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To
Dean R&D
23/8/2016

Project Completion Report

Design and Development of Vacuum Frying System for the Production of Healthy Snacks Products

File No. IDP/IND/2012/3 (General), dated: 11.09.2012

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23/8/2016

Funded by

Department of Science and Technology
Technology Bhavan, New Mehrauli Road
New Delhi- 110016

Submitted by

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1. The Department of Science and Technology, New Delhi and Dr. Anita Aggarwal, Scientist-D, Instrumentation Development Programme, Technology Development & Transfer Division, Department of Science & Technology, Ministry of Science and Technology, Technology Bhavan, New Mehrauli Road, New Delhi- 110 016.

2. Prof. Ram Rajasekharan, Director, CSIR-CFTRI, Mysore and Vice Chancellor, Tezpur University, Assam.

3. The Industrial Partner, M/s. Dynavac Systems, Bangalore.

4. The PI, Co-PI (s), the Members and concerned JRFs.

5. All the colleagues of CSIR-CFTRI, Mysore.

Status

Sl No.	Milestones	Status
01	Preparation of detailed engineering drawings (0 – 3 months)	Achieved
02	Fabrication of Vacuum Frying System (4 – 11 months)	Achieved
03	Trial runs/ Validation of the Vacuum Frying System (12 – 14 months)	Achieved
04	Developing frying protocol for healthy snacks (15 – 20 months)	Achieved
05	Field trials and demonstrations to selected users (21 – 23 months)	Achieved
06	Preparation of completion report for the project (24 months + extended period)	Achieved

Executive Summary

Design and development of vacuum frying system for the production of healthy snack products

- Vacuum frying is the frying process that is carried out under pressures well below atmospheric levels. Due to the low pressure, the frying points of the oil, and the boiling point of the moisture in the foods are lowered. The vacuum frying occurs in three phases such as frying, pressurization and cooling. It has several advantages such as, reduced oil content in the fried product, preserves the bioactive components, e.g., vitamin-C, β-carotene, betalain, charantin, phenolic compounds etc., natural color and flavor of the product. Due to the low temperature and oxygen free environment the process leads to less adverse effects on oil quality resulting in maintaining oil quality for long time.
- A prototype laboratory model (max. capacity 250 gm/ batch) of vacuum frying system was fabricated for generation of scientific data in turn, to help in scale-up of the system to pilot scale level.
- .An industrial model of vacuum frying system (max. capacity 10 kg/batch) was developed and fabricated successfully.
- Various trials were conducted to standardize process protocol for vacuum frying of products suh as potato chips, banana chips, bitter gourd chips, plantain chips, fried whole okra, kabuli chana, groundnut etc.
- From exploratory trials few products process know-how (banana chips, beetroot chips, bitter gourd chips) are standardized which can be used for commercial exploitation/ marketing.
- Cost for Land and Site development = Rs. 12,000,00.00
- Cost for Building and Civil work = Rs. 25,00,000.00
- Plant and Machinery Cost = Rs. 4,411,400.00
- Total Project cost for processing (250 kg/day/shift) banana slice = Rs. 10,266,419.00
- Cost of production of chips/ kg = Rs. 282.00.
- The approximate cost of the vacuum frying system (max. 10 kg/batch) ~15.00 lakhs.
- Pay-back period on simple return (depreciation + interest + profit before tax) on investment = 3.35 year.

PROJECT COMPLETION REPORT

Notes: 1 Three copies of the Project Completion Report should be sent within one month of the completion of the project
2 The Project Completion Report should be in the bound form.
3 Cover page should include the title of the project, file number, names and addresses of the investigation.

1 Title of the Project

'Design and Development of Vacuum Frying System for the Production of Healthy Snack Products'

2 Principal Investigator and Co-Investigators

Name and Address of Principal Investigators:

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Principal Scientist, Dept. of Traditional Food & Sensory Science (*Formerly Dept. of Lipid Science & Traditional Foods*), CSIR-CFTRI, Mysore - 570 020
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(ii) Dr. Charulata Mahanta
Professor, Dept. of Food Engineering and Technology, Tezpur University, Naapam, Tezpur, Assam

Co-Investigators:

(i) Shri. A. Chakkaravarthi, Senior Technical Officer, Dept. of Food Engineering, CSIR-CFTRI, Mysore - 570 020.

(ii) Shri. Dipankar Kalita, Technical Officer, Dept. of Food Enginnering and Technology, Tezpur University, Naapam, Tezpur, Assam

Members:	(i) Dr. B. R. Lokesh, Chief Scientist (Retd.), Dept. of Traditional Food and Sensory Science, CSIR-CFTRI, Mysore-570 020 (ii) Dr. A. G. Gopala Krishna, Chief Scientist (Retd.), Dept. of Traditional Food and Sensory Science, CSIR-CFTRI, Mysore-570 020 (iii) Dr. K.S.M.S. Raghavarao, Chief Scientist, Dept. of Food Engineering, CSIr-CFTRI, Mysore-570 020 (iv) Dr. N. K. Rastogi, Senior Principal Scientist, Dept. of Food Engineering, CSIR-CFTRI, Mysore-570 020 (v) Dr. Maya Prakash, Sr. Principal Scientist, Dept. of Traditional Food and Sensory Science, CSIR-CFTRI, Mysore-570 020.
Manpower:	(i) Mr. Rayees Ahmad Bakshi, JRF (12.12.2013- 28.05.2013) (ii) Mr. Praneeth Juvvi, JRF (07.06.2013 – 31.03.2015)
Total cost of the project:	Rs. 24,45,000 (CSIR-CFTRI, Mysore Rs. 10,72,400 (Tezpur University, Assam) Rs. 4, 00,000 (Industrial Partner's Contribution)

3 Implementing Institution and other collaborating Institutions

- Department of Food Engineering and Technology, Tezpur University, Napaam-784028, Tezpur, Assam, Tel: +91-3712-267007, 267008, 267009 Ext-5702, Fax: +91-3712-267006

4 Date of commencement

- The 25th September, 2012

5 Planned date of completion

-The 24th September, 2014

6 Actual date of completion

- The 31st March, 2015

7 (a) Objectives as stated in the project proposal

CSIR-CFTRI, Mysore

- To develop an industrial model vacuum frying system and frying protocol for frying by using this vacuum frying system for making various low fat healthy snack foods such as potato chips.

TEZPUR UNIVERSITY (TEZU):

1) Collection of raw materials from different places of Assam. Raw materials to be utilized for the project are jackfruit, pineapple, carambola, plantain, colocasia and yam.
2) Preliminary quality studies of the raw materials.
3) Preprocessing of the raw materials for vacuum drying.
4) Quality studies of the vacuum fried product.

(b) Objectives met

- An industrial model (10kg/batch) vacuum frying system has been developed. The frying protocol for frying using this vacuum frying system for making various low fat healthy snack foods, such as potato chips, banana chips, beetroot chips, bitter gourd (*karela*) chips, fried groundnut and *kabuli chana* have been developed.

8 (a) Milestones fixed as per the agreement

Description	Months					
	0-3	4-11	12-14	15-20	21-23	24
Preparation of detailed engineering drawings	■					
Fabrication of Vacuum Frying System	■	■				
Trial runs/ Validation of the Vacuum Frying System		■	■			
Developing frying protocol for healthy snacks				■	■	
Field trials and demonstrations to selected users					■	■
Preparation of completion report for the project						■

(b) Milestones achieved

End of December 2012

1. Preparation of detailed engineering drawings

End of August 2013

2. Fabrication of Vacuum Frying System

End of November 2013

3. Trial runs/ Validation of the Vacuum Frying System

End of May 2014

4. Developing frying protocol for healthy snacks
5. Optimization of the processing parameters
6. Sensory evaluation of the products

End of September 2014

7. Trials and demonstrations to selected users

End of March 2015

8. Preparation of completion report for the project

9 Deviation made from the original objectives if any, while implementing the project and reasons thereof.

- Not applicable.

10. Conclusions summarizing the achievements and indications of scope for future work

DETAILS OF R & D WORK DONE UNDER THE PROJECT

WORK CARRIED OUT AT CSIR-CFTRI, MYSORE

INTRODUCTION

The fried snacks foods are highly preferred in India. The present value of Indian snacks market is to be worth of Rs. 16340 crores and it is steadily growing at a rate of 15-20% per annum. Increasing consumer demand for good quality snack products with low fat, natural aroma and taste for health conscious consumers, stimulate the need for the design and development innovative approaches for processing (vacuum frying). Health conscious consumers prefer low fat snacks with high health benefits.

Frying is the cooking of food in oil or fat, a unit operation which is mainly used to alter the eating quality of a food. Secondly it has the preservative effect that results from thermal destruction of micro-organisms and enzymes, and reduction in water activity at the surface of the food or throughout the food, if it is fried in thin slices. Currently, fat uptake is considered as the major nutritional critical point of deep-fat frying because of the obesity prevalent in developed and even in developing regions where meals high in fat and sugar are the cheapest. The main challenge is therefore to improve the frying process by controlling and lowering the final fat content of the fried products. In addition, during frying, potentially toxic compounds may appear in the oil bath as consequence of oil deterioration due to oxygen, heat, and water. The frying also contributes to the degradation of food products by the formation of non-volatile compounds, *trans*-fatty acids, acrylamide in foods containing reducing sugar etc. So to reduce oil content in product and to prevent formation of these hazardous compounds one have to switch over towards the alternative approaches to deep frying, which ultimately not only lower down the risk of health hazards but also gives stability and longer shelf life to the product with lower cost of production by saving oil during frying and also gain the preference of consumers for buying low fat foods. One among the techniques to attain these objectives is vacuum frying.

Vacuum frying is defined as the frying process that is carried out under pressures well below atmospheric levels. Due to the pressure lowering, the boiling points both of the oil and the moisture in the foods are lowered. The vacuum frying occurs in three phases such as frying, pressurization and cooling. It has several advantages such as, reduces oil content in the fried product, preserves the natural color and flavor of the product due to the low temperature and oxygen content during the process, has less adverse effects on oil quality, maintaining good oil quality for long time, retention of bioactive components, e.g., vitamin-C, β-carotene, betalain, charantin and phenolic compounds. Recent consumer trends towards healthier and low fat products have had a significant impact on the snacks industries. Therefore, the work has been carried out on various commodities such as potato, banana, bitter gourd, beet root, okra, groundnut, kabuli chana, plantain etc.

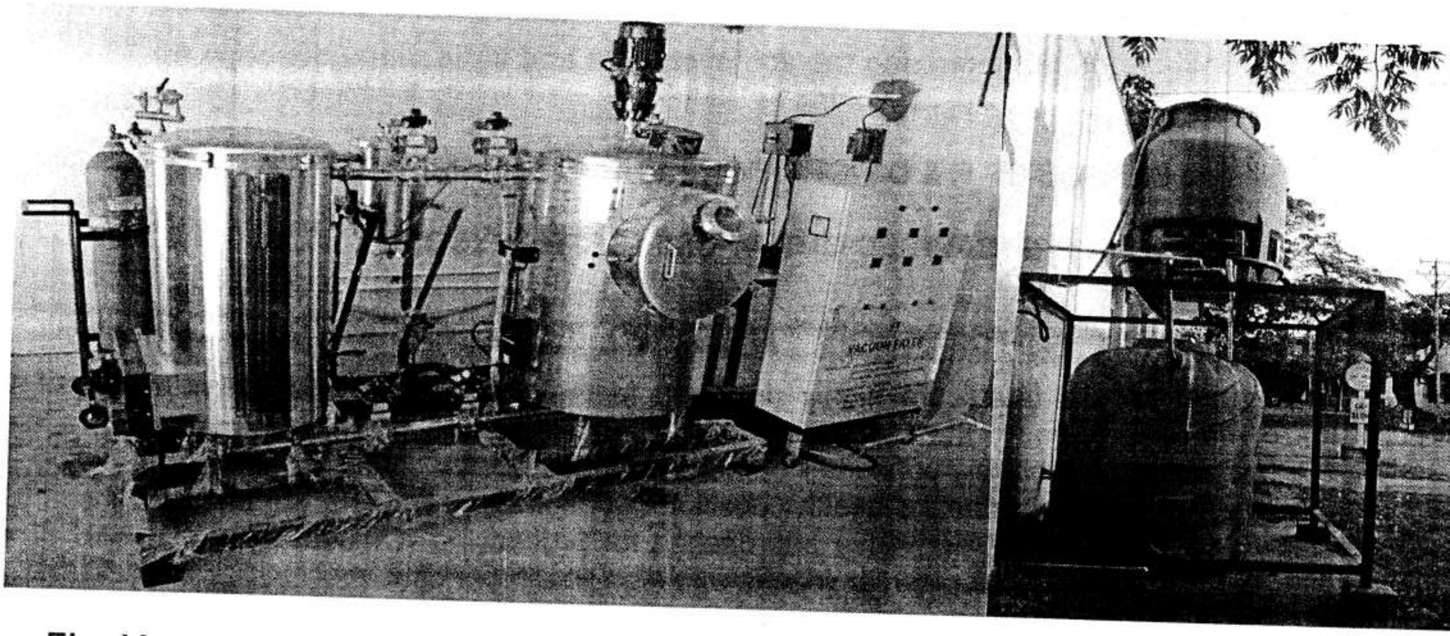


Fig. Vacuum Frying System Installed with Cooling Tower at CSIR-CFTRI, Mysore

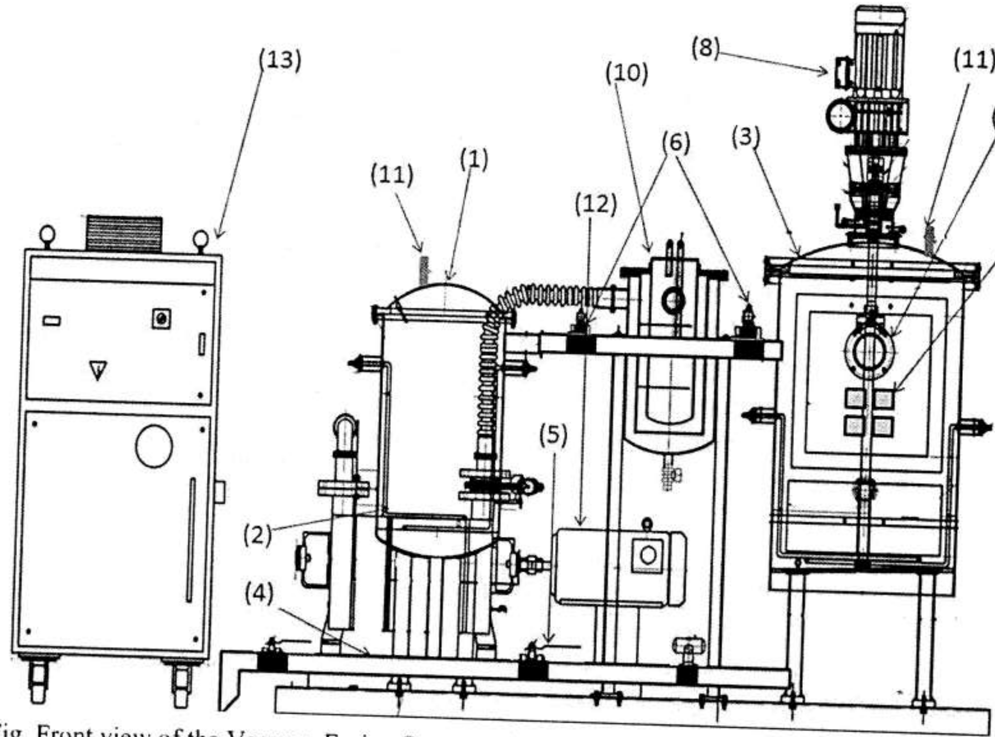


Fig. Front view of the Vacuum Frying System with connection details of condenser and vacuum pump,

Figure details: 1) Oil pre-heating chamber , 2) heating arrangement , 3) frying chamber, 4)two way connection for to-fro transfer of oil between Oil pre-heating chamber and frying chamber, 5) solenoid valve, 6) vacuum circuit, 7) four lobe basket, 8) motor, 9) viewing glass, 10) condenser, 11) safety valves, 12) water ring vacuum pump, 13) water chiller

RESULTS AND DISCUSION

1. Processing/ Production of Potato Chips

Consumption of excess fat is one of the reasons for obesity and cardiovascular diseases. Health conscious consumers normally prefer low-fat snacks. Deep-fat fried snacks generally contain 30-40% oil. Vacuum frying is carried out below atmospheric pressure at lower frying temperature. Application of vacuum facilitates faster removal of air from porous space and obstructs oil passage within food matrix leading to reduction in oil uptake. Lower temperature and minimal exposure to oxygen result in nutrient preservation, retaining oil quality and reduction of acryl amide formation.

