

# **FOAM MAT DRYING OF BANANA PULP FOR PREPARATION OF BANANA POWDER**

**By**

**KHIRA SAMIR MULCHAND**

**(Registration No. 2050217013)**

**B. Tech. (Agril. Engg.)**



**DEPARTMENT OF PROCESSING AND FOOD ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY  
JUNAGADH AGRICULTURAL UNIVERSITY**

**JUNAGADH – 362 001**

**AUGUST – 2019**

# **FOAM MAT DRYING OF BANANA PULP FOR PREPARATION OF BANANA POWDER**

**A THESIS SUBMITTED TO  
JUNAGADH AGRICULTURAL UNIVERSITY  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF TECHNOLOGY**

**(Agricultural Engineering)**

**IN**

**PROCESSING AND FOOD ENGINEERING**

**BY**

**KHIRA SAMIR MULCHAND**

**(Registration No. 2050217013)**

**B. Tech. (Agril. Engg.)**



**DEPARTMENT OF PROCESSING AND FOOD ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY  
JUNAGADH AGRICULTURAL UNIVERSITY  
JUNAGADH – 362 001**

**AUGUST – 2019**

# *DEDICATION*

*To my parents and elder sister  
The reason for what I become today.  
Thanks for your great support and continuous  
care.*

*To my true friends  
I am really grateful to you.  
You have been my inspiration.*

*To my respected guide  
Who is the continuous Source of  
Inspiration and constant encouragement for me.*

*Samir Khira...*



**DEPARTMENT OF PROCESSING AND FOOD ENGINEERING  
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY  
JUNAGADH AGRICULTURAL UNIVERSITY, JUNAGADH – 362 001**

**Name of student**

**Major Guide**

Khira Samir Mulchand

Dr. D. K. Antala

**FOAM MAT DRYING OF BANANA PULP FOR PREPARATION OF  
BANANA POWDER**

**ABSTRACT**

**Keywords:** banana, foam mat drying, drying characteristics, quality evaluation, banana powder

India is the one of the largest producer of banana (*Musa paradisiac* L.) in the world. Banana is considered a common man's fruit and is rightly called the dessert fruit. Banana, being a tropical fruit, has a very short shelf life. Foam mat drying allows dehydration of heat sensitive, high sugar content and viscous food like banana which is difficult to dry. The foam mat dried products are cost effective and highly stable against deteriorative microbial, chemical and biochemical reactions. The banana powder can be used as food ingredient and natural flavouring agent in other products during off season. This reduces the glut in the market and farmers fetch remunerative price during harvesting season in the domestic market.

High yielding banana variety of *Grand Naine* which is most commonly grown in Saurashtra region was selected for the experiment. The ripened banana (stage-5) was procured from the local market of Junagadh, Gujarat. The experiment was carried out in the Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh during the year 2018-19. Fruits having  $15 \pm 1$  °Brix TSS were cut into small slices of 3-5 mm and dipped in 1% (w/w) solution of sodium meta bisulphite for 2 min and then rinsed in water for 30 s. Blending and whipping of pulp was carried out with a portable hand blender for proper mixing of air with the pulp. The effect of three foaming parameters viz., foaming agent (2.5, 4.53, 7.5, 10.47 and 12.5%), foaming stabilizer (0.1, 0.18, 0.3, 0.42 and 0.5%) and whipping time (5, 9, 15, 21 and 25 min) were optimized on foam expansion, foam stability and foam density of banana pulp using response surface methodology. Whey protein isolate was used as foaming agent and methyl cellulose was used as foaming stabilizer.

The optimum treatment conditions were found to be 5.35% foaming agent, 0.45% foaming stabilizer and 9.43 min whipping time with foam expansion of 138.95%, foam stability of 96.33% and foam density of 0.43 g/cc. The performance of this model was also verified by conducting an experiment at the optimized condition. It could reveal that the experimental value was very close to the predicted value that confirmed the validation of derived model.

Optimized parameters for foaming properties of banana pulp were selected for further drying of foamed banana. Drying of foamed banana pulp was carried out at four

levels of drying temperature (55, 60, 65 and 70 °C) and three levels of foam thickness (2, 4 and 6 mm) in a tray dryer. After drying, dried sample was scrapped, grinded and sieved through mesh no. 35 sieve. Drying characteristics *viz.*, drying time, drying rate and moisture ratio of foam mat drying of banana pulp were evaluated.

