0.434/h

c) Repair and maintenance cost @ 2 % (R)

$$R = \frac{C}{UL} \times 0.02$$

= Rs. 0.014

Total fixed cost (D + I + R) = (0.72 + 0.43 + 0.014) = Rs. 1.168/h

2. Operational cost/Variable cost

i) Power consumption = 3 kW/h

(Energy cost @ 3.40/units) = Rs. 10.2/h

ii) Labour cost @ Rs. 300 per day (8 hours) per person

= Rs. 37.5/h

iii) Raw material cost (Rs. 28/kg fruit @40% of pulp per kg fruit)

= Rs. 28

Raw material cost for frying 1 kg chips = Rs. 130

Oil cost per kg (980 ml) = Rs.97

Oil consumption/kg of chips = (80 ml)

Oil cost for frying 1 kg chips = Rs. 9.7

Cost of packaging material per kg = Rs.8.5

Chilli/Salt / miscellaneous per kg = Rs. 20

Total variable cost = (10.2+37.5+ 130+ 9.7+ 8.5 +20)/h

= Rs. 215.9/h

Total cost of production = 1.168 + 215.9

= 237.06/h

Revenue by selling chips = Rs 300/ kg

Cost : Benefit Ratio = 1:1.26

APPPENDIX – III

Atmospheric Frying - Analysis of Variance Tables

Source	DF	SS	MSS	F-Calculated
A	2	6.242	3.121	260.573
B	2	0.162	0.081	6.781
A × B	4	0.181	0.045	3.775
Error	9	0.108	0.012	
Total	17	6.694		

a) Moisture

GM = 4.40 CV= 2.48

MEAN OF A × B

	B1	B2	B3
A1	5.280	5.205	5.145
A2	4.110	4.340	4.120
A3	4.055	3.845	3.550

MEAN OF A:

5.21 4.19

MEAN OF B:

4.48 4.46 4.27

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.145	0.063	0.045
B	0.145	0.063	0.045
A × B	0.251	0.109	0.077

A = Frying temperature
B = Frying time

b) Peroxide value

Source	DF	SS	MSS	F-Calculated
A	2	59.792	29.896	2864.304
B	2	4.148	2.074	198.709
A × B	4	8.759	2.190	209.805
Error	9	0.094	0.010	
Total	17	72.793		

GM = 18.52 CV= 0.53

Mean Table OF A × B

	B1	B2	B3
A1	14.315	16.500	17.370
A2	19.735	18.315	19.285
A3	19.880	20.565	20.785

MEAN OF A:

16.06 19.11 20.41

MEAN OF B:

17.97 18.46 19.14

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.135	0.059	0.042
B	0.135	0.059	0.042
A × B	0.234	0.102	0.072

A = Frying temperature

B = Frying time

c) Free fatty acid

Source	DF	SS	MSS	F-Calculated
A	2	0.729	0.365	431.658
B	2	0.011	0.006	6.757
A × B	4	0.050	0.012	14.710
Error	9	0.008	0.001	
Total	17	0.798		

GM = 0.71 CV=4.45

MEAN OF A × B

	B1	B2	B3
A1	0.345	0.455	0.510
A2	0.860	0.755	0.750
A3	0.840	0.925	0.970

MEAN OF A:

0.43 0.78 0.91

MEAN OF B:

0.68 0.71 0.74

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.038	0.017	0.012
B	0.038	0.017	0.012
A × B	0.067	0.029	0.021

A = Frying temperature

B = Frying time

d) Oil absorption

Source	DF	SS	MSS	F-Calculated
A	2	149.010	74.505	551.287
B	2	7.502	3.751	27.755
A × B	4	3.728	0.932	6.896
Error	9	1.216	0.135	
Total	17	161.457		

GM= 45.29 CV=0.81

MEAN TABLE OF A × B

	B1	B2	B3
A1	40.050	41.985	43.170
A2	46.120	46.625	46.850
A3	48.110	48.790	48.915

MEAN OF A:

41.73 46.53 48.60

MEAN OF B:

44.76 45.80 46.31

TABLE OF SEM , SED AND C.D.