A laboratory scale vacuum frying system is integrated based on our design for production of low-fat potato chips with lower acryl amide content. Potato and refined, bleached, deodorized palm oil (RBDPO) were procured from a local super market. The potato slice was undergone frying by using the following methods.

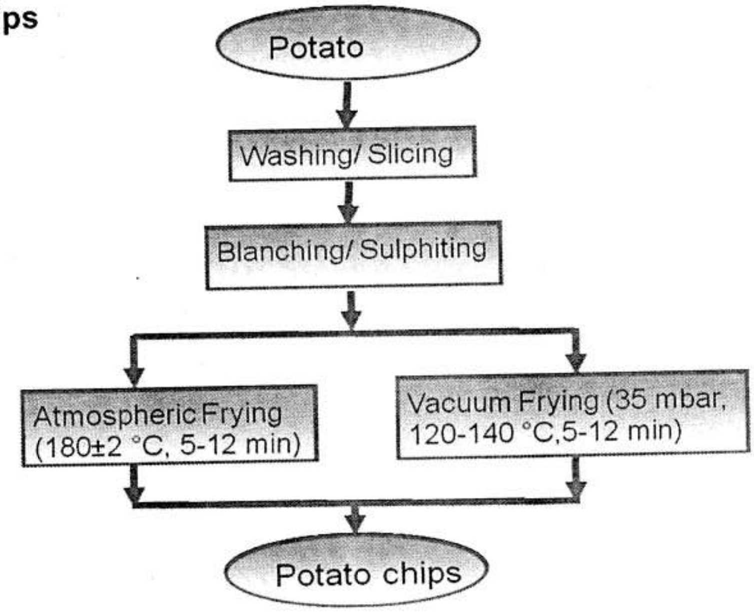


Fig. Flow Chart for the Production of Potato Chips

The results indicated that there was a significant ($p<0.05$) decrease in oil content of the potato chips (13.44-20.84%) fried under vacuum as compared to control fried at atmospheric pressure (43.2-49.08%) for a period of 5-12 min.

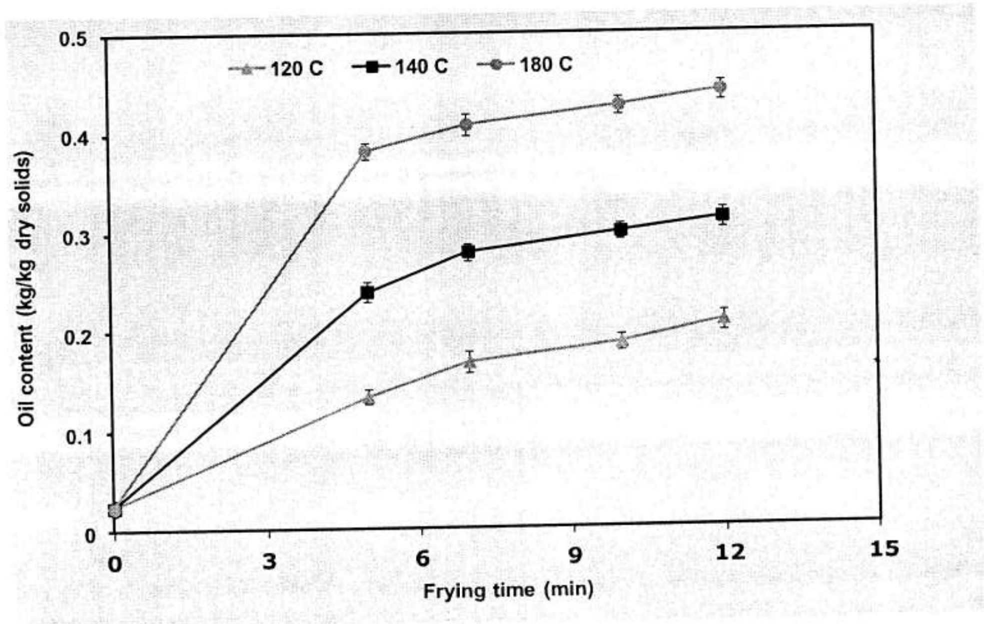


Fig. Oil uptake by potato chips (control, 180 °C and vacuum fried, 120 -140 °C)

The colour of the products indicated that vacuum helps to increase lightness of the product.

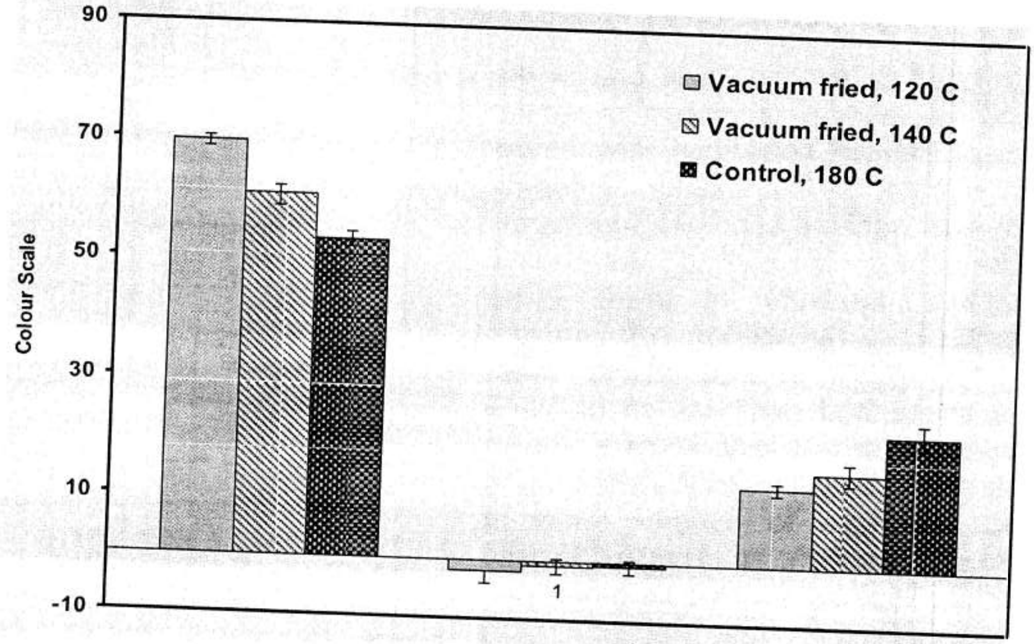


Fig. Colour of the potato chips (control, 180 °C and vacuum fried, 120 -140 °C)

The texture of the products indicated that the vacuum helps to produce better quality product with less breaking strength.

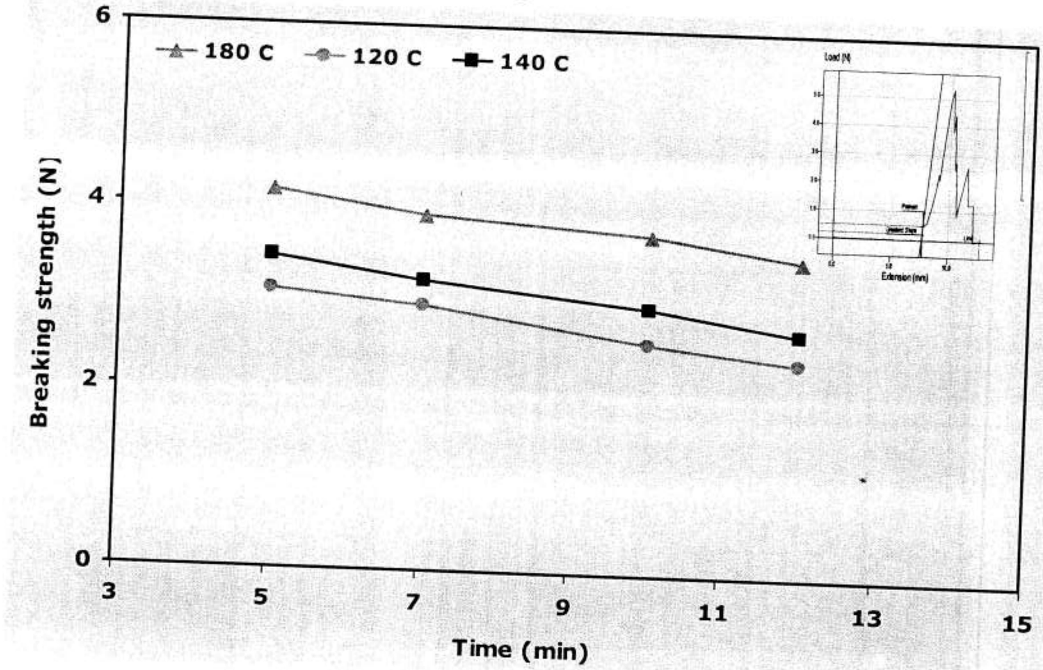


Fig. Texture of potato chips (control, 180 °C and vacuum fried, 120 -140 °C)

The formation of acryl amide was found to be lower for vacuum fried product (2.24-25.1 µg/g) (140 °C) as compared to product obtained in atmospheric frying (5.5-51.4 µg/g) at (180 °C). There is no acryl amide formation observed at 120 °C).

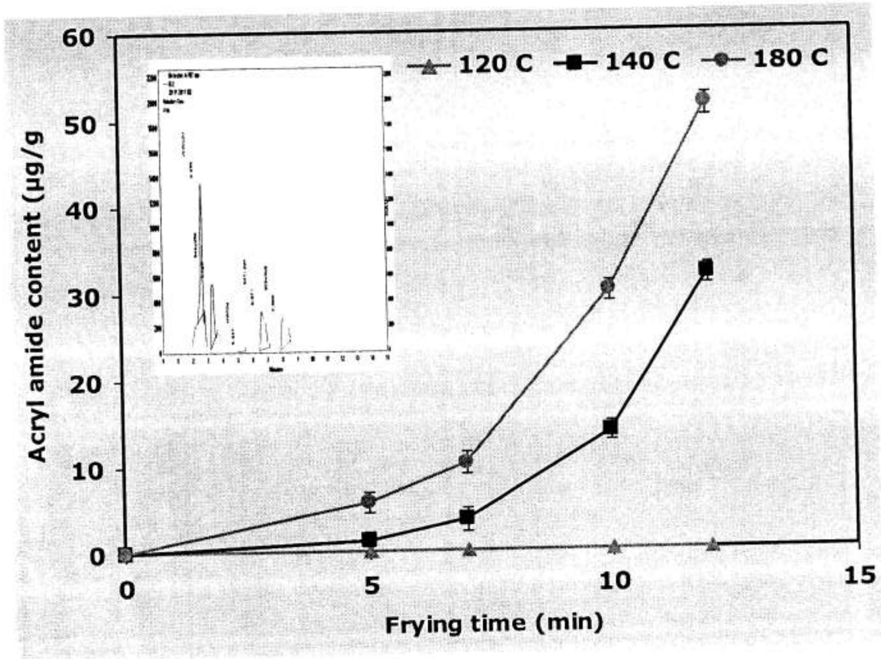


Fig. Acryl amide of product (control, 180 °C and vacuum fried, 120-140 °C)

The sensory analysis revealed higher overall acceptability for vacuum fried product and no significant difference ($p<0.05$) observed with the conventional product.

Table. Sensory scores of the potato chips

Sensory Attributes	Frying	
	Atmosphere	Vacuum
Appearance	8.0±0.2	8.1±0.4
Colour	8.5±0.2	8.6±0.1
Crispness	8.5±0.2	8.4±0.3
Taste	8.5±0.2	8.3±0.2
Overall Acceptability	8.4±0.1	8.3±0.1

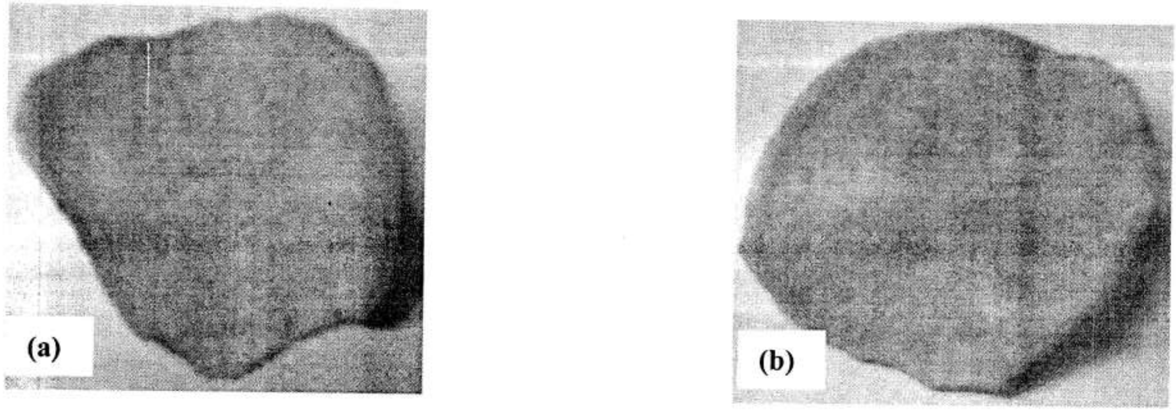


Fig. Potato chips obtained using frying under (a) atmosphere and (b) vacuum

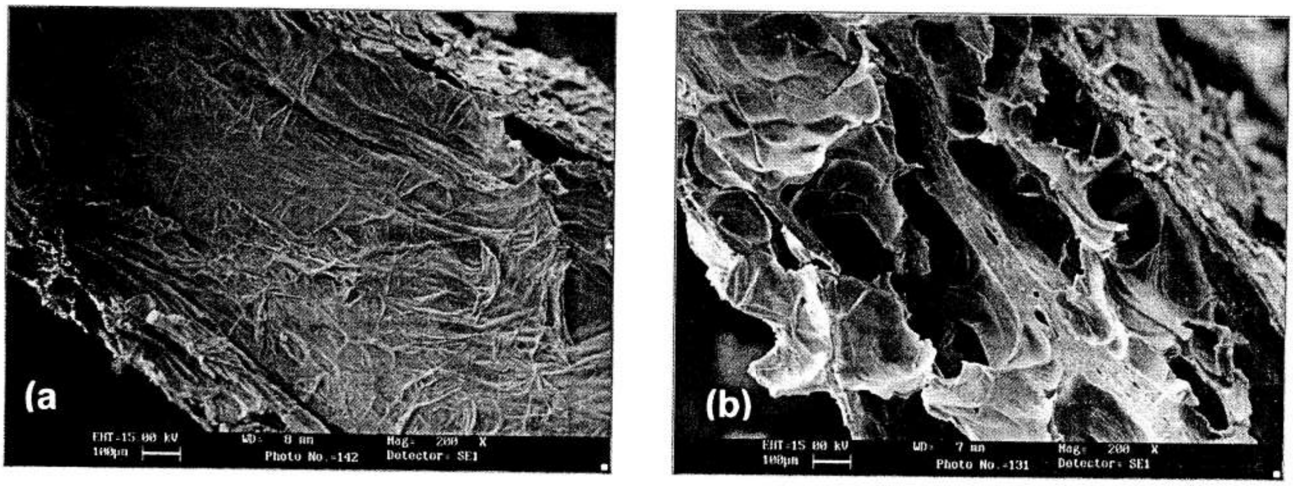


Fig. SEM pictures of potato chips obtained using frying under (a) atmosphere and (b)

The SEM pictures of potato chips obtained during vacuum frying showed porous structure in comparison to the atmospheric fried (control) product.