Maximum drying time (300 min) was observed at 55 °C drying temperature and 6 mm foam thickness while minimum drying time (120 min) was observed at 70 °C drying temperature and 2 mm thickness. Drying time for drying temperature 60 °C and 2 mm foam thickness was recorded 180 min. Maximum drying rate (0.310 g water/g dry matter/min) was found for 70 °C for drying temperature for 2 mm foam thickness and minimum drying rate (0.113 g water/g dry matter/min) was recorded for 55 °C drying temperature for 6 mm foamed thickness of banana pulp. There was rapid decrease in moisture ratio with faster rate at initial stage of 50 to 70 min of drying in all cases, however in later stage of drying, the decrease in moisture ratio was at slower rate.

Quality parameters *viz.*, physical properties, biochemical properties, functional properties and sensory characteristics of banana powder were carried out after drying of banana foam. Maximum recovery (37.86%), total sugars (39.25%), non-reducing sugar (39.14%), ascorbic acid (0.89 mg/100 g), pH (4.53), water solubility index (66.10%), water absorption index (408.48%) and minimum reducing sugar (0.11%), titratable acidity (0.35%) of banana powder was found for treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) and it was found at par with treatment combination T<sub>2</sub>t<sub>1</sub> (60 °C and 2 mm) for most of the case.

Maximum sensory score (8.2) in term of appearance, texture, flavour, taste and overall acceptability of foam mat dried banana powder was observed in treatment combination T<sub>2</sub>t<sub>1</sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness.

Longer drying time (300 min), more moisture content (5.38) and low sensory score (7.6) was found for treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) while moderate drying time (150 min), physico-chemical properties and maximum sensory score (8.2) was found for treatment combination T<sub>2</sub>t<sub>1</sub> (60 °C and 2 mm).

From the above study, it could be concluded that treatment combination T<sub>2</sub>t<sub>1</sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness was found to be best among all the treatments considering overall quality and drying time for preparation of banana powder

**COLLEGE OF AGRICULTURAL ENGINEERING AND  
TECHNOLOGY  
JUNAGADH AGRICULTURAL UNIVERSITY  
JUNAGADH**

**CERTIFICATE – I**

This is to certify that the thesis/project work report entitled “**FOAM MAT DRYING OF BANANA PULP FOR PREPARATION OF BANANA POWDER**” submitted by **KHIRA SAMIR MULCHAND** (Reg. No. 2050217013) in partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in the subject of **PROCESSING AND FOOD ENGINEERING** to the Junagadh Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. He has successfully completed the comprehensive / preliminary examination held on **March 7, 2019** as required under the regulation for Post-graduate studies. He has submitted *Kachcha* bound thesis on **June 19, 2019**.

**Place:** Junagadh

**Date:** 19/06/2019

**(D. K. Antala)**

Major Guide and  
Assistant Professor,  
Dept. of Renewable Energy Engineering  
College of Agricultural Engg. & Tech.  
J.A.U., Junagadh.

**COLLEGE OF AGRICULTURAL ENGINEERING AND  
TECHNOLOGY  
JUNAGADH AGRICULTURAL UNIVERSITY  
JUNAGADH**

**CERTIFICATE-II**

Date: 07-08-2019

This is to certify that the thesis/project work report entitled “**FOAM MAT DRYING OF BANANA PULP FOR PREPARATION OF BANANA POWDER**” submitted by **KHIRA SAMIR MULCHAND** to Junagadh Agricultural University, Junagadh in partial fulfilment of the requirements for award of the degree of **MASTER OF TECHNOLOGY** in the subject of **PROCESSING AND FOOD ENGINEERING** after recommendation by the external examiners were defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory. We, therefore, forward with recommendation.