Factors	C.D.	SED	SEM
A	0.487	0.212	0.150
B	0.487	0.212	0.150
A × B	0.843	0.368	0.260

A = Frying temperature

B = Frying time

e) Chips out-turn

Source	DF	SS	MSS	F-Calculated
A	2	0.278	0.139	2.599
B	2	7.515	3.757	70.296
A × B	4	10.460	2.615	48.924
Error	9	0.481	0.053	
Total	17	18.733		

GM = 41.65 CV=0.55

MEAN TABLE A x B

	B1	B2	B3
A1	52.115	50.980	51.030
A2	49.965	52.405	50.955
A3	49.935	52.940	50.460

MEAN OF A:

51.37 51.10 51.11

MEAN OF B:

50.67 52.10 50.81

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	N/A	0.133	0.094
B	0.306	0.133	0.094
A × B	0.530	0.231	0.163

A = Frying temperature

B = Frying time

f) Crispiness

Source	DF	SS	MSS	F-Calculated
A	2	283,724.593	141,862.297	4,913.369
B	2	38,806.553	19,403.277	672.028
A × B	4	685,100.681	171,275.170	5,932.077
Error	9	259.854	28.873	
Total	17	1,007,891.682		

GM =2186.57 CV= 0.24

MEAN OF A:

2085.99 2379.06 2151.84

MEAN OF B:

2222.69 2252.01 2142.18

MEAN OF A × B

	B1	B2	B3
A1	2,285.160	2,082.260	1,890.550
A2	2,025.840	2,675.240	2,436.120
A3	2,357.090	1,998.540	2,099.890

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	7.117	3.102	2.194
B	7.117	3.102	2.194
A × B	12.327	5.373	3.800

A = Frying temperature

B = Frying time

APPPENDIX – IV

Atmospheric Frying - Analysis of Variance Tables for Sensory Scores

a) Colour

Source	DF	SS	M.S.S	F-Calculated
A	2	0.207	0.103	36.311
B	2	0.385	0.192	67.678
A × B	4	0.592	0.148	52.086
Error	9	0.026	0.003	
Total	17	1.210		

GM = 7.54 CV = 0.72

MEAN OF A × B

	B1	B2	B3
A1	7.215	7.775	7.760
A2	7.545	7.835	7.615
A3	7.545	7.665	7.015

MEAN OF A:

7.58 7.66 7.40

MEAN OF B:

7.43 7.75 7.46

TABLE OF SEM , SED AND C.D.

Factors	C.D.	SED	SEM
A	0.071	0.031	0.022
B	0.071	0.031	0.022
A × B	0.122	0.053	0.038

A = Frying temperature

B = Frying time

b) Flavour

Source	DF	S.S	MSS	F-Calculated
A	2	0.501	0.251	108.394
B	2	0.314	0.157	67.931
A × B	4	0.996	0.249	107.672
Error	9	0.021	0.002	
Total	17	1.832		

GM = 7.53 CV=0.59

MEAN OF A × B

	B1	B2	B3
A1	7.525	7.825	7.700
A2	7.475	7.710	7.700
A3	7.700	7.520	6.695

MEAN OF A

7.68 7.62 7.30

MEAN OF B

7.56 7.68 7.36

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.064	0.028	0.020
B	0.064	0.028	0.020
A × B	0.110	0.048	0.034

A = Frying temperature

B = Frying time

c) Texture

Source	DF	SS	MSS	F-Calculated
A	2	1.764	0.882	80.592
B	2	0.067	0.034	3.073
A × B	4	0.261	0.065	5.973
Error	9	0.098	0.011	
Total	17	2.191		

GM= 7.66 CV= 1.36

MEAN OF A × B

	B1	B2	B3
A1	7.050	7.225	7.575
A2	8.000	8.125	8.025
A3	7.745	7.590	7.635

MEAN OF A:

7.28 8.05 7.65

MEAN OF B:

7.59 7.64 7.74

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.139	0.060	0.043
B	N/A	0.060	0.043
A × B	0.240	0.105	0.074

A = Frying temperature

B = Frying time

d) Taste

Source	DF	SS	MSS	F-Calculated
A	2	1.151	0.576	189.255
B	2	0.103	0.052	16.952
A × B	4	1.166	0.291	95.826
Error	9	0.027	0.003	
Total	17	2.448		

GM= 7.52 CV= 0.72

MEAN OF A × B

	B1	B2	B3
A1	7.075	7.175	7.675
A2	7.585	8.125	7.925
A3	7.640	7.555	6.955

MEAN OF A:

7.30 7.87 7.38

MEAN OF B:

7.43 7.61 7.51

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.073	0.032	0.023
B	0.073	0.032	0.023
A × B	0.127	0.055	0.039

A = Frying temperature

B = Frying time

e) Overall acceptability

Source	DF	SS	MSS	F-Calculated
A	2	0.537	0.268	40.800
B	2	0.281	0.141	21.369
A × B	4	1.274	0.318	48.421
Error	9	0.059	0.007	
Total	17	2.151		

GM = 7.57　　　　　CV= 3.20

MEAN OF A × B

	B1	B2	B3
A1	7.100	7.275	7.850
A2	7.475	8.100	7.860
A3	7.655	7.765	7.080

MEAN OF A:

7.40　　　7.81　　　7.51

MEAN OF B:

7.41　　　7.71　　　7.59

TABLE OF SEM, SED AND C.D.

Factors	C.D.	SED	SEM
A	0.107	0.047	0.033
B	0.107	0.047	0.033
A × B	0.186	0.081	0.057

A = Frying temperature

B = Frying time

APPPENDIX – V
Vacuum Frying - Analysis of Variance Tables

a) Moisture content

Source	DF	SS	MSS	F-Calculated
A	1	47.780	47.780	14,712.551
B	2	13.371	6.686	2,058.674
C	2	0.825	0.413	127.046
A × B	3	1.612	0.537	165.426
A × C	3	0.074	0.025	7.642
B × C	6	0.014	0.002	0.732
A× B × C	6	0.045	0.008	2.317
Error	24	0.078	0.003	
Total	47	63.801		

GM =4.88 CV = 1.12

MEAN VALUE OF A × B

	B1	B2	B3
A1	6.368	5.890	5.394
A2	4.714	3.849	3.103

MEAN VALUE OF A× C

	C1	C2	C3	C4
A1	6.057	5.975	5.833	5.670
A2	4.183	3.997	3.772	3.602

MEAN VALUE OF B × C

	C1	C2	C3	C4
B1	5.750	5.640	5.460	5.313
B2	5.130	4.950	4.773	4.625
B3	4.480	4.368	4.175	3.970

MEAN VALUE OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	6.510	6.040	5.620	4.990	4.220	3.340
C_2	6.460	5.950	5.515	4.820	3.950	3.220
C_3	6.320	5.840	5.340	4.600	3.705	3.010
C_4	6.180	5.730	5.100	4.445	3.520	2.840

MEAN VALUE OF A:

5.88 3.88

MEAN VALUE OF B:

5.54 4.86 4.24

MEAN VALUE OF C:

5.12 4.98 4.80 4.63

TABLE OF SEM, SED AND C.D

Factors	**C.D.**	**SED**	**SEM**
A	0.034	0.016	0.012
B	0.042	0.020	0.014
C	0.059	0.028	0.020
AB	0.048	0.023	0.016
AC	0.068	0.033	0.023
BC	N/A	0.040	0.028
ABC	N/A	0.057	0.040

A = Vacuum level

B = Frying temperature

C = Frying time

b) Peroxide value

Source	DF	SS	MSS	F-Calculated
A	1	23.548	23.548	7,605.810
B	2	12.809	6.404	2,068.574
C	2	1.558	0.779	251.656
AB	3	2.451	0.817	263.849
AC	3	0.285	0.095	30.691
BC	6	0.654	0.109	35.221
ABC	6	0.973	0.162	52.379
Error	24	0.074	0.003	
Total	47	42.352		

GM =7.21 CV= 0.75

MEAN OF AB

	B1	B2	B3
A1	5.895	6.718	6.935
A2	7.290	7.680	8.780

MEAN OF BC

	C1	C2	C3	C4
B1	6.250	6.250	6.925	6.945
B2	7.025	7.143	7.253	7.375
B3	7.465	7.885	7.945	8.135

MEAN OF AC

	C1	C2	C3	C4
A1	6.223	6.290	6.787	6.763
A2	7.603	7.895	7.962	8.207

MEAN OF ABC

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	5.320	6.630	6.720	7.180	7.420	8.210
C_2	5.320	6.600	6.950	7.180	7.685	8.820
C_3	6.470	6.820	7.070	7.380	7.685	8.820
C_4	6.470	6.820	7.000	7.420	7.930	9.270