Table. Oil content of potato chips made with various treatments during vacuum frying

Sample	Treatment	Frying		Oil content (%)	
		Atmospheric	Vacuum	Atmospheric	Vacuum
Potato	---	175±2 °C	120 °C, kPa	42.4±0.1	20.3±0.1
Potato	KMS + Citric acid	175±2 °C	120 °C, kPa	38.4±0.9	16.5±0.5
Potato	$NaHCO_3$	175±2 °C	120 °C, kPa	43.7±0.1	21.0±0.3
Potato	Guar gum	175±2 °C	120 °C, kPa	41.5±0.6	18.2±0.6

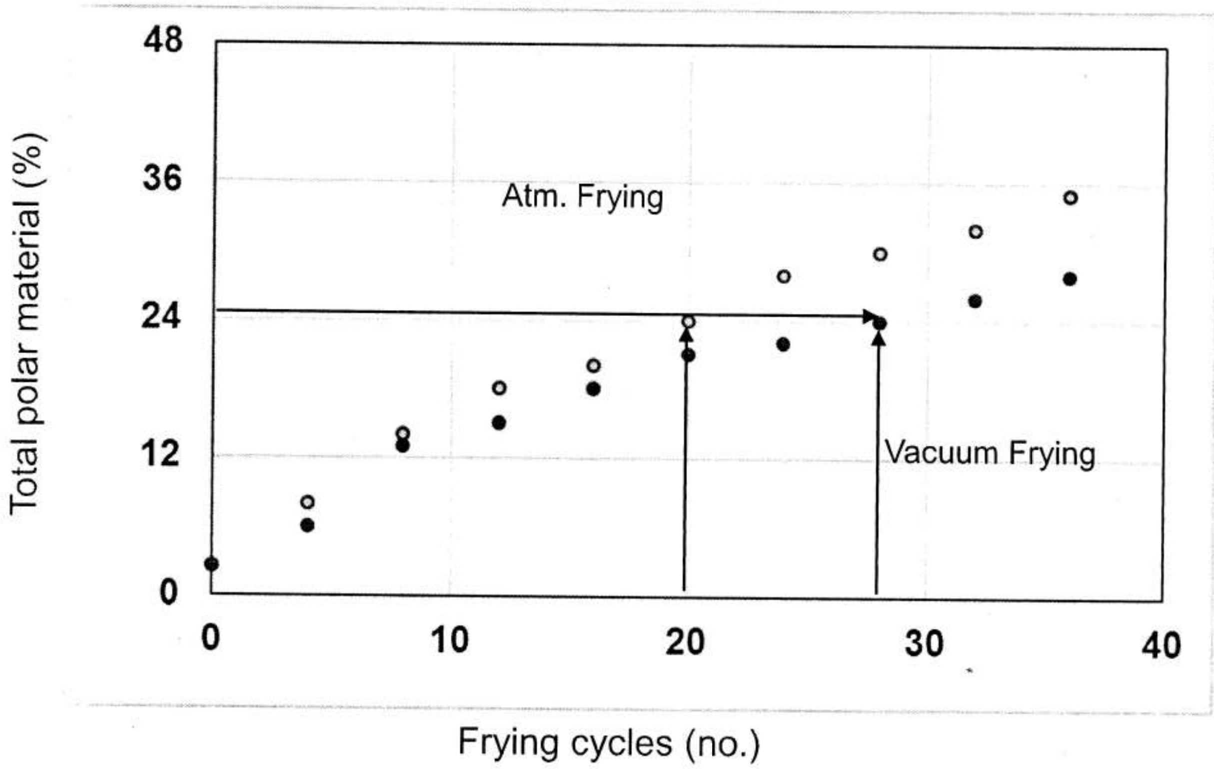


Fig. Total polar material of fried oil during atmospheric and vacuum frying of potato

The above figure indicated that turnover of vacuum frying oil is more than atmospheric frying oil to reach the discarding point (24% TPM), that substantiated the lower rate of degradation of oil during vacuum frying in comparison to atmospheric frying.

2.0 Optimization of vacuum frying process parameters for production of *Banana* chips and evaluation of product characteristics

Banana chips are popular in Southern part of India. It has several health benefits including controlling blood pressure, maintaining heart health, boosting mood and preserving memory.

- Experimental Design

(Central Composite Rotatable Design)
Independent Variables (5 levels)

Parameters	-1.682	-1	0	1	+1.682
Temperature (°C)	86	100	120	140	154
Vacuum pressure (kPa)	1.3	3.0	5.5	8.0	9.7
Time (min)	2.6	4.0	6.0	8.0	9.4

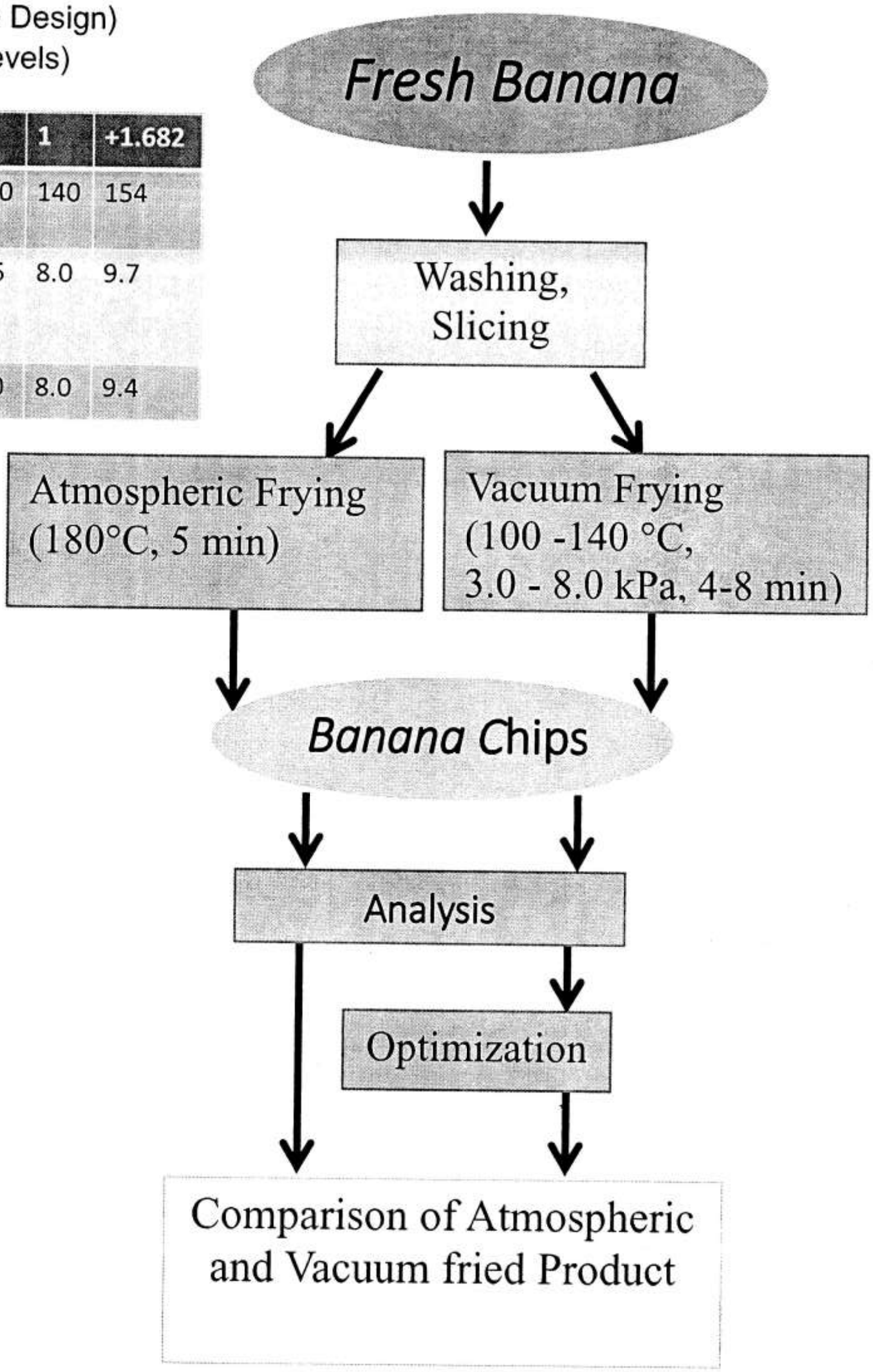


Fig. Flow Chart for the Production of Banana Chips

2.1 Diagnostic checking of the model

The six responses in the experiments namely, oil content (Y_1), breaking force (Y_2), L*-value (Y_3), a* -value (Y_4), b* -value (Y_5) and overall acceptability (Y_6) were measured. These responses were presented by the coefficients for the actual functional relations of second order polynomials for predicting responses (Y_i) as follows:.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 . x_2 + \beta_{13} x_1 . x_3 + \beta_{23} x_2 . x_3 + \varepsilon$$

The effect of temperature, time and absolute pressure on responses such as oil content, breaking force, L*-value, a*-value, b*-value and overall acceptability are reported by coefficient of second order polynomials. Response surface based on these coefficients are shown in **Fig.1** and were selected based on the observation of the data and initial optimization of the individual responses. In general, exploration of the response surfaces indicated a complex interaction between variables.

2.2 Effect of absolute pressure and frying time on oil content

At the different level of absolute pressure (1.3 kPa, coded value -1.682), the oil content was found to increase with an increase in time (**Fig. 1**). This may be due to, wet solid material absorbs heat from the oil and outer surface of the material gets dried rendering in diffusion gradient and the moisture escaped from the interior portion of the product in the form of vapor leads to pressure gradient. The spaces left behind by the evaporating moisture being occupied by the oil. At the lowest level of time (2.6 min, coded value -1.682) the oil content was found to increase with increase in absolute pressure (**Fig. 1**). At the highest level of time (9.7 min, coded value 1.682) the oil content values were found to marginal decrease with increase in absolute pressure.

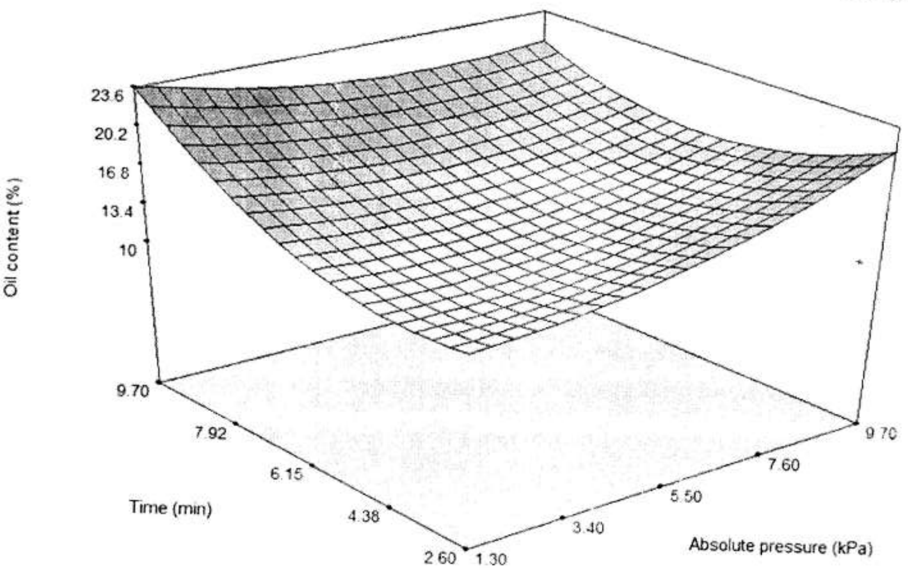


Fig. 1 Response surface plot for the oil content as a function of time and absolute pressure at temperature 120 °C

2.3 Optimization of conditions for vacuum fried banana chips

In the present study, the operational parameters were optimized using response surface methodology. The contour plots for the response were generated as shown in **Fig. 2(a-f)** and compared visually. An acceptable compromise was made following the criteria for the oil content (Y_1) ≤ 14.5%, breaking force (Y_2) ≤ 10.46 N, L* value (Y_3) ≥ 63.5, a* value (Y_4) ≤ 3.31, b* value (Y_5) ≥ 34.43 and overall acceptability (Y_6) ≥ 7.5. These conditions were chosen based on the observation of the superimposition of contour plots. The contour plots were superimposed (**Fig. 3**) and the regions that the best satisfied all the constraints were selected as the optimum conditions and based on that, a combination (A, B, C and D) could be selected from the shaded area. Superimposition of contour plots indicated that time 6 min, temperature 101-106 °C and absolute pressure 2.51-3.97 kPa fulfilled the above mentioned criteria for optimization.

2.4 Validation of results

The suitability of the model equations for predicting the optimum response values was tested using recommended optimum conditions as determined by graphical optimization approach. These conditions were validated experimentally and compared with the predicted values obtained from the model (Eq.1). The experimental values were found to be in agreement with the predicted values. The following **Table 1** showed decrease in oil content (63.1 %), breaking force, a* and increase in L*, b* and overall acceptability values in case of vacuum fried banana chips as compared to atmospheric fried banana chips.