**(G. V. Marviya)**  
Minor Guide and  
Associate Research Scientist  
Main Oilseeds Research Station  
J.A.U., Junagadh

**(D. K. Antala)**  
Major Guide and  
Assistant Professor  
Dept. of Renewable Energy Engg.  
College of Agricultural Engg. & Tech.  
J. A. U., Junagadh

**(Navneet Kumar)**  
External Examiner and Associate Professor & Head  
College of Agricultural Engineering & Technology  
Anand Agricultural University, Godhra

**(M. N. Dabhi)**  
Research Engineer and Head  
Dept. of Processing and Food Engg.  
College of Agricultural Engg. & Tech.  
J. A. U., Junagadh

**(N. K. Gontia)**  
Principal and Dean  
College of Agricultural Engg. & Tech.  
J. A. U., Junagadh

**Approved By**

**(V. P. Chovatia)**  
Director of Research and Dean, P. G. Studies  
Junagadh Agricultural University  
Junagadh

## ACKNOWLEDGEMENT

*I have unique privilege and pleasure to express my deep sense of gratitude and sincere thanks to my affectionate teacher and honorable Major Advisor, **Dr. D. K. Antala**, Assistant Professor, Renewable Energy Engineering Department, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh for his keen and abiding interest, illuminating guidance, constant encouragement and constructive criticisms, sympathetic attitudes, amiable behavior and keen interest throughout the course of studies, research work and preparation of manuscript.*

*I am obliged to the Co-guide of advisory committee **Dr. G. V. Marviya**, Associate Research Scientist, Main Oilseeds Research Station, JAU, Junagadh and member of advisory committee **Dr. N. K. Dhamsaniya**, Associate Professor, **Dr. S. P. Cholera**, Assistant Professor and **Dr. P. R. Davara**, Assistant Research Engineer, Processing and Food Engineering Department, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh for their valuable & timely guidance & suggestions during the course of studies and keenly reviewing the manuscript of the thesis.*

*I acknowledge with thanks to **Dr. A. R. Pathak**, Honorable Vice-chancellor, Junagadh Agricultural University, Junagadh and **Dr. V. P. Chovatiya**, Director of Research & Dean P.G. Studies, Junagadh Agricultural University, Junagadh for providing necessary facilities for conducting the research work.*

*I also express my sincere thanks and respect to **Dr. N. K. Gontia**, Principal and Dean, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh and **Dr. P. M. Chauhan**, Professor and Head, Renewable Energy Engineering Department, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.*

*I also express my sincere thanks to **Dr. B. A. Golakiya**, Professor and Head, Department of Biochemistry, College of Agriculture, Junagadh for their constructive suggestions. I am also thankful to **Dr. U. K. Kandoliya**, Assistant Professor, **Shri. Vijaybhai Bajaniya**, Laboratory Technician and **Dr. Neha Bodar**, Senior Research Fellow, **Nitaben Dave** and **Varshaben Bajaniya**, Department of Biochemistry, College*

*of Agriculture, Junagadh Agricultural University, Junagadh for providing necessary facilities and for their valuable & timely guidance.*

*I am sincerely thankful to **Er. Bhargav Khodifad**, Ph.D Research Scholar, Department of Processing and Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh for providing guidance and necessary help during period of my study and research work.*

*I wish to express my deepest gratitude to all the staff members of the Department of Processing & Food Engineering, College of Agricultural Engineering and Technology, Junagadh and Department of Biochemistry, College of Agriculture, Junagadh for their continuous help and constructive suggestions during the course of the study.*

*My pen would cease to write forever if I forget to put on paper my dearest friends Er. Kashyap Thakkar, Er. Ashish Bheda, Er. Mohit Muliya, Er. Nimisha Thumar, Er. Zigma Sahoo, Er. Parth Saparia, Er. Viraj Naliyapara, Ar. Rushang Kandoliya, Chandkantbhai Sachaniya, Kishorbhai Posiya for their encouragement, moral support, unconditional love, active help rendered from the time I met them till forever and for believing in me when I ceased to believe in myself and their excellent company throughout my post graduate curriculum.*

*Diction is not enough to express my gratitude to my beloved family whose selfless love, filial affection, constant encouragement, obstinate sacrifices, sincere prayers, expectations and blessings have always been vital source of inspiration in my life. One last word; since it is practically impossible to list all the names who contributed contributions to my work, it seems proper to issue a blanket of thanks for those who helped me directly or indirectly during the course of study.*

*Finally, I thank God for bestowing me with divine spirit, essential strength and necessary support to find my way towards a glorious career amidst several hurdles and struggles.*