MEAN OF A:

6.51 7.91

MEAN OF B:

6.59 7.19 7.85

MEAN OF C:

6.91 7.09 7.37 7.48

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.033	0.016	0.011
B	0.041	0.020	0.014
C	0.047	0.023	0.016
AB	0.057	0.028	0.020
AC	0.066	0.032	0.023
BC	0.081	0.039	0.028
ABC	0.115	0.056	0.039

A = Vacuum level
B = Frying temperature
C = Frying time

c) Free fatty acid

Source	DF	SS	MSS	F-Calculated
A	1	0.227	0.227	74.689
B	2	0.196	0.098	32.325
C	3	0.047	0.016	5.107
AB	2	0.061	0.031	10.044
AC	3	0.023	0.008	2.518
BC	6	0.008	0.001	0.440
ABC	6	0.011	0.002	0.621
Error	24	0.073	0.003	
Total	47	0.646		

GM =0.62 CV = 8.83

MEAN VALUE OF A × B

	B1	B2	B3
A1	0.515	0.560	0.595
A2	0.614	0.636	0.833

MEAN VALUE OF A × C

	C1	C2	C3	C4	
A1	0.547	0.547	0.567	0.567	
A2	0.618	0.672	0.737	0.750	

MEAN VALUE OF B × C

	C1	C2	C3	C4	
B1	0.548	0.550	0.580	0.580	
B2	0.540	0.573	0.630	0.650	
B3	0.660	0.705	0.745	0.745	

MEAN VALUE OF A ×B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	0.500	0.550	0.590	0.595	0.530	0.730
C_2	0.500	0.550	0.590	0.600	0.595	0.820
C_3	0.530	0.570	0.600	0.630	0.690	0.890
C_4	0.530	0.570	0.600	0.630	0.730	0.890

MEAN OF VALUE A:

0.55 0.69

MEAN VALUE OF B:

0.56 0.59 0.71

MEAN VALUE OF C:

0.58 0.60 0.65 0.65

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.033	0.016	0.011
B	0.040	0.019	0.014
C	0.046	0.022	0.016
AB	0.057	0.028	0.019
AC	N/A	0.032	0.022
BC	N/A	0.039	0.028
ABC	N/A	0.055	0.039

A = Vacuum level
B = Frying temperature
C = Frying time

d) Chips out-turn

Source	DF	SS	MSS	F-Calculated
A	1	367.127	367.127	149,488.056
B	2	70.712	35.356	14,396.305
C	3	6.174	2.058	2,234.425
AB	2	10.975	5.488	145.286
AC	3	1.070	0.357	838.004
BC	6	1.258	0.210	85.383
ABC	6	0.592	0.099	40.191
Error	24	0.059	0.002	
Total	47	457.967		

GM =40.02 CV= 0.11

MEAN VALUE OF A × B

	B1	B2	B3
A1	36.595	36.780	38.410
A2	40.808	42.713	44.859

MEAN VALUE OF A × C

	C1	C2	C3	C4
A1	36.677	37.517	37.290	37.563
A2	42.260	42.550	43.000	43.362

MEAN VALUE OF B × C

	C1	C2	C3	C4
B1	38.305	38.870	38.680	38.950
B2	39.285	39.755	39.835	40.110
B3	40.815	41.475	41.920	42.328

MEAN VALUE OF A×B×C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	36.240	36.300	37.490	40.370	42.270	44.140
C_2	37.200	36.880	38.470	40.540	42.630	44.480
C_3	36.400	36.910	38.560	40.960	42.760	45.280
C_4	36.540	37.030	39.120	41.360	43.190	45.535

MEAN OF A:
37.26 42.79

MEAN OF B:
38.70 39.74 41.63

MEAN OF C:
39.46 40.03 40.14 40.46

TABLE OF SEM, SED AND C.D

Factors	**C.D.**	**SED**	**SEM**
A	0.030	0.014	0.010
B	0.036	0.018	0.012
C	0.051	0.025	0.018
AB	0.042	0.020	0.014
AC	0.059	0.029	0.020
BC	0.072	0.035	0.025
ABC	0.102	0.050	0.035