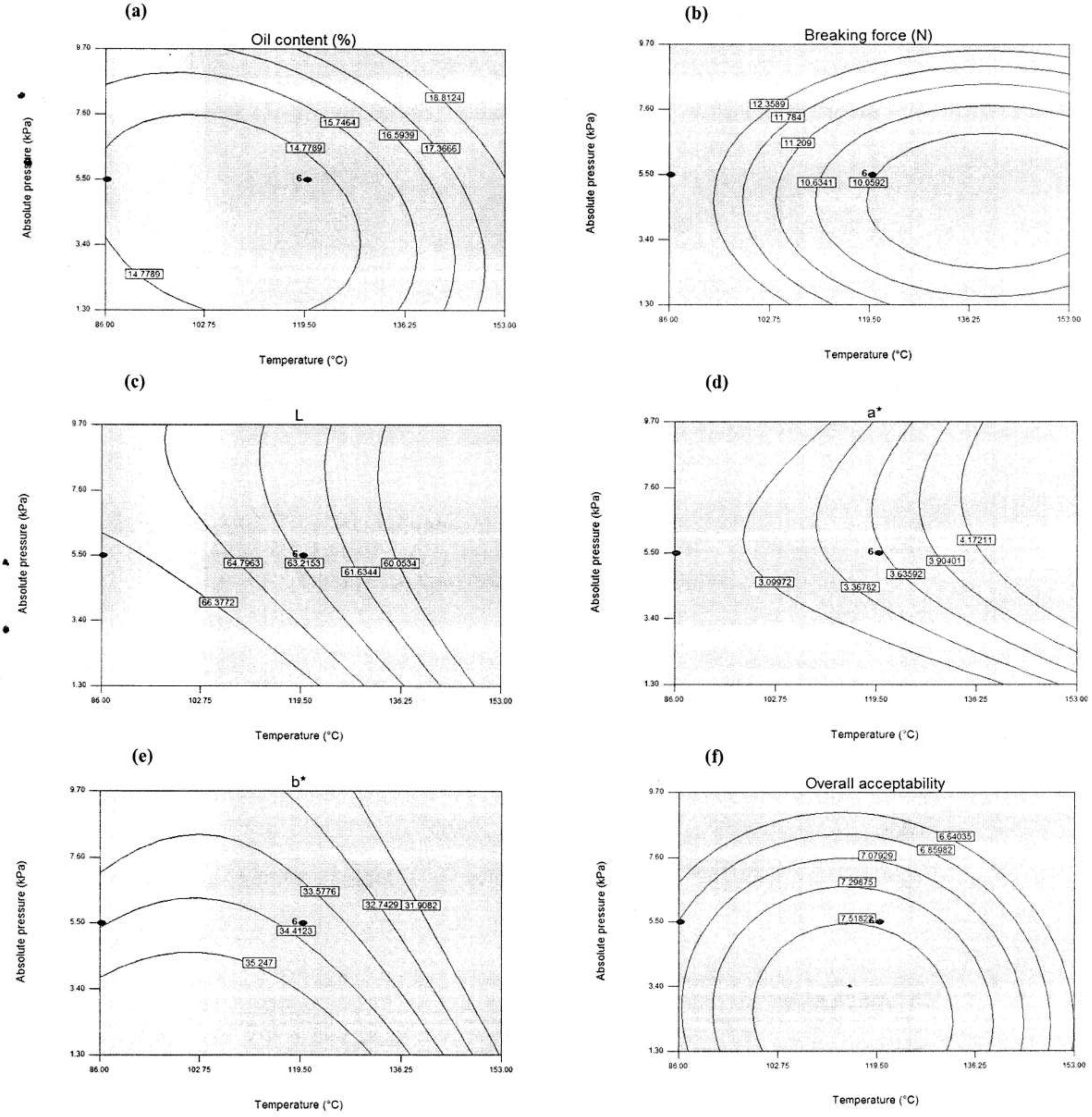


Fig. 2 Contour plots showing the effect of temperature and absolute pressure on (a) oil content, (b) breaking force, (c) L* value, (d) a* value, (e) b* value, and (f) overall acceptability. For all experiments time was kept constant for 6 min

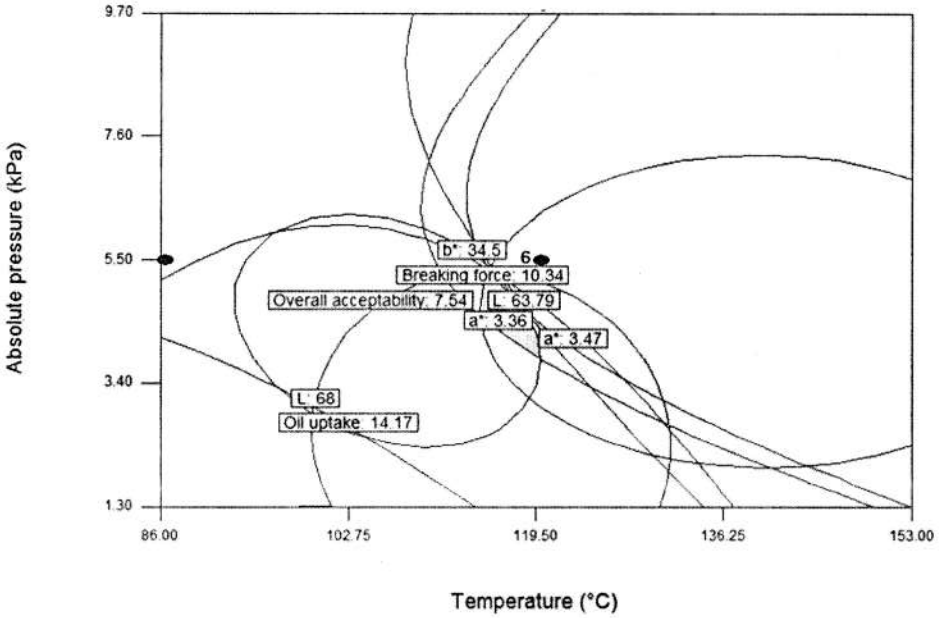


Fig. 3 Superimposed contour plots showing the shaded overlapping area for which oil content oil content (Y_1) ≤ 14.5%, breaking force (Y_2) ≤ 10.46 N, L* value (Y_3) ≥ 63.5, a* value (Y_4) ≤ 3.31, b* value (Y_5) ≥ 34.43 and overall acceptability (Y_6) ≥ 7.5.

Table. 1 Comparative results of parameters in banana chips

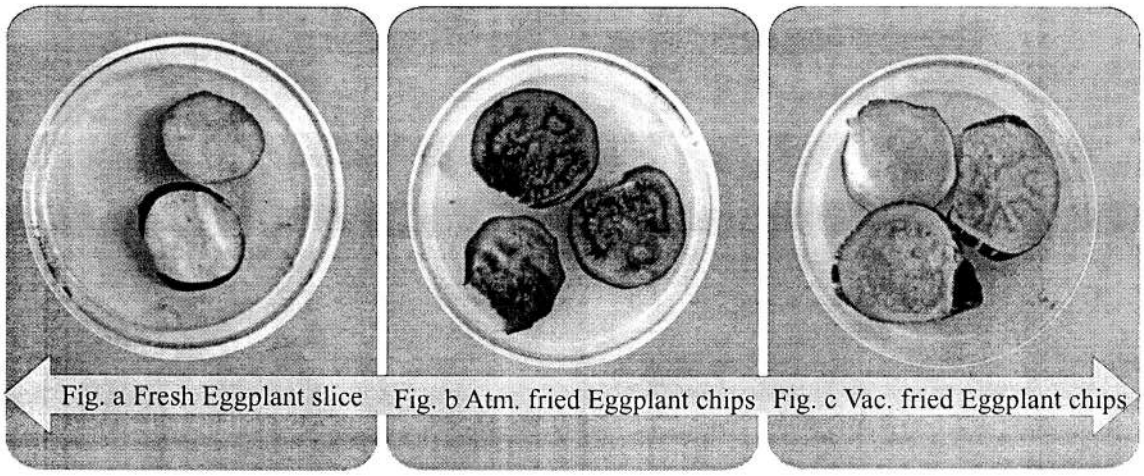
	Oil uptake (%)	**Breaking force (N)**	**L***	**a***	**b***	**Overall acceptability**
Atmospheric Frying	37.64±0.4	11.7±0.2	40.1±0.5	10.2±0.5	10.4±0.3	6.0±0.1
Vacuum Frying	13.86±0.3	10.31±0.2	63.47±0.5	3.38±0.3	34.36±0.2	7.5±0.2

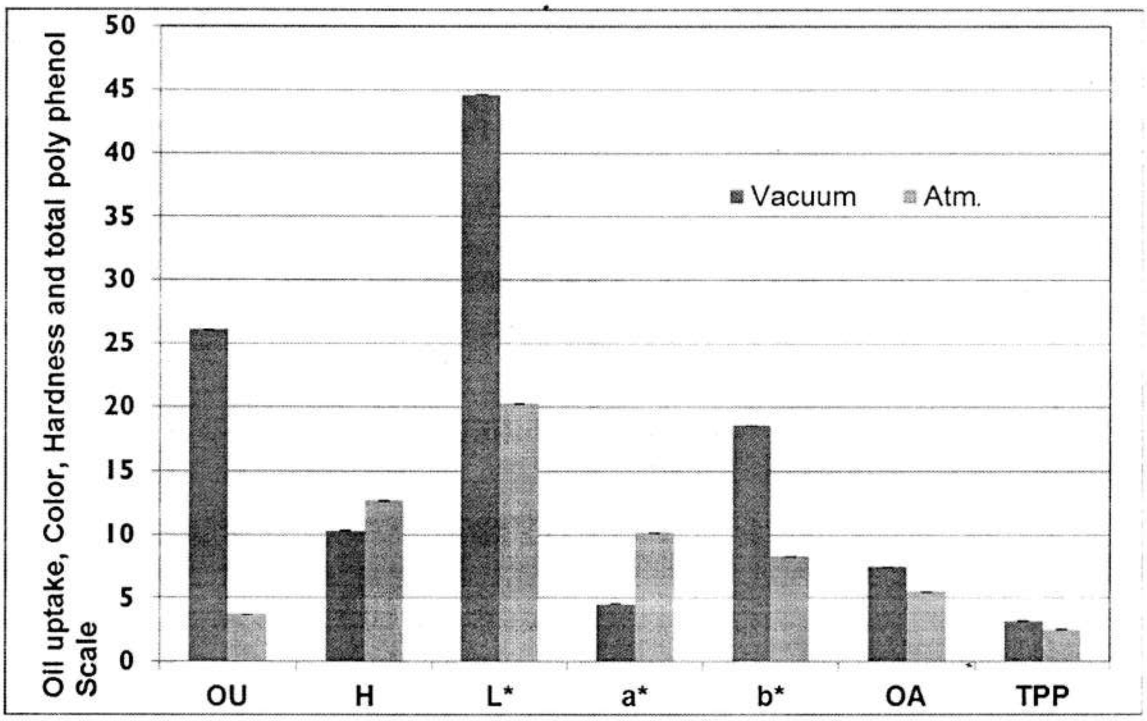
2.5 Conclusion

In this study it was observed that vacuum frying can prove to be an efficient alternative method that can be used to reduce oil content in fried foods such as banana chips compared to atmospheric frying. The super imposition of contour plots indicated that time 6 min, temperature ranging from 114 to 119 °C and vacuum ranging from 3.9 to 5.3 kPa resulted in oil content (Y_1) ≤ 14.5%, breaking force (Y_2) ≤ 10.46 N, L* value (Y_3) ≥ 63.5, a* value (Y_4) ≤ 3.31, b* value (Y_5) ≥ 34.43 and overall acceptability (Y_6) ≥ 7.5. Therefore, vacuum frying is a healthier frying method for production of snack foods.

RESULTS OF OTHER EXPERIMENTS

The brinjal (eggplant) contains various phyto-nutrients having anti-oxidant activity and free radical scavenger which protect cell membranes from damage.





Where, OU = Oil uptake, H = Hardness, L*= lightness, a*= (+) redness/ (-) blueness, b*= (+) yellowness/ (-) greenness, OA= Overall acceptability, TPP = Total Polyphenol content

The *Kabuli Chana* is an important source of protein for millions of people in the developing countries, particularly in South Asia, who are largely vegetarian either by choice or because of economic reasons. In addition to having (20-22%) protein *kabuli chana* is rich in fiber, minerals (phosphorous, calcium, magnesium, iron and zinc) and beta carotene.

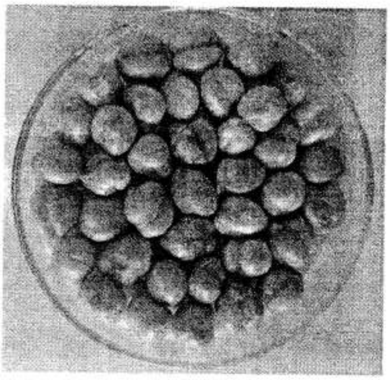


Fig. Kabuli Chana (vacuum fried)

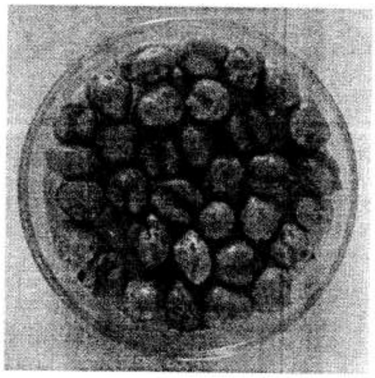


Fig. Kabuli Chana (market sample)

Table. Oil content of Kabuli Chana obtained using vacuum frying system

Sample	Treatment	Frying		Oil content (%)	
		Atmospheric	Vacuum	Atmospheric	Vacuum
Kabuli chana	Overnight soaking, salt	Compared with market available product	110±2 °C, 3.0 kPa, 14 min	33.1±0.1	16.45±0.2

OTHER VACUUM FRIED PRODUCTS

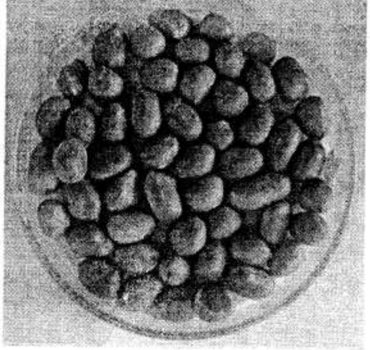


Fig. Groundnut

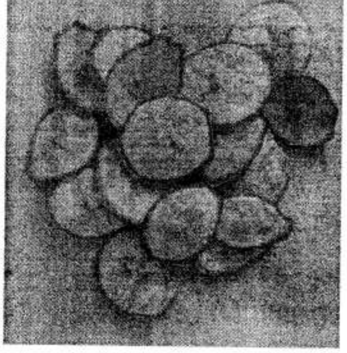


Fig. Plantain chips

Fig. *Okra*

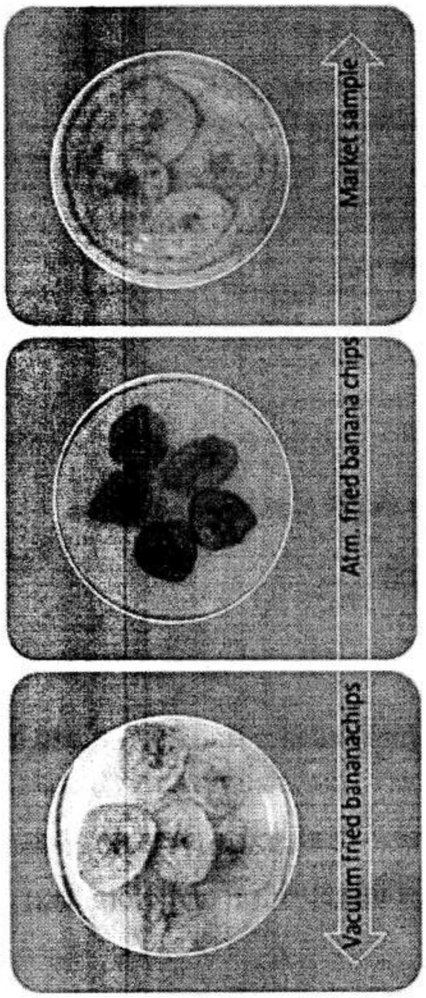
PROCESS KNOW-HOW

By using successfully designed and development of Vacuum Frying System the following process protocols were standardized for further commercialization of the process.

(a) Processing of Banana Chips

Banana is the second largest produced fruit after citrus, contributing about 16% of the world's total fruit production. India is largest producer of banana, contributing to 27% of world's banana production. The unripen bananas were sliced using mechanical slicer (Robot coupe, CL 50, USA.) having 0.3 to 0.4 cm diameter. Proto type vacuum fryer fabricated locally using SS304 material with suitable heating elements. Inside the vessel, there is a frying basket and spinning facility (de-oiling system) with a maximum speed of 2000 rpm. Vacuum is achieved in the vessel by a oil ring pump with a vacuum capacity of 3.0 kPa. The frying process consists of loading 8-10 kg/batch slices into the basket for submerged, frying in oil (150 l) and creating vacuum in the vessel during frying, after frying the basket was raised, and the same was allowed to spin at preset speed for 5 min. Then the vessel was pressurized and the banana chips were allowed to cool to ambient temperature before storing them in metalized BOPP bags.