*...any omission in this small manuscript does not mean lack of gratitude.*

**Place:** Junagadh  
**Date:** 08/08/2019

**(Khira Samir Mulchand)**

# CONTENTS

<b>CHAPTER NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
<b>I</b>	<b>INTRODUCTION</b>	<b>1-5</b>
<b>II</b>	<b>REVIEW OF LITERATURE</b>	<b>6-31</b>
	2.1 Nutritional composition of ripe banana	6
	2.2 Post harvest losses of fruits and vegetables	7
	2.3 Drying of fruits and vegetables	9
	2.3.1 Foam mat drying of fruits and vegetables	9
	2.3.1.1 Foam mat drying of banana	9
	2.3.1.2 Foam mat drying of mango	11
	2.3.1.3 Foam mat drying of papaya	13
	2.3.1.4 Foam mat drying of tomato	15
	2.3.1.5 Foam mat drying of other fruits	16
	2.3.2 Different drying methods of fruits and vegetables	23
	2.4 Drying characteristics of fruits and vegetables	25
	2.5 Quality of fruit powder	28
<b>III</b>	<b>MATERIALS AND METHODS</b>	<b>32-54</b>
	3.1 Experimental details	32
	3.1.1 Selection of ripe banana	32
	3.1.2 Cutting	33
	3.1.3 Pre-treatment	33
	3.1.4 Foaming of ripe banana pulp	36
	3.2 Experiment No. 1: Foaming process	37

## CONTENTS

<b>CHAPTER NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
	3.2.1 Experimental design	37
	3.2.1.1 Statistical analysis	40
	3.2.1.2 Optimization and validation of model	41
	3.2.2 Dependent parameters for foamed pulp	41
	3.2.2.1 Foaming properties	41
	3.2.2.1.1 Foam expansion	41
	3.2.2.1.2 Foam stability	41
	3.2.2.1.3 Foam density	42
3.3	Experiment No. 2: Foam mat drying	42
	3.3.1 Treatment details	43
	3.3.2 Experimental details	44
	3.3.2.1 Tray drying	44
	3.3.2.2 Grinding of dried product	46
3.4	Drying characteristics	46
	3.4.1 Drying time (min)	46
	3.4.2 Drying rate (g water/g dry matter-min)	47
	3.4.3 Moisture ratio	47
3.5	Quality evaluation of banana powder by foam mat drying	47
	3.5.1 Physical properties	47
	3.5.1.1 Recovery (%)	47
	3.5.1.2 Bulk density (g/cc)	48

## CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
	3.5.2 Biochemical properties	48
	3.5.2.1 Moisture content (%)	48
	3.5.2.2 Total sugars (%)	48
	3.5.2.3 Reducing sugar (%)	49
	3.5.2.4 Non reducing sugar (%)	49
	3.5.2.5 Titratable acidity (%)	50
	3.5.2.6 Ascorbic acid (mg/100 g)	50
	3.5.2.7 pH	50
	3.5.3 Functional properties	53
	3.5.3.1 Water solubility index (WSI) (%)	53
	3.5.3.2 Water absorption index (WAI) (%)	53
	3.6 Sensory evaluation	53
	3.7 Statistical analysis	54
<b>IV</b>	<b>RESULTS AND DISCUSSION</b>	<b>55-88</b>
	4.1 Biochemical properties of fresh banana pulp	55
	4.2 Response surface analysis	56
	4.3 Different treatments on the foam properties of banana pulp	56
	4.3.1 Effect of foaming agent, foaming stabilizer and whipping time on foam expansion of banana pulp	56
	4.3.1.1 Effect of foaming agent and foaming stabilizer on foam expansion	58
	4.3.1.2 Effect of foaming agent and whipping time on foam expansion	59

## CONTENTS

<b>CHAPTER NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
	4.3.1.3 Effect of foaming stabilizer and whipping time on foam expansion	59
	4.3.2 Effect of foaming agent, foaming stabilizer and whipping time on foam stability of banana pulp	64
	4.3.2.1 Effect of foaming agent and foaming stabilizer on foam stability	64
	4.3.2.2 Effect of foaming agent and whipping time on foam stability	65
	4.3.2.3 Effect of foaming stabilizer and whipping time on foam stability	65
	4.3.3 Effect of foaming agent, foaming stabilizer and whipping time on foam density of banana pulp	69
	4.3.3.1 Effect of foaming agent and foaming stabilizer on foam density	70
	4.3.3.2 Effect of foaming agent and whipping time on foam density	70
	4.3.3.3 Effect of foaming stabilizer and whipping time on foam density	74
4.4	Optimization and validation of process variables	75
	4.4.1 Improved method suggested for foaming properties	76
4.5	Drying of banana powder	77
	4.5.1 Drying characteristics of banana powder	77
	4.5.1.1 Drying time	77
	4.5.1.2 Drying rate	78
	4.5.1.3 Moisture ratio	80
4.6	Quality of banana powder by foam mat drying	81