A = Vacuum level
B = Frying temperature
C = Frying time

e) Crispiness

Source	DF	SS	MSS	F-Calculated
A	1	6,779,211.223	6,779,211.223	1,597,163.171
B	2	5,895,352.511	2,947,676.256	694,464.267
C	2	604,888.119	201,629.373	47,503.315
AB	3	194,873.797	97,436.898	22,955.860
AC	3	150,214.426	50,071.475	11,796.699
BC	6	793,945.248	132,324.208	31,175.213
ABC	6	705,325.652	117,554.275	27,695.458
Error	24	101.869	4.245	
Total	47	15,123,912.845		

GM= 1809.89 CV= 0.11

MEAN VALUE OF A × B

	B1	B2	B3
A1	955.839	1,686.458	1,502.823
A2	1,572.309	2,402.409	2,425.265

MEAN VALUE OF A × C

	C1	C2	C3	C4
A1	1,164.173	1,346.183	1,394.958	1,621.510
A2	2,097.925	2,085.808	2,095.293	2,254.283

MEAN VALUE OF B × C

	C1	C2	C3	C4
B1	1,145.667	1,304.705	1,236.643	1,369.280
B2	1,738.095	1,922.905	2,016.135	2,500.597
B3	2,009.385	1,920.378	1,982.600	1,943.813

MEAN VALUE OF A x B x C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	711.750	1,454.085	1,326.685	1,579.585	2,022.105	2,692.085
C_2	911.620	1,606.015	1,520.915	1,697.790	2,239.795	2,319.840
C_3	1,044.150	1,716.150	1,424.575	1,429.135	2,316.120	2,540.625
C_4	1,155.835	1,969.580	1,739.115	1,582.725	3,031.615	2,148.510

MEAN VALUE OF A:

1,381.706 2,133.327

MEAN VALUE OF B:

1,264.074 2,044.433 1,964.044

MEAN VALUE OF C:

1,631.049 1,715.996 1,745.126 1,937.897

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	1.228	0.595	0.421
B	1.504	0.728	0.515
C	1.736	0.841	0.595
AB	2.127	1.030	0.728
AC	2.456	1.189	0.841
BC	3.007	1.457	1.030
ABC	4.253	2.060	1.457

A = Vacuum level
B = Frying temperature
C = Frying time

f) Oil absorption

Source of Variation	DF	SS	MSS	F-Calculated
A	1	5.713	5.713	3.066
B	2	45.669	22.834	12.255
C	3	3.214	1.071	0.575
AB	2	1.201	0.601	0.322
AC	3	1.884	0.628	0.337
B C	6	3.148	0.525	0.282
ABC	6	2.766	0.461	0.247
Error	24	44.717	1.863	
Total	47	108.313		

GM= 24.96 CV= 1.66

MEAN OF A × B

	B1	B2	B3
A1	24.32	25.20	26.33
A2	23.20	24.62	25.96

MEAN OF A × C

	C1	C2	C3	C4
A1	25.23	25.12	25.51	25.27
A2	23.99	24.41	24.84	25.15

MEAN OF B × C

	C1	C2	C3	C4
B1	23.170	23.470	24.105	24.305
B2	25.005	24.885	25.135	24.630
B3	25.660	25.950	26.295	26.700

MEAN OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	23.920	25.960	25.820	22.420	24.050	25.500
C_2	24.100	25.270	26.010	22.840	24.500	25.890
C_3	24.530	25.450	26.570	23.680	24.820	26.020
C_4	24.740	24.140	26.940	23.870	25.120	26.460

MEAN OF A:

25.28 25.59

MEAN OF B:

23.76 24.91 26.15

MEAN OF C:

24.61 24.76 25.17 25.21

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.790	0.39	0.27
B	0.996	0.48	0.34
C	NS	0.55	0.38
AB	NS	0.68	0.48
AC	NS	0.78	0.55
BC	NS	0.96	0.68
ABC	NS	1.36	0.95

A = Vacuum level

B = Frying temperature

C = Frying time

APPPENDIX – VI

Vacuum Frying - Analysis of Variance Tables for Sensory Scores

a) Colour

Source	DF	SS	MSS	F-Calculated
A	1	0.936	0.936	45.198
B	2	16.739	8.370	404.241
C	3	0.877	0.292	14.112
AB	2	8.050	4.045	194.400
AC	3	2.109	0.703	33.962
BC	6	1.998	0.333	16.080
ABC	6	1.163	0.194	9.365
Error	24	0.497	0.021	
Total	47	32.369		