Material Balance:



Fresh Banana
(Nendran variety, 300 kg)

↓

Washing, Slicing
(30 - 40 mm)

↓

Sliced Banana
(250 kg)

↓

Vacuum Frying
(100±2 °C, 3.0 kPa, 5.34 min)

↓

***Banana* Chips**
(65 kg)

↓

Packing

Table. Comparison of quality characteristics of Banana chips with commercially available product

	Oil uptake (%)	Breaking force (N)	L*	a*	b*	Overall acceptability
Atmospheric Frying	37.64±0.4	11.7±0.2	40.1±0.5	10.2±0.5	10.4±0.3	9.5±0.1
Vacuum Frying	13.86±0.3	10.3±0.2	63.5±0.5	3.4±0.3	34.4±0.2	12.2±0.2
Commercial Product (market sample)	36.84±0.4	13.7±0.2	44.1±0.5	9.4±0.5	38.5±0.3	10.9±0.1

(Colour values: L*, a*, b*)

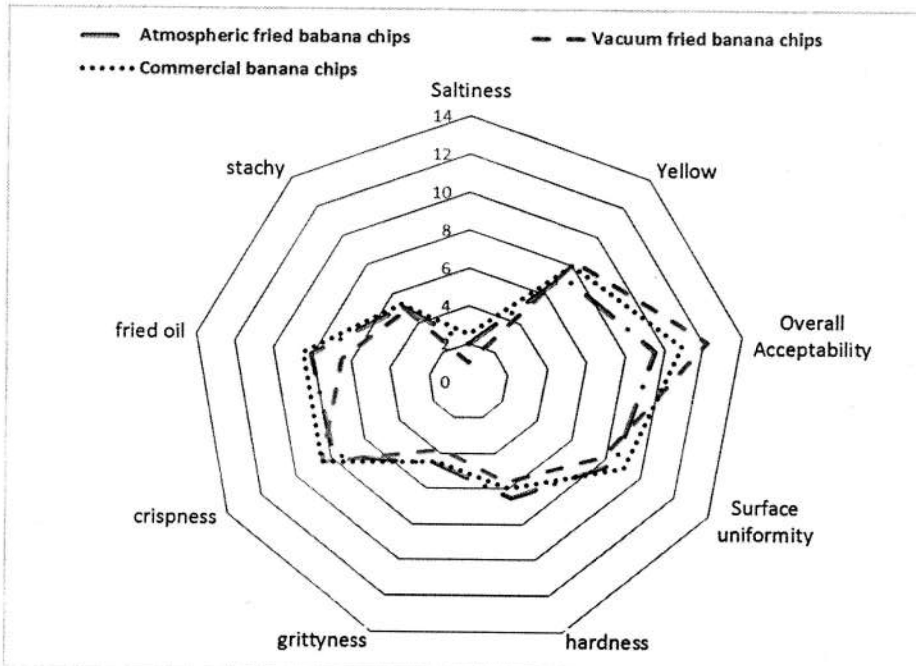


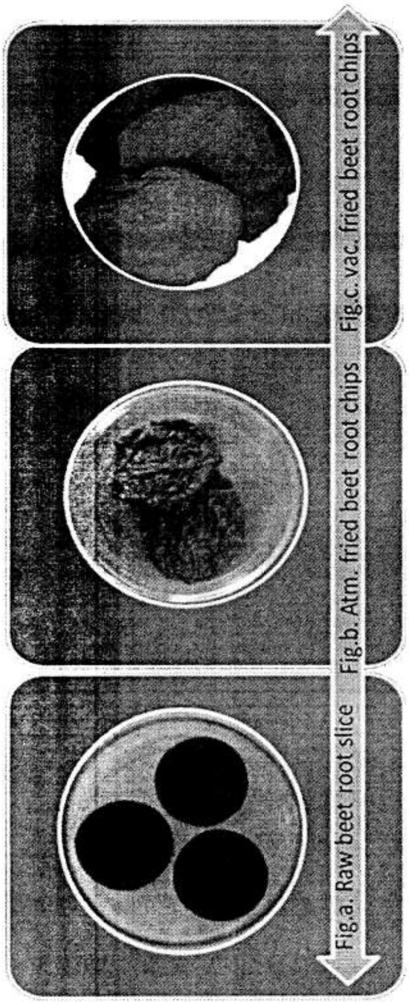
Fig. Sensory scores of banana chips

- Cost for Land and Site development = Rs. 12,00,000.00
- Cost for Building and Civil work = Rs. 25,00,000.00
- Plant and Machinery Cost = Rs. 4,411,400.00
- Total Project cost for processing (250 kg/day/shift) banana slice = Rs. 1,02,66,419.00
- Cost of production of banana chips/ kg = Rs. 282.00.
- The approximate cost of the vacuum frying system (max. 10 kg/batch) ~15.00 lakhs.
- Pay-back period on simple return (depreciation + interest + profit before tax) on investment = 3.35 year.

(b) Processing of Beetroot Chips

Beeroot (*Beta vulgaris*) is good for health. It contains betalains. Betalains consist of two sub-classes: betacyanins (red-violet pigments) and betaxanthins (yellow-orange pigments). These compounds have antimicrobial and antiviral effects and also can inhibit the cell proliferation of human tumour cells. The consumption of beetroot (rich in anti-oxidants) can contribute to protection from age-related diseases and prevent diseases like cancer, cardiovascular diseases etc. The raw beetroot were sliced using mechanical slicer (Robot coupe, CL 50, USA.) having 0.3 to 0.4cm diameter. Proto type vacuum fryer fabricated locally using SS304 material with suitable heating elements. Inside the vessel, there is a frying basket and spinning facility (de-oiling system) with a maximum speed of 2000 rpm. Vacuum is achieved in the vessel by oil ring pump with a vacuum capacity of 3.0 kPa. The frying process consists of loading 8-10 kg/batch slices into the basket for submerged, frying in oil (150 l) and creating vacuum in the vessel during frying, after frying the basket was raised, and the same was allowed to spin at preset speed for 5 min. Then the vessel was pressurized and the banana chips were allowed to cool to ambient temperature before storing them in metalized BOPP bags.

Material Balance:



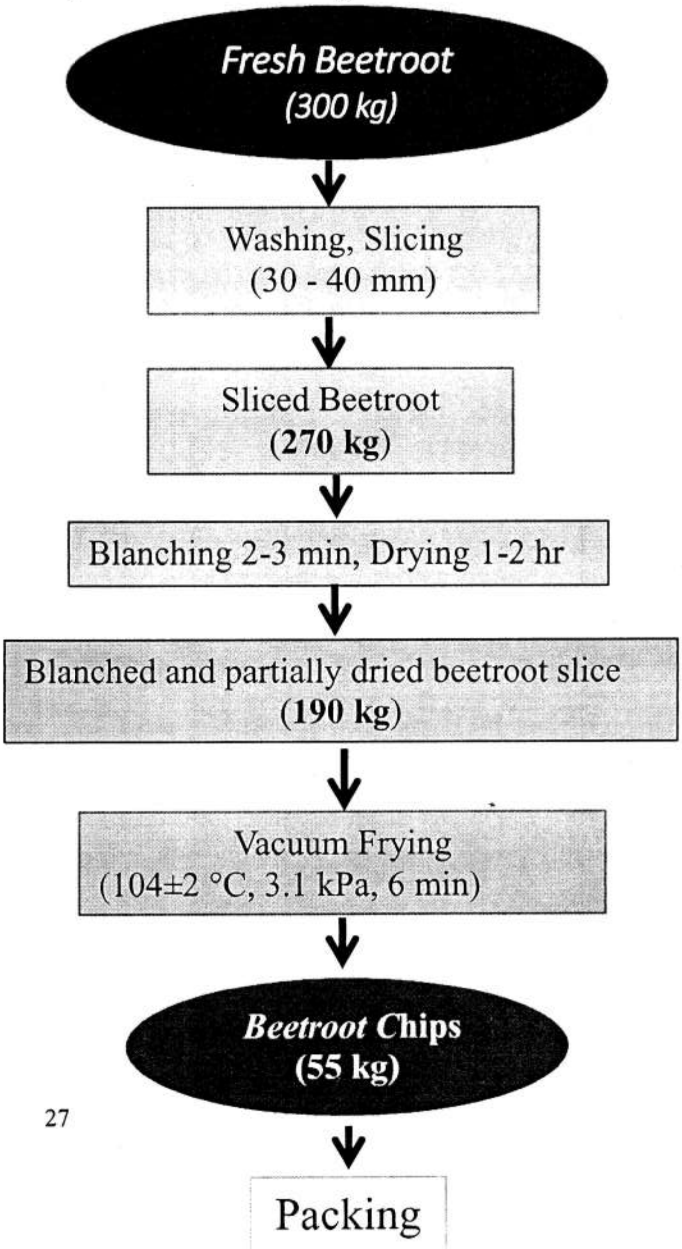


Table. Comparison of quality characteristics of Beetroot chips

	Oil uptake (%)	Breaking force (N)	L*	a*	b*	Betalain content (mg/l)	Overall acceptability
Atmospheric Frying	38.4±0.3	19.7±0.2	21.1±0.5	15.2±0.2	2.4±0.1	2.6±0.1	8.0±0.3
Vacuum Frying	15.4±0.4	11.4±0.2	28.6±0.5	17.6±0.3	6.6±0.2	13.7±0.02	12.5±0.2

(Colour values: L*, a*, b*)

- Cost for Land and Site development = Rs. 12,00,000.00
- Cost for Building and Civil work = Rs. 25,00,000.00
- Plant and Machinery Cost = Rs. 44,11,400.00
- Total Project cost for processing (270 kg/day/shift) beetroot slice = Rs. 1,02,91,169.00
- Cost of production of banana chips/ kg = Rs. 318.00.
- The approximate cost of the vacuum frying system (max. 10 kg/batch) ~15.00 lakhs.
- Pay-back period on simple return (depreciation + interest + profit before tax) on investment = 3.16 year.

(b) Processing of Bitter gourd (*karela*) chips

The bitter gourd *(Momordica charantia)* grows in India and tropical areas of Asia, the Amazon, East Africa, and the Caribbean. *Karela* has many active principles that have therapeutic values, these medicinal plants are widely prescribed for the prevention and treatment of various diseases like diabetes, dysmenorrhea, eczema, emmenagogue, galactagogue, gout, jaundice, kidney (stone), leprosy, leucorrhea, piles, pneumonia, psoriasis, rheumatism and scabies. One of the active components responsible for this action is charantin. The raw beetroot were sliced using mechanical slicer (Robot coupe, CL 50, USA.) having 0.3 to 0.4 cm diameter. Proto type vacuum fryer fabricated locally using SS304 material with suitable heating elements. Inside the vessel, there is a frying basket and spinning facility (de-oiling system) with a maximum speed of 2000 rpm. Vacuum is achieved in the vessel by oil ring pump with a vacuum capacity of 3.0 kPa. The frying process consists of loading 8-10 kg/batch slices into the basket for submerged, frying in oil (150 l) and creating vacuum in the vessel during frying, after frying the basket was raised, and the same was allowed to spin at preset speed for 5 min. Then the vessel was pressurized and the banana chips were allowed to cool to ambient temperature before storing them in metalized BOPP bags.

Material Balance

***Fresh Bitter gourd* (*300 kg*)**

↓

Washing, Slicing (30 - 40 mm)

↓

Sliced Bitter gourd (**250 kg**)

↓

Steam blanching, 5 min (**246 kg**)

↓

Ambient air drying, 25 °C, 3 hr (**182 kg**)

↓

Vacuum Frying (100±2 °C, 3.0 kPa, 5.32 min)

↓

Bitter gourd Chips (30 kg)

↓

Packing

Table. Comparative results of parameters in *karela* chips

	Oil uptake (%)	Breaking strength (N)	L*	a*	b*	Charantin (%)	Overall acceptability score
Vacuum Frying (100 °C, 30 mbar, 5.32 min)	26.8	11.6	43.1	2.8	18.98	0.054	11.6
Atmospheric Frying	51.4	13.7	21.1	10.2	8.38	0.016	8.0

(Colour values: L*, a*, b*)

- Cost for Land and Site development = Rs. 12,00,000.00
- Cost for Building and Civil work = Rs. 25,00,000.00
- Plant and Machinery Cost = Rs. 44,11,400.00
- Total Project cost for processing (250 kg/day/shift) bitter gourd slice = Rs. 1,02,99,419.00
- Cost of production of banana chips/ kg = Rs. 330.00.
- The approximate cost of the vacuum frying system (max. 10 kg/batch) ~15.00 lakhs.
- Pay-back period on simple return (depreciation + interest + profit before tax) on investment = 3.1 year.

11 S & T benefits accrued:

(i) List of research publications with details, if any

A. List of Paper (oral)/ Poster Presentations:

- The following Poster was presented in the 7th International Food Convention (IFCON) on "NSuRE Healthy Foods" (Nutritional Security through Sustainable Development, Research & Education for Healthy Foods) on December 18-21, 2013, organized by AFST(I) in association with CSIR-CFTRI, DFRL and NIFTEM at CSIR-CFTRI Campus, Mysore, Karnataka, India
    - Praneeth Juvvi, Chakkaravarthi A, Sukumar Debnath, Rastogi NK, Raghavarao KSMS, Gopala Krishna AG and Lokesh BR. *Optimization of process conditions to retain anti-diabetic molecule in vacuum fried karela (Momordica charantia L.) chips*
    - Sukumar Debnath, Moorthy Karthika Selvi, Praneeth Juvvi and A.G. Gopala Krishna. *Safe-guarding of health promoting bioactive molecules of snacks food using vacuum frying*
    - Moorthy Karthika Selvi, Sukumar Debnath and Gopala Krishna AG. *Development of savoury snacks food rich in health promoting micronutrients using vacuum frying*
- The following poster was presented in the international conference on 3S-saftey security and sustainability: Innovations in food and bioprocess industries held on Jan 27-28, 2015 organized by department of Food Technology & Biochemical Engineering, Jadavpur University.
    - Sukumar Debnath*, Praneeth Juvvi and A. Chakkaravarthi and *Emerging technique for healthier frying for production of Reduced-fat red beetroot (Beta vulgaris L.) chips*
- The following poster was presented in the National seminar cum workshop on Innovative prospects in food processing: integration of engineering and biological sciences (IPFP-2015) organized by the Department of Food Engineering & Technology, Tezpur University during 27-28 March 2015.
    - Praneeth Juvvi, Prathana Dutta, Dipankar Kalitha, Charu lata Mahanta, Sukumar Debnath. *Effect of vacuum on changes in quality attributes during production of fried healthy eggplant chips*
- The following paper (*invited talk*) was presented in the National seminar cum workshop on Innovative prospects in food processing : integration of engineering and biological sciences (IPFP-2015) organized by the Department of Food Engineering & Technology, Tezpur University during 27th-28th March, 2015

- Sukumar Debnath. *Machineries for Indian Traditional Foods with special reference to Vacuum Fryer*

- The following paper is presented (*oral*) in the Indian Science Congress, held during January 3-7, 2016 at the University of Mysore, Mysore

    - Sukumar Debnath*, Praneeth Juvvi, A. Chakkaravarthi. *Vacuum frying - an alternative method to produce healthy banana chips*

B. Manuscript communicated to the journal for publication:

- Praneeth Juvvi, A. Chakkaravarthi, Sukumar Debnath*, N. K. Rastogi and A. G. Gopala Krishna (2015). *Optimization of vacuum frying conditions for the production of bitter gourd (Momordica charantia L.) chips using RSM, Journal of Food Processing and Preservation.*

- Praneeth Juvvi, A. Chakkaravarthi and Sukumar Debnath* (2015). *Emerging technique for healthier frying for production of Reduced-fat red beetroot (Beta vulgaris L.) chips. Journal of Food Science and Technology (under revision).*

C. Prizes received:

- The following poster was received II Prize in the International Conference on 3S: Safety, Security and Sustainability- Innovations in Food and Bioprocess Industries
    - Praneeth Juvvi, A. Chakkaravarthi and Sukumar Debnath*. *Emerging technique for healthier frying for production of Reduced-fat red beetroot (Beta vulgaris L.) chips. Journal of food science and technology.*

- The following poster was received III Prize in National Seminar-cum-Workshop on Innovative Prospects in Food Processing: Integration of Engineering and Biological Sciences (IPFP-2015)

    - Praneeth Juvvi, Prathana Dutta, Dipankar Kalitha, Charu lata Mahanta, Sukumar Debnath. *Effect of vacuum on changes in quality attributes during production of fried healthy eggplant chips*

(ii) Manpower trained on the project

(a) Mr. Rayees Ahmed Bakshi, JRF (12.12.2012 to 28.05.2013)

(b) Mr. Praneeth Juvvi, JRF (07.06.2013 to 31.03.2015)

(iii) Replication Potential

- The technology can be replicated from the capacity of 1 kg to 25 kg per batch raw materials input.
- However, for high capacities it may be suggested to make/ use continuous vacuum frying system.