## CONTENTS

CHAPTER NO.	TITLE	PAGE NO.
4.6.1	Physical properties	81
4.6.1.1	Recovery (%)	81
4.6.1.2	Bulk density (g/cc)	83
4.6.2	Biochemical properties	84
4.6.2.1	Moisture content (%)	84
4.6.2.2	Total sugars (%)	86
4.6.2.3	Reducing sugar (%)	87
4.6.2.4	Non reducing sugar (%)	88
4.6.2.5	Titrateable acidity (%)	89
4.6.2.6	Ascorbic acid (mg/100 g)	90
4.6.2.7	pH	91
4.6.3	Functional properties	92
4.6.3.1	Water solubility index (%)	92
4.6.3.2	Water absorption index (%)	94
4.6.4	Sensory evaluation	95
4.6.4.1	Appearance	95
4.6.4.2	Texture	97
4.6.4.3	Flavour	98
4.6.4.4	Taste	98
4.6.4.5	Overall acceptability	99
4.6.5	Improved method suggested for drying of foamed banana	100

## CONTENTS

<b>CHAPTER NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
<b>V</b>	<b>SUMMARY AND CONCLUSIONS</b>	<b>101-107</b>
	5.1 Experiment No. 1: Foaming properties of banana pulp	102
	5.2 Experiment No. 2: Drying of foamed banana	104
	<b>BIBLIOGRAPHY</b>	<b>i-xiii</b>
	<b>APPENDIX</b>	<b>A-N</b>

## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
2.1	Nutritional composition of ripened banana pulp	6
3.1	Independent parameters and their coded and actual values employed for foaming properties of banana pulp	38
3.2	Matrix of experimental central composite rotatable design for foaming banana pulp	39
3.3	Independent variables	43
3.4	Treatment combinations for foam-mat drying of banana pulp	43
3.5	Dependent variables	43
4.1	Composition of fresh banana used for research work	56
4.2	Experimental data of foam properties of banana pulp	57
4.3	Analysis of variance (ANOVA) table and regression coefficients for response surface quadratic model of different foaming properties of banana pulp	58
4.4	Constraints, criteria and output for numerical optimization of foaming properties of banana pulp	75
4.5	Effect of drying conditions on physical properties of banana powder	82
4.6	Effect of drying conditions on biochemical properties of banana powder	85
4.7	Effect of drying conditions on functional properties of banana powder	94

## LIST OF FIGURES

---

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
3.1	Experimental process flow chart for preparation of ripe banana powder by foam mat drying	35
3.2	Foaming unit	36
4.1	Response surface plot for foam expansion as a function of foaming agent and foaming stabilizer	61
4.2	Contour plot for foam expansion as a function of foaming agent and foaming stabilizer	61
4.3	Response surface plot for foam expansion as a function of foaming agent and whipping time	62
4.4	Contour plot for foam expansion as a function of foaming agent and whipping time	62
4.5	Response surface plot for foam expansion as a function of foaming stabilizer and whipping time	63
4.6	Contour plot for foam expansion as a function of foaming stabilizer and whipping time	63
4.7	Response surface plot for foam stability as a function of foaming agent and foaming stabilizer	66
4.8	Contour plot for foam stability as a function of foaming agent and foaming stabilizer	66
4.9	Response surface plot for foam stability as a function of foaming agent and whipping time	67
4.10	Contour plot for foam stability as a function of foaming agent and whipping time	67
4.11	Response surface plot for foam stability as a function of foaming stabilizer and whipping time	68
4.12	Contour plot for foam stability as a function of foaming stabilizer and whipping time	68