GM =6.49 CV =2.23

MEAN OF A × B

	B1	B2	B3
A1	6.068	6.770	6.240
A2	5.270	7.218	7.428

MEAN OF A × C

	C1	C2	C3	C4
A1	6.478	6.448	6.243	6.267
A2	6.117	6.733	7.053	6.650

MEAN OF B × C

	C1	C2	C3	C4
B1	5.295	5.790	5.790	5.800
B2	6.688	7.203	7.460	6.625
B3	6.910	6.780	6.695	6.950

MEAN OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	6.240	6.875	6.320	4.350	6.500	7.500
C_2	6.150	6.885	6.310	5.430	7.520	7.250
C_3	5.780	7.120	5.830	5.800	7.800	7.560
C_4	6.100	6.200	6.500	5.500	7.050	7.400

MEAN OF A:

6.35 6.63

MEAN OF B:

5.66 6.99 6.83

MEAN OF C:

6.29 6.59 6.64 6.45

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.086	0.042	0.029
B	0.105	0.051	0.036
C	0.121	0.059	0.042
AB	0.149	0.072	0.051
AC	0.172	0.083	0.059
BC	0.210	0.102	0.072
ABC	0.297	0.144	0.102

A = Vacuum level
B = Frying temperature
C = Frying time

b) Flavour

Source	DF	SS	MSS	F-Calculated
A	1	0.071	0.071	0.300
B	2	11.299	5.650	23.838
C	2	9.400	4.700	19.832
AB	3	2.157	0.719	3.034
AC	3	1.795	0.598	2.524
BC	6	2.393	0.399	1.683
ABC	6	3.980	0.663	2.799
Error	24	5.688	0.237	
Total	47	36.784		

GM =6.28 CV= 7.75

MEAN OF A×B

	B1	B2	B3
A1	6.215	6.575	6.180
A2	4.983	6.659	7.098

MEAN OF A × C

	C1	C2	C3	C4
A1	6.203	6.467	5.957	6.667
A2	6.010	6.753	6.215	6.007

MEAN OF B × C

	C1	C2	C3	C4
B1	5.410	5.935	5.800	5.250
B2	6.325	7.085	6.308	6.750
B3	6.585	6.810	6.150	7.010

MEAN OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	6.090	6.400	6.120	4.730	6.250	7.050
C_2	6.200	6.750	6.450	5.670	7.420	7.170
C_3	6.070	6.650	5.150	5.530	5.965	7.150
C_4	6.500	6.500	7.000	4.000	7.000	7.020

MEAN OF A:

6.32 6.24

MEAN OF B:

5.59 6.61 6.63

MEEAN OF C:

6.10 6.61 6.08 6.33

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	NS	0.141	0.099
B	0.355	0.172	0.122
C	0.410	0.199	0.141
AB	0.5030	0.243	0.172
AC	NS	0.281	0.199
BC	NS	0.344	0.243
ABC	1.005	0.487	0.344

A = Vacuum level
B = Frying temperature
C = Frying time

c) Texture

Source	DF	SS	MSS	F-Calculated
A	1	1.373	1.373	276.505
B	2	11.257	5.629	1133.312
C	2	7.754	3.877	780.649
AB	3	1.760	0.587	118.101
AC	3	0.054	0.018	3.627
BC	6	1.097	0.183	36.811
ABC	6	0.600	0.100	20.126
Error	24	0.119	0.005	
Total	47	24.014		

GM =6.32 CV = 1.11

MEAN OF A × B

	B1	B2	B3
A1	5.959	6.436	6.060
A2	5.321	6.758	7.391

MEAN OF A × C

	C1	C2	C3	C4
A1	5.883	6.277	6.280	6.167
A2	6.135	6.640	6.712	6.473

MEAN OF B × C

	C1	C2	C3	C4
B1	5.263	5.730	5.793	5.775
B2	6.093	7.010	6.810	6.475
B3	6.673	6.635	6.885	6.710

MEAN OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	5.525	6.105	6.020	5.000	6.080	7.325
C_2	6.110	6.670	6.050	5.350	7.350	7.220
C_3	6.200	6.470	6.170	5.385	7.150	7.600
C_4	6.000	6.500	6.000	5.550	6.450	7.420