(iv) Linkages developed

- The linkages of the following industries/institute were developed for transfer of technology:

❖ The industrial partner (M/s. Dynavac Systems, Bangalore) has shown interest to take the technology.

❖ The Department of Food Engineering., Kerala Agricultural University has shown interest to take the technology (Machinery).

❖ The PRAN Industries have shown interest to take the technology.

❖ Malaylam Exports, Kochi has shown to take the technology.

❖ Kejriwal Bee Care India (Pvt.) Ltd., New Delhi came to CSIR-CFTRI, discussed and shown interest to take the technology (Process).

12. FUTURE SCOPE

Since lot of demands of vacuum frying system are there, development of Continuous Vacuum Frying System is highly inevitable. Also there is a need to develop process protocol for various products to fry under vacuum conditions which were hitherto made by conventional frying methods. The protocol to be developed need to be optimized for delivering heathy, nutritive snack foods to the customers.

COLLABORATIVE WORK DONE BY TEZPUR UNIVERSITY (TEZU)

Effect of drying and frying on the phytochemical content and antioxidant activity of bitter gourd (*Momordica charantia*), culinary plantain (*Musa ABB*) and jackfruit (*Artocarpus heterophyllus*)

1.0 Introduction

Fruits and vegetables are recognized as excellent sources of antioxidants, ascorbic acid and other phytochemicals. Plant-based foods are known to contain significant amounts of bioactive compounds that can provide desirable health benefits beyond basic nutrition and reduce the risk of degenerative diseases such as cancer and cardiovascular diseases (Ames et al., 1993). Deep-coloured vegetables and fruits are known to be good sources of phenolics, including flavonoid and anthocyanin, and carotenoids (Qian et al., 2004; Sass-Kiss et al., 2005; Trappey et al., 2005; Cieslik, 2006). Phenolic compounds in foods include simple phenols and phenolic acid, hydroxicinnamic acid derivatives and the flavonoids. These classes of phenolics influence the quality, acceptability and stability of processed foods by acting as flavourants, colorants and antioxidants. The presence of carboxylic acid groups in numerous phenolic compounds can result in the inhibition of lipid oxidation by metal chelation. The presence of conjugated ring structures and hydroxyl groups allows phenolics to actively scavenge and stabilize free radicals (Decker, 1995). The exploration of effective antioxidant and functional ingredients from natural dietary sources like fruits, vegetables, oilseeds, grains and herbs are increasing day by day (Iqbal et al., 2007). Most of these antioxidants are believed to play a potential role to interfere/retard the process of lipid oxidation by reacting with free radicals, chelating catalytic metals and scavenging oxygen in lipid-based food products and biological systems (Sultana et al., 2008). Thus, the preservation of the seasonal fruits and vegetables with high nutritional value in the form of snacks can be beneficial. In recent years, fast food snacks industry has emerged as one of the important sectors for the modern consumers with a special desire for fried snack foods. Dehydration is one of the most widely used methods for fruits and vegetables preservation. Its main objective is the removal of water to the level at which microbial spoilage and deterioration reactions are minimised. However, it is well known that during hot-air drying, vegetables undergo physical, structural, chemical and nutritional changes that can affect quality attributes like texture, colour, flavour, and nutritional value (Di Scala & Crapiste, 2008). Fried products are liked by all age groups and play an important role in consumer's diet because of their unique flavour and texture. Frying is a quick process which leads to a sterile and dry product with relatively longer shelf life (Maity et al., 2014). Deep-fat frying is defined as a process where a food is cooked by immersing it in edible oil or fat heated above the boiling point of water and in the process, there is removal of water from the food material. The process is traditionally carried out under atmospheric conditions and the frying temperature is usually near to 180°C (Dobraszczyk et al., 2006).

Kubola and Siriamornpun (2008) reported that the fruit extract of bitter gourd has a high value of antioxidant activity and phenolic content and found gallic acid as a predominant phenolic compound. Extract powder of fresh and dried whole fruit of bitter gourd lowered blood sugar in diabetic rats, as reported by Virdi et al (2003). The bitter gourd extracts showed anti-diabetic, hepato-renal protective and hypolipidemic effects in alloxan-induced diabetic rats as reported by El Batran et al (2006). Jackfruit is a rich source of phytonutrient including phenolic compounds and offers opportunities for development of value added products such as nutraceuticals and food applications to enhance health benefits. The antioxidant activity decreases with increasing ripening status. In a study reported by Benett et al (2010), (+) catechin, gallocatechin, and (-) epicatechin, as well as condensed tannins were detected in the soluble extract of the fruit pulp of the banana variety cultivated in Mysore. Recent studies have shown that there are significant levels of total free phenolics in the pulp ranging from 11.8 to 90.4 mg of gallic acid equivalents 100/g of fresh weight. An evaluation of banana pulp as a source of cloud components for the juice industry also revealed that bananas have high phenolic content (138 mg of gallic acid equivalents/L) (Balasundram et al., 2006).

Keeping in mind the nutritional properties of fruits and vegetables and also the consumer's appeal for fried-crispy snacks, vegetable and fruit samples like bitter gourd (*Momordica charantia*), kachkol (*Musa ABB*), jackfruit (*Artocarpus heterophyllus*) and carambola (*Averrhoa carambola)* are good candidates for study on drying and frying effects. Thus, study was undertaken to characterise the raw fruit pulp of bitter gourd, kachkol and jackfruit for phytochemical content and antioxidant capacities and study the effect of drying (at 55, 65 and 75°C) and frying at 170°C under atmospheric condition on these properties.

2.0 Materials and methods

2.1. Chemicals and reagents

Chemicals used in the study were of analytical grade purchased from Sigma, Merck and Himedia. All the standards were purchased from Sigma.

2.2 Sample collection

Fresh bitter gourd (*M. charantia*), culinary plantain (*Musa ABB*), jackfruit (*Artocarpus heterophyllus*), and carambola (*Averrhoa carambola)* were purchased from local market around Tezpur University campus. The vegetable and fruit samples were picked at its unripe stage and stored immediately at 7 °C before use.

2.3 Sample preparation

Initially, the vegetable samples were washed thoroughly with tap water before peeling to remove any adhering dirt or dust particles. The surface moisture was removed with the help of absorbent paper. The bitter gourd, plantain, jackfruit and carambola samples were transversely cut into slices of about 2 mm thickness. The cut slices of each sample were divided equally into three parts. One portion was retained as raw and from the other two portions one lot was used for frying and other lot was subjected to air- drying treatment.

2.4 *Drying procedure*

The drying process of the fruit and vegetable slices was conducted in a laboratory scale convective tray dryer. The sample slices were placed in single layers over the trays of the drier and drying of samples was carried out at specified temperature of hot air and fixed air velocity. Initial weights of the samples were noted and samples were kept inside the preheated drying chamber after steady state condition was achieved. The sample trays were taken out for weighing at every 15 min interval for 1 h, after that at every 30 min interval till constant weight was achieved. Each experiment was replicated thrice and average values were taken for analysis. The experiment was carried out at 55, 65 and 75 °C for three thickness levels of the samples, i.e., 2mm, 3mm and 4mm respectively. Before each experiment the temperature and velocity of air were checked and fixed.

2.5 *Mathematical modeling of drying curves*

Drying curves were fitted to the experimental data using ten different moisture ratio equations (Table 1). However, the moisture ratio (MR) was simplified to M/M_o instead of the $(M - M_e)/(M_O - M_e)$ (Ertekin and Yaldiz et al., 2004).

Table 1. Mathematical model applied to drying curve

Sl No.	Model name	Model	References
1	Newton	MR = exp(-kt)	(Mujumdar, 2006; Erenturk et al., 2004)
2	Page	MR = exp(-ktn)	(Page, 1949)
3	Modified Page	MR = exp[- (kt)n]	(Yaldiz et al., 2001)
4	Handerson and Pabis	MR = a exp(-kt)	(Henderson & Papis, 1961)
5	Logarithmic	MR = a exp(-kt) + c	(Yagcioglu et al., 1999)
6	Two term	MR = a exp(-kot) + b exp(-k1t)	(Madamba et al., 1996)
7	Two term exponential	MR = a exp(-kt) + (1- a)exp(-kat)	(Sharaf-Elden et al., 1980)
8	Wang and Singh	MR = Mo + at + bt2	(Ozdemir and Devres,1999)
9	Approximation of diffusion	MR = a exp(-kt) + (1- a)exp(-kbt)	(Yaldiz et al., 2001)
10	Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	(Verma et al., 1985)

The moisture ratios were calculated at three temperatures and were used to interpret the drying kinetics. These readings were used in fitting the different mathematical models. The non- linear regression analysis was conducted using Origin (Origin Lab, Northampton, MA) to fit the experimental data to the selected models which are given in **Table 1**. The coefficient of determination (R^2) is one of the primary criteria that was used to evaluate the fit quality among these models.

2.6 Deep fat frying of samples

Frying was carried out in olive oil at 170°C for 5 min under atmospheric condition. After each frying experiment, the fried vegetable slices were removed from the fryer and excess oil was allowed to drain out on holding on a stainless steel rack. The extra oil was removed gently from the surface of the fried slices with the help of tissue paper.

2.7 Determination of total phenolic content (TPC) and total flavonoid content (TFC)

2.7.1 Extraction of polyphenols from the samples

The polyphenols from the pulp of the vegetable samples was extracted in acidified ethanol. Sample (1g) was pasted in a mortar and pestle with 10 ml of 2% acetic acid in ethanol. The final solid: solvent concentration was made up to 1:10. The mixture was stirred at 160 rpm for 3h in shaking incubator (Certomat 1S, Sartorius) at 20°C. After extraction, the crude extracts were centrifuged at 12,000 rpm (Sigma 3-18k – Zentrifugen, Germany) for 15 min. The supernatant was collected for each sample and the extract was assessed for total phenolic content, flavonoid content and antioxidant activity.

2.7.2 Method for determination of total phenolic content

The total phenolics concentration in each extract was determined following the Folin- Ciocalteu assay (Kubola and Siriamornpun, 2008) with minor modification. To 200 µl of sample extract, 0.5 ml of the Folin- Ciocalteu reagent, 2ml of 20% sodium carbonate and 2.3 ml distilled water were added. After 45min of reaction at ambient temperature, the absorbance at 765 nm was measured in a UV-Vis spectrophotometer (Cecil, Aquarius 7400). Gallic acid was taken as standard. The total phenolic content was then expressed as gallic acid equivalents (GAE) in mg/100g dry sample.

2.7.3 Method for determination of total flavonoid content

The flavonoid content was determined by aluminum trichloride method (Chang et al., 2002). Briefly, 0.5 ml of the extract was mixed with 1.5 ml of 95% ethanol, 0.1 ml of 10% aluminum trichloride ($AlCl_3$), 0.1 ml of 1M potassium acetate, and 2.8 ml of deionised water. After incubation at room temperature for 40 min, the absorbance of reaction mixture was measured at 415 nm against de-ionised water taken as blank in a UV-Vis spectrophotometer (Cecil, Aquarius 7400). Results were expressed as quercetin equivalent (mg QE/ 100g) of sample.

2.8 Identification and quantification of phenolic compounds by RP-HPLC

For the study on extent of retention of polyphenols in the fruit and vegetable samples in raw state and after drying and frying, RP-HPLC study was conducted. RP-HPLC (Waters) gradient elution method (Saikia et al., 2015) was used to identify the major phenolic acid composition of the polyphenol extracts. Symmetry 300^{TM} C_{18} (5µm, 4.6×250 mm) column with a binary pump (Waters, 1525) and a UV- vis detector (Waters, 2489) were used. The polyphenol extracts from bitter gourd, kachkal and jackfruit samples were evaporated under vacuum, and then re-dissolved in 1ml methanol. All the extracts were then filtered through a membrane filter (0.22 µm) before injection.

Mobile phase used was acidified ultrapure water (0.1% acetic acid, pH 3.2, mobile phase A) and methanol (mobile phase B). The gradient method: 80% A (0-8 min), 65% A (9-12min), 45% A (13-16 min), 30% A (17-20 min), 20% A (21-30 min), 10% of A (31-34 min) and then washing of the column with 65% A (35-39 min) and lastly, 80% A (40-45 min) was followed. The sample volume of 20µl was used. The flow rate was maintained at 0.8 ml/min and wavelengths used for UV- vis detector were 254 nm and 325 nm. The standards used for comparison and identification were (+) catechin, caffeic acid, coumaric acid, gallic acid, syringic acid, chlorogenic acid, rutin, quercetin, ferulic acid and ascorbic acid.

2.9 Measurement of antioxidant activity

2.9.1 Determination of DPPH radical scavenging activity

Radical scavenging activity of the fruit and vegetable extracts were measured by determining the inhibition rate of DPPH (2, 2-diphenyl-1-pycrylhydrazyl) radical by the method of Zhang and Hamauzu (2004) with minor modification. Fresh, dried or fried samples (10g) were mixed with 15 ml of 80% methanol. Each homogenate was stirred at 160 rpm for 3h in shaking incubator (Certomat 1S, Sartorius). After extraction in incubation shaker, the crude extracts were centrifuged at 12000 rpm (Sigma 3-18k – Zentrifugen, Germany) for 15 min. The supernatant of each methanol extract was diluted to 5% concentration for the measurement of total antioxidant activity. DPPH solution (0.1mM in methanol) was prepared and 4 ml of this solution was treated with 0.2 ml of the diluted extract. A control was treated with 0.2 ml of distilled water instead of the extract. The mixture was left to stand at room temperature for 60 min before the decrease in absorbance at 517 nm was measured. Antioxidant activity was expressed as the percentage of DPPH decrease using the equation.

$$AA\ (\%) = \frac{Control\ absorbance - Sample\ absorbance}{Control\ absorbance} \times 100$$

2.9.2 Determination of antioxidant activity with ABTS assay

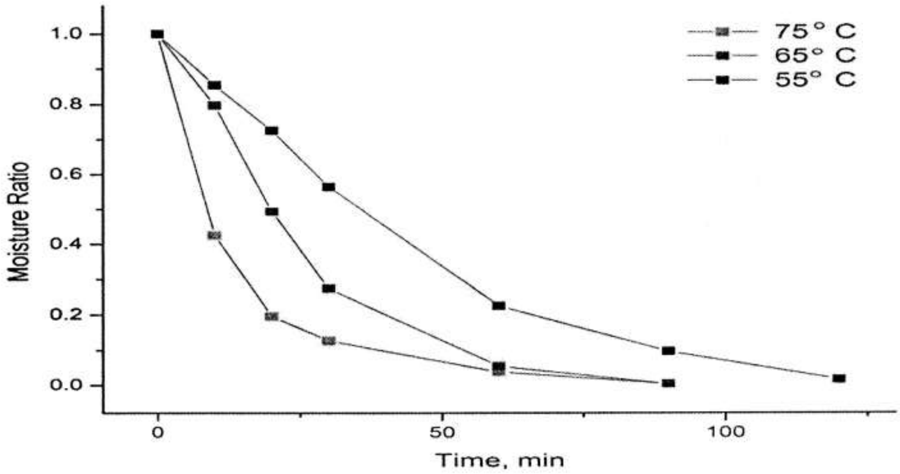
The ABTS assay was based on the method reported by Floegel et al (2011). Briefly, 2.5 mM of ABTS was mixed with 1 mM of 2, 2 - azobis (2-amidinopropane) dihydrochlolride in 10 mM phosphate buffered saline (PBS) solution, pH 7.4. The mixture was heated in water bath at 50°C for 30 min. The blue-green ABTS solution was cooled to room temperature and diluted with fresh PBS buffer until absorbance of 0.650 ± 0.020 at 734 nm was obtained. Then, 20 µL of trolox standard or sample was mixed with 980 µl of ABTS solution and incubated for 10 min in 37° C water bath. A control consisted of 50% (v/v) methanol in 980 µl of radical solution. The coefficient of variation (CV) for ABTS assay was found to be 4.72% within a day (n = 10).