MEAN OF A:

6.15 6.49

MEAN OF B:

5.64 6.59 6.72

MEAN OF C:

6.00 6.45 6.49 6.32

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.042	0.020	0.014
B	0.051	0.025	0.018
C	0.073	0.035	0.025
AB	0.059	0.029	0.020
AC	0.084	0.041	0.029
BC	0.103	0.050	0.035
ABC	0.145	0.070	0.050

A = Vacuum level
B = Frying temperature
C = Frying time

d) Taste

Source	DF	SS	MSS	F-Calculated
A	1	0.783	0.783	37.868
B	2	17.001	8.501	411.194
C	2	2.368	0.789	38.1832
AB	3	11.656	5.828	281.916
AC	3	1.081	0.360	17.430
BC	6	0.705	0.118	5.687
ABC	6	1.045	0.174	8.423
Error	24	0.496	0.021	
Total	47	35.136		

GM =6.12 CV =2.36

MEAN OF A × B

	B1	B2	B3
A1	5.845	6.079	6.055
A2	4.724	6.834	7.188

MEAN OF A × C

	C1	C2	C3	C4
A1	5.933	6.077	6.128	5.833
A2	5.708	6.343	6.717	6.225

MEAN OF B × C

	C1	C2	C3	C4
B1	4.938	5.360	5.590	5.250
B2	6.000	6.730	6.858	6.238
B3	6.525	6.540	6.820	6.600

MEAN OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	5.800	6.000	6.000	4.075	6.000	7.050
C_2	6.020	6.130	6.080	4.700	7.330	7.000
C_3	6.060	6.185	6.140	5.120	7.530	7.500
C_4	5.500	6.000	6.000	5.000	6.475	7.200

MEAN OF A:

5.99 6.24

MEAN OF B:

5.28 6.45 6.62

MEAN OF C:

5.82 6.21 6.42 6.02

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SEM**
A	0.086	0.042	0.029
B	0.105	0.051	0.036
C	0.121	0.059	0.042
AB	0.148	0.072	0.051
AC	0.171	0.083	0.059
B C	0.210	0.102	0.072
ABC	0.297	0.144	0.102

A = Vacuum level

B = Frying temperature

C = Frying time

d) Overall acceptability

Source	DF	SS	MSS	F-Calculated
A	1	0.137	0.137	17.772
B	2	19.759	9.879	1,282.377
C	2	10.781	5.390	699.703
AB	3	1.720	0.573	74.406
AC	3	1.110	0.370	48.029
BC	6	0.927	0.154	20.053
ABC	6	0.853	0.142	18.460
Error	24	0.185	0.008	
Total	47	35.471		

GM = 6.27 CV =1.42

MEAN OF A × B

	B1	B2	B3
A1	5.973	6.375	6.318
A2	4.785	6.826	7.374

MEAN OF A × C

	C1	C2	C3	C4
A1	6.183	6.253	6.283	6.167
A2	5.840	6.375	6.798	6.300

MEAN OF B × C

	C1	C2	C3	C4
B1	5.160	5.425	5.530	5.400
B2	6.175	6.790	7.088	6.350
B3	6.700	6.728	7.005	6.950

MEAN VALUE OF A × B × C

	A_1			A_2		
	B_1	B_2	B_3	B_1	B_2	B_3
C_1	6.000	6.350	6.200	4.320	6.000	7.200
C_2	6.050	6.350	6.360	4.800	7.230	7.095
C_3	6.040	6.600	6.210	5.020	7.575	7.800
C_4	5.800	6.200	6.500	5.000	6.500	7.400

MEAN OF A

6.22 6.32

MEAN OF B

5.37 6.60 6.84

MEAN OF C

6.01 6.31 6.54 6.23

TABLE OF SEM, SED AND C.D.

Factors	**C.D.**	**SED**	**SED**
A	0.052	0.025	0.018
B	0.064	0.031	0.022
C	0.074	0.036	0.025
AB	0.091	0.044	0.031
AC	0.105	0.051	0.036
BC	0.128	0.062	0.044
ABC	0.181	0.088	0.062

A = Vacuum level

B = Frying temperature

C = Frying time