3.0 Results and discussion

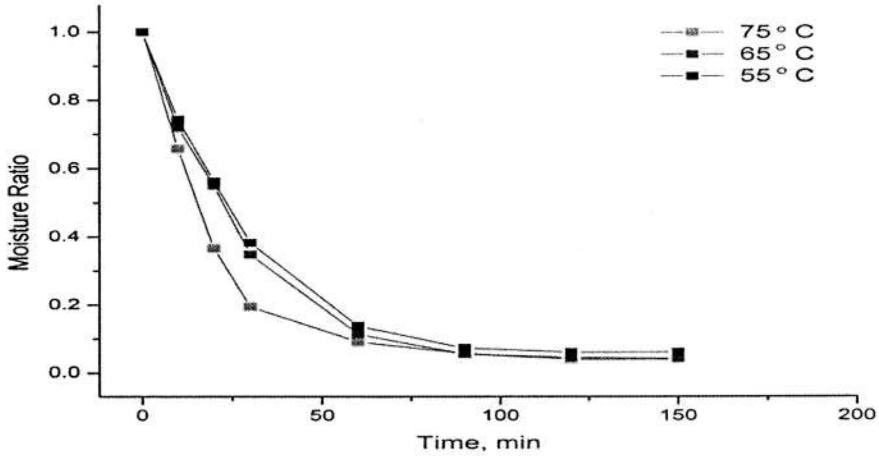
3.1 Analysis for drying curve

The drying kinetics is presented in terms of the moisture ratio as a function of drying time. **Fig. 1** shows the relation between moisture ratio and drying time for all the three drying temperatures.

The results showed that the drying time decreased with increase in drying temperature. Drying rate decreased continuously with time and decreasing moisture content. The data that was recorded during the experiment were fitted to the 10 mathematical models. The values of determination coefficient (R^2) and the reduced chi-square (χ^2) for different air temperatures determined using regression analysis are shown in **Table 2**. The Modified Page model was found to be the best fitted model in the bitter gourd drying curves with lowest Chi-square value (0.0009519) and highest R^2 value (0.99554).

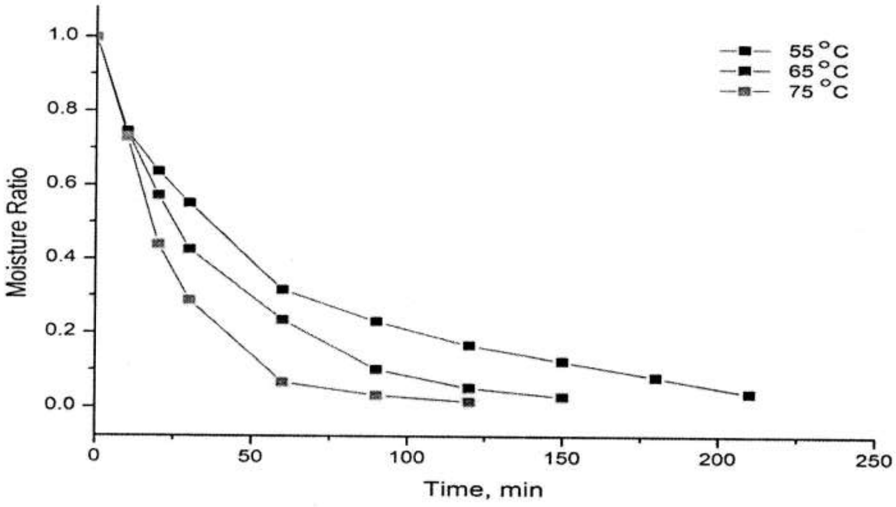


(a)

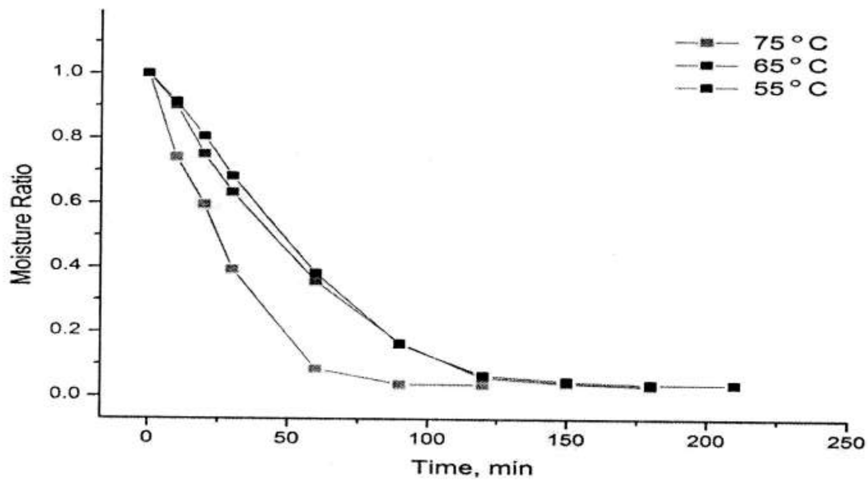


(b)

Similarly, Page model was found best fitted in kachkol drying curves as well as jackfruit drying curves. In case of carambola drying curves, the two term exponential model was found to fit best. The constant parameters of Chi-square value and R^2 value of all the best fitted models are presented in **Table 3** and from the constant values of for the models, theoretical MR can be calculated.



(c)



(d)

Fig.1 The drying curves of (a) bitter gourd, (b) kachkol, (c) jackfruit, and (d) carambola at 55°C, 65°C and 75 ° C.

3.2 Total phenolic content and total flavonoid content

The atmospheric frying at 170°C and air- drying treatments (at 55°, 65° and 75°C) caused significant changes in the total phenolic content and flavonoid content in the selected fruit and vegetable samples (**Table 4**).

But cooking processes were not always detrimental to the phytochemical properties. It depended in some cases on the method used and species considered for cooking (Boari et al., 2013). Frying of all the three samples, bitter gourd, kachkol and jackfruit showed a significant decrease in the TPC value compared to their control (raw vegetable).

Table 2. Average chi-square values and R^2 values of different drying models

Dried samples (55°,65°,75°C)	**Models Average**	**Chi-square**	**R^2**
Bitter gourd	Modified Page Model	0.000951	0.99554
Kachkol	Page Model	0.000853	0.99433
Jackfruit	Page Model	0.000311	0.99824
Carambola	Two term exponential Model	0.000321	0.99812

Table 3: Drying kinetic constants of two term exponential model

Models	Temperature (°C)	Constants	
		k	a
Modified Page Model for bitter gourd	55	0.02557	1.70224
	65	0.03901	1.49689
	75	0.08749	0.70057
Page Model for kachkol	55	0.03152	0.98861
	65	0.0426	1.04005
	75	0.07567	0.72118
Page Model for jackfruit	55	0.02283	1.17644
	65	0.01247	1.15658
	75	0.04629	0.76928
Two term exponential Model for carambola	55	0.02551	1.91383
	65	0.0254	1.79892
	75	0.04336	1.7176

Sultana et al. (2008) also reported that total phenolic content of vegetables (peas, carrot, spinach, cabbage, cauliflower, yellow turnip and white turnip) decreased on frying and microwave cooking. The three samples exhibited decrease in TPC at all the three temperatures of drying. However, the retention of TPC was found to be more at 75°C than 65°C and 55°C. This is probably due to the reason that at higher air drying temperature the duration of exposure to the heating environment is less. Chen et al. (2011) observed that when the citrus fruit (*Citrus sinensis* (L.) Osbeck) peels were dried at 50 and 60 °C, the total phenolic contents were significantly lower than those of fresh peels. However, the phenolic content gradually increased as drying temperature increased. The highest total phenolic content was in the peel dried at 100 °C. Partial drying of tomatoes was found to lower the phenolic content by 30% but drying of pepper gave contradicting results (Toor and Savage, 2006). Vega- Galvez et al (2009) observed that the total phenolic content of red pepper content decreased as air-drying temperature decreased. Lopez et al (2010) in their work explained that an increase in drying temperature had an important effect on the total phenolic content of blueberry varieties compared with the fresh sample. Long drying times associated with low process temperatures (e.g., 50, 60, and 70 °C) contribute to diminish the protective effect against oxidative damage to cells. Furthermore, a significant increase in polyphenols concentration observed at high temperature (e.g., 90 °C) was probably due to generation of different antioxidant compounds with a varying degree of antioxidant activity (Shotorbani et al., 2013).

The three samples exhibited both positive and negative effects on flavonoid content upon air-drying (at 55, 65 and 75°C) and frying at 170°C. The flavonoid content of bitter gourd significantly decreased on both frying and air-drying treatments (at 55°C and 65°C) except drying at 75°C. Whereas in case of kachkol, the flavonoid content increased on frying and decreased on air-drying than that of its fresh sample. In jackfruit, the flavonoid content increased at higher air-drying temperature of 75°C and atmospheric frying at 170°C. There was no difference in the flavonoid content of jackfruit at 55 and 65°C. Application of heat during cooking involves changes in the structural integrity and cellular matrix of the vegetables and this causes both positive and negative effects on the phytochemical properties. It was observed that cooking caused a significant change in the phenolic and flavonoid content in vegetables (Saikia et al., 2013). Chen et al (2011) in their work reported that the total flavonoid content of orange (Citrus sinensis (L.) Osbeck) peel extracts decreased with lower heating temperature (<80 °C) and increased with higher heating temperature (>90 °C). Ho and Lin (2008) indicated that the flavonoid content increased with heating time, but the total flavanone glycoside content of the 150 °C heated Huyou peel was lower than that of the 120 °C (Xu et al., 2007). In case of kachkol and jackfruit an increasing trend was observed upon frying, which could be because of some structural alteration of the flavonoid compounds and breakdown of cellular matrix. Further, in some instances, application of heat could cleave the phenolic-sugar glycosidic bonds resulting in the formation of phenolic aglycons, which have high reactivity with Folin Ciocalteau reagent and thus lead to an increased value of total phenolic content (Singleton et al., 1999).

Also cooking could lead to decomposition of some polyphenols bound to dietary fibre of vegetables releasing free phenolic compounds that increase their detection (Stewart *et al.*, 2000). The overall difference in the results of the total phenolics and flavonoids of the selected vegetables could be due to the presence of different phenolic groups in the vegetables and their susceptibility to change or destruction during the three cooking treatments (Bernhardt and Schlich, 2006).

3.3 Antioxidant capacity

The study on the radical scavenging activity associated with the phenolic compounds based on the air- drying temperatures and frying treatment can be seen on **Table 5**. Antioxidant capacity was determined by ABTS and DPPH assays.

The drawbacks and advantages of each one of the available antioxidant capacity assays make it necessary to use different techniques (Rufino et al; 2011). Antioxidant activity assessed by both the methodologies showed a similar trend of change in the antioxidant activity of bitter gourd, kachkol and jackfruit samples. In case of bitter gourd, the antioxidant activity increased on frying at 170°C and air-drying at (55, 65 and 75°C) as assessed by DPPH and ABTS assays. In kachkol, an increasing trend was observed in its antioxidant activity when assessed by ABTS, while there was not much increase in DPPH activity. Similar results have been reported by Turkmen et al (2005) in pepper, peas and broccoli, where the antioxidant activity increased or remained unchanged based on the type vegetable not the type of cooking.

Table 4. Results of total phenolic content and total flavanoid content of extract from bitter gourd, kachkol and jackfruit.

Samples	Treatment	Total phenolic content (mgGAE/100 g DW)	Total flavanoid content (mg QE/100g DW)
Bitter gourd	Raw	933.42 ± 0.19	481.47 ± 0.02
	Fried	194.19 ± 0.09	132.20 ± 0.11
	Dried at 55°C	221.45 ± 0.11	158.68 ± 0.16
	Dried at 65°C	238.27 ± 0.12	198.31 ± 0.08
	Dried at 75°C	461.67 ± 0.25	980.17 ± 0.18
Kachkol	Raw	1744.50 ± 0.02	191.70 ± 0.02
	Fried	976.60 ± 0.23	288.26 ± 0.25
	Dried at 55°C	473.68 ± 0.15	39.65 ± 0.19
	Dried at 65°C	778.38 ± 0.11	50.98 ± 0.32
	Dried at 75°C	1125.30 ± 0.04	71.92 ± 0.25
Jackfruit	Raw	4774.70 ± 0.23	8.91 ± 0.15
	Fried	1023.73 ± 0.12	75.205 ± 0.11
	Dried at 55°C	267.50 ± 0.02	7.66 ± 0.18
	Dried at 65°C	333.10 ± 0.12	8.45 ± 0.19
	Dried at 75°C	725.80 ± 0.05	47.02 ± 0.21

Table 5. Antioxidant activity of bitter gourd, kachkol and jackfruit

Samples	Treatment	DPPH (%)	ABTS (mM/100g)
Bitter gourd	Raw	13.96	195.43
	Fried	51.12	678.22
	Dried at 55°C	60.45	814.05
	Dried at 65°C	75.87	837.20
	Dried at 75°C	77.92	888.90
Kachkol	Raw	93.76	700.12
	Fried	95.38	782.33
	Dried at 55°C	94.43	735.67
	Dried at 65°C	94.56	779.42
	Dried at 75°C	96.76	787.68
Jackfruit	Raw	24.40	4879.29
	Fried	20.11	1393.50
	Dried at 55°C	12.23	178.62
	Dried at 65°C	15.12	354.95
	Dried at 75°C	15.56	844.07

Frying and air-drying treatments, however, had adverse effects on the antioxidant activity of jackfruit sample. The decrease of antioxidant activity has been reported in samples like tomato, cabbage, radish and roselle leaves by Saikia et al (2013). Also Wolosiak et al (2009) reported a loss of antioxidant activity by 10-17% when frozen beans were cooked. So, the decreasing trend observed in jackfruit probably may be due to the fact that it was stored at -20°C before use.

However, air-drying of the samples exhibited an increasing trend of antioxidant activity with increase in drying temperature (55°C<65°C<75°C). Lopez et al (2010) reported in his work that the dehydration of blueberry varieties at higher temperature (e.g, at 80 and 90°C) exhibited higher antioxidant activity rather than at lower temperatures (e.g, at 50 and 60°C). This behaviour shows that drying process at low temperatures that takes longer time results in a decrease in antioxidant activity (Garau et al., 2007).

The possible reason for the above results could be that there are hundreds of different phytochemicals present in food and each has different characteristics of reacting to the changes in their cellular matrix caused by heat treatments or frying. This could lead to an increase or decrease in the antioxidant activities of the vegetables (Saikia et al., 2013). The phenolic content and antiôxidant activity have a strong relationship between them (Velioglu *et al.,* 1998).

3.5 RP-HPLC study of the crude polyphenolic extract of bitter gourd, kachkol and jackfruit

The methanolic extracts of polyphenol obtained from the flesh tissues of bitter gourd, kachkol and jackfruit were separated by RP HPLC and number of phenolic acids (chlorogenic acid, caffiec acid, quercetin, syringic acid, ferulic acid, coumaric acid and rutin) was detected (**Table 6 and Fig. 2**). As the peak intensity of the sample at 325 nm was not that high and clear, the peaks obtained at 254 nm were considered. The phenolic acids identified in pomace extract were, gallic acid (RT = 3.2 min), catechin (RT = 11.9 min), chlorogenic acid (RT = 13.5 min), caffeic acid (RT = 14.5 min), syringic acid (RT = 14.7 min), ferulic acid (RT=16.5), coumaric acid (RT = 16.7 min), rutin (RT = 17.3 min), quercetin (RT =19.9 min), and ascorbic acid (RT = 3.9 min).

The raw bitter gourd exhibited the prescence of ascorbic acid caffiec acid in dominant quantity of 100.4 mg/100g and 91.4mg/100g dry matter. Caffeic and ascorbic acid content decreased after frying and air-drying treatment, while the phenolic antioxidants like ferulic acid, quercetin and rutin content increased significantly. Syringic acid was detected after frying treatment. Kubola and Siriamornpun (2008) reported the presence of caffeic acid and ferulic acid in the fruit pulp of bitter gourd in his study.

In case of raw kachkol, rutin and ferulic acid was detected in higher quantity (21.967mg/100g and 20.190 mg/100g dry matter, respectively) than other phenolic compounds. Chlorogenic acid, caffeic acid and quercetin were found to increase on frying while ferulic acid and rutin decreased. The phenolic compounds like ferulic acid and quercetin were found to increase on drying at 65°C.

The HPLC study of phenolics in raw jackfuit revealed the prescence of chlorogenic acid (260mg/100g dm), ferulic acid (100.75mg/100g dm), and ascorbic acid (315.75mg/100g dm) in predominant amount. The entire phenolic compounds such as chlorogenic acid, ferulic acid, rutin and quercetin showed a decreasing trend with frying and air-drying treatment on jackfruit. But the decrease was more on frying compared to drying. The retention was found to be more at 55 and 65°C than at 75°C.

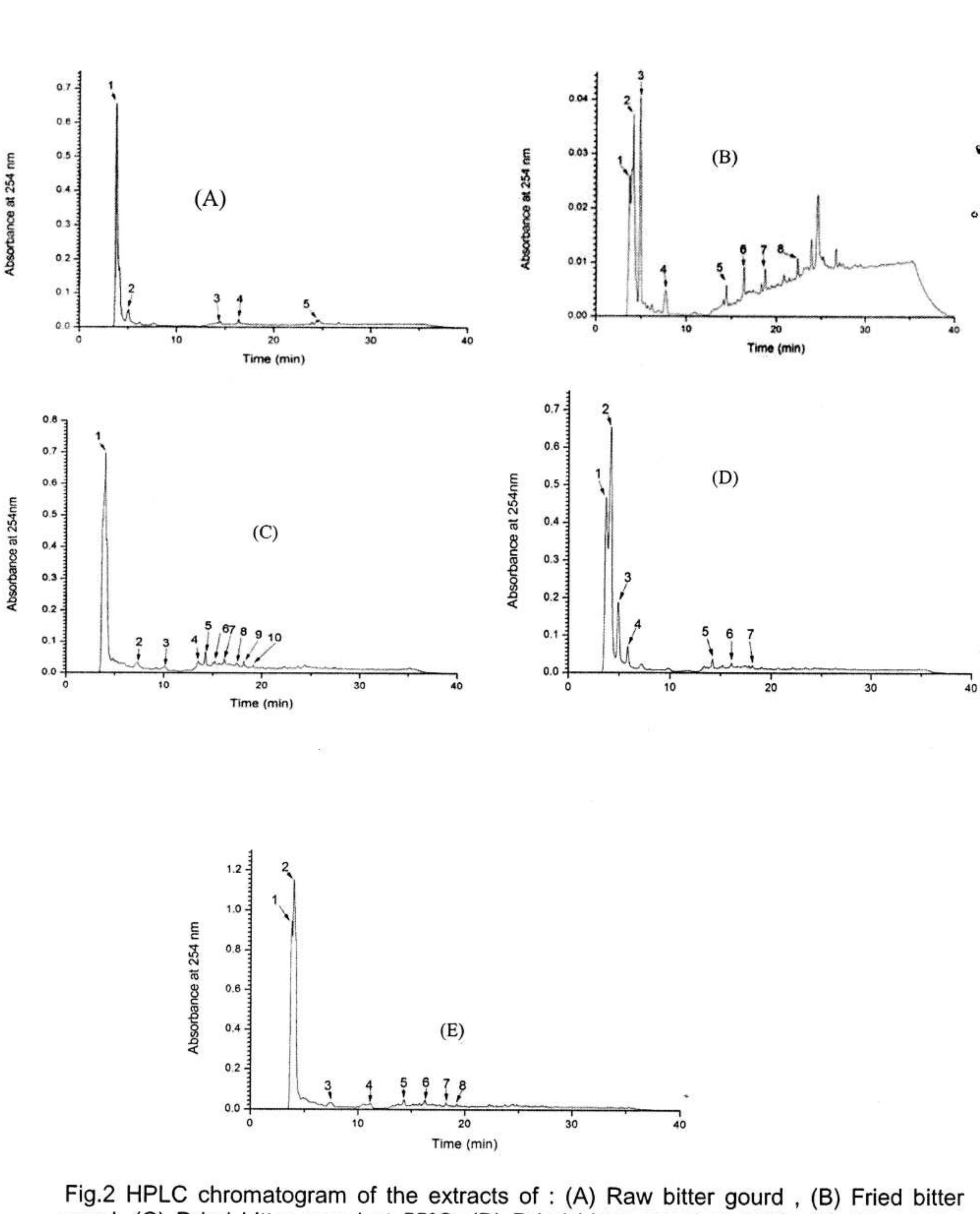


Fig.2 HPLC chromatogram of the extracts of : (A) Raw bitter gourd , (B) Fried bitter gourd, (C) Dried bitter gourd at 55°C, (D) Dried bitter gourd at 65°C, (E) Dried bitter gourd at 75°C at 254 nm. 1=ND, 2= ascorbic acid, 3= ND, 4=ND, 5=Caffeic acid, 6=Ferulic acid, 7=ND, 8=Quercetin.

Table 6. RP-HPLC results of the crude polyphenol extract from bitter gourd, kachkol and jackfruit.

Phenolic acids	Bitter Gourd (mg/ 100g DW)					Kachkol (mg/100g DW)					Jackfruit(mg/100g DW)				
	Raw	Fried	Dried			Raw	Fried	Dried			Raw	Fried	Dried		
			55°C	65°C	75°C			55°C	65°C	75°C			55°C	65°C	75°C
Gallic acid															
Catechin															
Chlorogenic acid	0.006	10.90				14.88	22.91	10.11		2.19	260.0	4.83	12.08	10.35	
Caffiec acid	91.4	25.8	88.7	68.8	24.9	10.52	13.58								
Quercetin	0.001	2.33			19.1	3.13	4.82	2.59	15.256	1.60	55.62	3.72	30.05	8.35	3.45
Syringic acid		7.74													
Ferulic acid	27.11	574.3	11.0	116.5	122.9	20.19		14.26	22.33		100.75	9.66	46.72	28.54	14.69
Coumaric acid							17.26	11.64	4.523						
Rutin	.005	6.54				21.97	9.38	6.32	14.5	2.62	39.10	2.20	14.31	22.29	5.82
Ascorbic acid	100.4	218.0	312.3	56.7	71.11	28.07	601.62	25.82	361.80	1.77	315.78	26.94	82.12	60.55	27.33

Columns with no values indicate that the phenolic acids were not detected.

4.0 Conclusion

Drying of the vegetable slices was studied for its drying kinetics. Moisture removal process followed falling rate stage which was governed by the diffusion process. In order to explain the drying behavior, different models were applied and fitted to the experimental data. According to the statistical analysis applied to all the models and on the basis of highest R^2 and lowest χ^2 value, two term exponential model was found to be best suited model adequately describing the drying behavior of vegetable samples. The drying time is inversely proportional to temperature, as expected. The final empirical relation established can be used to calculate effective diffusivities at any temperature for drying the given vegetable samples.

Heat treatments like frying and drying affect the antioxidant capacities of different vegetables differently. While there was positive effect on bitter gourd and kachkol, adverse effect was noticed on jackfruit indicating differences in the nature of polyphenols present. Among the polyphenols, quercetin, ferulic acid and rutin were commonly present in the studies vegetables.

Name and Signature with Date

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(Principal Investigator)

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Heat treatments like frying and drying affect the antioxidant capacities of different vegetables differently. While there was positive effect on bitter gourd and kachkol, adverse effect was noticed on jackfruit indicating differences in the nature of polyphenols present. Among the polyphenols, quercetin, ferulic acid and rutin were commonly present in the studies vegetables.

Name and Signature with Date

(Shri. A. Chakkaravarthi) (Dr. Sukumar Debnath)

29/03/2016

(Co-investigator) **(Principal Investigator)**

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Charu Lata Mahanta 29/3/2016

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UTILIZATION CERTIFICATE (TWO COPIES)

FOR THE FINANCIAL YEAR 2014-2015 (01/04/2014-03/02/2015)

1. Title of the Project/ Scheme	Design and Development of Vacuum Frying System for the production of Healthy Snacks Products
2. Name of the Institution	Tezpur University
3. Principal Investigator	Prof. Charu Lata Mahanta
4. Deptt. of Science & Technology letter No. & date sanctioning the project	IDP/IND/2012/3(General) Date: 11/09/2012
5. Head of account as given in the original sanction letter	Non-recurring = NIL Recurring = ₹ 10,72,400/-
6. Amount brought forward from the previous financial year quoting DST letter No. and date in which the authority to carry forward the said amount was given	i Amount **₹ 36,407/-** ii Letter No. iii Date
7. Amount received during the financial year (Please give No. & date of DST's sanction letter for the amount)	i Amount **4,50,000/-** ii Letter No. IDP/IND/2012/3(General) iii Date 09/06/2014
8. Interest earned	**₹ 1,274/-**
9. Total amount that was available for expenditure (excluding commitments) Rs. during the financial year	**₹ 4,87,681/-**
10. Actual expenditure (excluding commitments) incurred during the financial year (Upto 31st March, 2015)	**₹ 5,03,283/-**
11. Balance amount available at the end of the financial year	(-) **₹ 15,602/-**
12. Unspent balance refunded if any (Please give details of cheque, Demand draft No. etc.)	None
13. Amount to be carried forward to the next financial year (including interest earned)	₹ NIL

UTILIZATION CERTIFICATE

Certified that out of **₹ 4,50,000/-** of grants-in-aid sanctioned during the year 2014 in favour of Registrar, Tezpur University under the Department of Science & Technology Letter No. IDP/IND/2012/3 (General), Date: 09/06/2014, and **₹ 36407/-** the unspent balance of previous year and interest earned **₹** 1274/- a sum of **₹ 5,03,283/-** (Rupees five lakhs three thousand two hundred eighty three only) has been utilized for the purpose of salary, equipments, consumables (excluding the commitments) for which it was sanctioned and excess expenditure of **₹ 15,602**/- was incurred.

Charu Lata Mahanta
10/12/2015
Signature of Principal Investigator with date

Principal Investigator
Dept. of Food Engg. & Tech.
Tezpur University
Tezpur -784 028, Assam

11.12.15
Signature of Registrar/ Accounts Officer
Finance Officer
Tezpur University

Signature of Head of the Institute
Registrar
Tezpur University

Consolidated Statement of Expenditure (9.50 Lakhs)

Sr. No	Sanction Heads (I)	Funds Allocated (sanctioned (II)		Fund (instalment) recd (₹) (III)		Interest earned (₹)		Expenditure (₹) (IV)			Total Expenditure (₹) (V)	Balance as on 3/2/2015 (₹) (II-V)
		1st yr	2nd yr	1st	2nd	2nd yr	3rd yr	11/9/2012 - 31/03/2013	1/4/2013 - 31/3//2014	1/4/2014 - 3/2//2015		
1	Manpower costs	2,11,200	2,11,200	₹ 5,00,000/-	₹ 4,50,000/-	₹ 3,855/-	₹ 1,274/-	77,333	1,57,333	1,60,000	3,94,666	NIL
2	Consumables	1,25,000	1,25,000					NIL	1,25,000	1,45,569	2,70,569	NIL
3	Travel	50,000	50,000					NIL	5,280	50,216	55,496	NIL
4	Contingencies	1,00,000	1,00,000					NIL	62,752	87,248	1,50,000	NIL
5	Others, if any	NIL	NIL					NIL	NIL	NIL	NIL	NIL
6	Equipments	NIL	NIL					NIL	NIL	NIL	NIL	NIL
7	Overhead expenses	50,000	50,000					39,750	NIL	60,250	1,00,000	NIL
8	**Total (₹)**	**5,36,200**	**5,36,200**					**1,17,083**	**3,50,365**	**5,03,283**	**9,70,731**	**NIL**

Fund allocated		: ₹ 10,72,400
Fund Released		: ₹ 9,50,000/-
Interest earned		: ₹ 5129/-
Total		: ₹ 9,55,129/-
Fund Utilized		: ₹ 9,70,731/-
Excess	(-)	: ₹ 15,602/-

Charu Lata Mahanta
Name and signature of Principal Investigator
Date: 4/12/2015
Principal Investigator
Dept. of Food Engg. & Tech.
Tezpur University
Tezpur -784 028, Assam

11.12.15
Signature of Competent financial authority (with seal)
Date:
Finance Officer
Tezpur University

UTILIZATION CERTIFICATE (TWO COPIES)

FOR THE FINANCIAL YEAR 2013-2014 (01/04/2013-31/03/2014)

1. Title of the Project/ Scheme	Design and Development of Vacuum Frying System for the production of Healthy Snacks Products	
2. Name of the Institution	Tezpur University	
3. Principal Investigator	Prof. Charu Lata Mahanta	
4. Deptt. of Science & Technology letter No. & date sanctioning the project	IDP/IND/2012/3(General) Date: 11/09/2012	
5. Head of account as given in the original sanction letter	Non-recurring = NIL Recurring = ₹ 10,72,400/-	
6. Amount brought forward from the previous financial year quoting DST letter No. and date in which the authority to carry forward the said amount was given	i Amount	**₹ 3,82,917/-**
	ii Letter No. IDP/IND/2012/3(General)/2	
	iii Date	09/06/2014
7. Amount received during the financial year (Please give No. & date of DST's sanction letter for the amount)	i Amount	NIL
	ii Letter No.	
	iii Date	
8. Interest earned	**₹ 3,855/-**	
9. Total amount that was available for expenditure (excluding commitments) Rs. during the financial year	**₹ 3,86,772/-**	
10. Actual expenditure (excluding commitments) incurred during the financial year (Upto 31st March, 2014)	₹ 3,50,365/-	
11. Balance amount available at the end of the financial year	₹ 36,407/-	
12. Unspent balance refunded if any (Please give details of cheque, Demand draft No. etc.)	None	
13. Amount to be carried forward to the next financial year (including interest earned)	**₹ 36,407/- (including interest)**	

UTILIZATION CERTIFICATE

Certified that out of ₹ **NIL/-** of grants-in-aid sanctioned during the year 2012 in favour of Registrar, Tezpur University under the Department of Science & Technology Letter No. IDP/IND/2012/3 (General), Date: 11/09/2012, and ₹ **382917/-** the unspent balance of the previous year and interest earned ₹ 3855/-, a sum of **₹3,50,365/-** (Rupees three lakhs fifty thousand three hundred sixty five only) has been utilized for the purpose of salary, equipments, consumables (excluding the commitments) for which it was sanctioned and the balance of ₹ **36,407/-** remaining unutilized at the end of the year has been surrendered to Government will be adjusted during the year 2014-15.

Charu Lata Mahanta
10/12/2015
Signature of Principal Investigator with date

Principal Investigator
Dept. of Food Engg. & Tech.
Tezpur University
Tezpur -784 028, Assam

11-12-15
Signature of Registrar/ Accounts Officer

Finance Officer
Tezpur University

Signature of Head of the Institute

Registrar
Tezpur University