---

## LIST OF FIGURES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
4.13	Response surface plot for foam density as a function of foaming agent and foaming stabilizer	71
4.14	Contour plot for foam density as a function of foaming agent and foaming stabilizer	71
4.15	Response surface plot for foam density as a function of foaming agent and whipping time	72
4.16	Contour plot for foam density as a function of foaming agent and whipping time	72
4.17	Response surface plot for foam density as a function of foaming stabilizer and whipping time	73
4.18	Contour plot for foam density as a function of foaming stabilizer and whipping time	73
4.19	Process flow chart recommended for foaming properties of banana pulp	76
4.20	Effect of drying conditions on drying time of foamed banana	78
4.21	Effect of drying conditions on drying rate for 2 mm foamed banana	78
4.22	Effect of drying conditions on drying rate for 4 mm foamed banana	79
4.23	Effect of drying conditions on drying rate for 6 mm foamed banana	79
4.24	Effect of drying conditions on moisture ratio for 2 mm foamed banana	80
4.25	Effect of drying conditions on moisture ratio for 4 mm foamed banana	81
4.26	Effect of drying conditions on moisture ratio for 6 mm foamed banana	81
4.27	Effect of drying conditions on recovery of banana powder	83
4.28	Effect of drying conditions on bulk density of banana powder	83

## LIST OF FIGURES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE NO.</b>
4.29	Effect of drying conditions on moisture content of banana powder	86
4.30	Effect of drying conditions on total sugars of banana powder	87
4.31	Effect of drying conditions on reducing sugar of banana powder	88
4.32	Effect of drying conditions on non reducing sugar of banana powder	89
4.33	Effect of drying conditions on titratable acidity of banana powder	90
4.34	Effect of drying conditions on ascorbic acid of banana powder	91
4.35	Effect of drying conditions on pH of banana powder	92
4.36	Effect of drying conditions on water solubility index of banana powder	93
4.37	Effect of drying conditions on water absorption index of banana powder	95
4.38	Effect of drying conditions on appearance of banana powder	97
4.39	Effect of drying conditions on texture of banana powder	97
4.40	Effect of drying conditions on flavour of banana powder	98
4.41	Effect of drying conditions on taste of banana powder	99
4.42	Effect of drying conditions on overall acceptability of banana powder	99
4.43	Process flow chart recommended for drying conditions of banana foam	100

## LIST OF PLATES

PLATE NO.	TITLE	PAGE NO.
3.1	Ripe banana	33
3.2	Banana slices immersed in 1% sodium meta bisulphite	33
3.3	Banana slices rinsed in water	34
3.4	Chemicals used to prepare banana pulp foam	34
3.5	Air pump	37
3.6	Hand blender	37
3.7	Determination of foam stability of foamed banana pulp	42
3.8	Tray dryer	45
3.9	Tray drying of foamed banana pulp	45
3.10	Grinding of foamed dried banana pulp	46
3.11	Sieving of banana powder	46
3.12	Determination of moisture content from banana powder	51
3.13	Determination of total sugars of banana powder	51
3.14	Determination of reducing sugar of banana powder	51
3.15	Determination of titratable acidity of banana powder	52
3.16	Determination of ascorbic acid of banana powder	52
3.17	Determination of pH of banana powder	52
3.18	Sensory evaluation of banana powder	54
4.1	Appearance of banana powder at different drying conditions	96

## LIST OF APPENDIX

APPENDIX NO.	TITLE	PAGE NO.
A	District wise production of banana fruit in Gujarat state during the year 2015-16	A
B	ANOVA for model statistics for the dependent variables of foaming properties	B
C	Sensory evaluations for foam mat dried banana powder	C
D	Drying time of banana foam at different drying conditions	D
E1	Drying rate of banana foam at 2 mm foam thickness and different drying temperature	E
E2	Drying rate of banana foam at 4 mm foam thickness and different drying temperature	F
E3	Drying rate of banana foam at 6 mm foam thickness and different drying temperature	G
F1	Moisture ratio of banana foam at 2 mm foam thickness and different drying temperature	H
F2	Moisture ratio of banana foam at 4 mm foam thickness and different drying temperature	I
F3	Moisture ratio of banana foam at 6 mm foam thickness and different drying temperature	J
G1	Mean data of physical properties of banana powder	K
G2	Mean data of biochemical properties of banana powder	L
G3	Mean data of functional properties of banana powder	M
H	Details of the mean value of sensor evaluation of different foam mat dried banana powder	N
I	Recommended flow chart for preparation of banana powder by foam mat drying	O

---

## LIST OF ABBREVIATIONS AND NOMENCLATURE

---

3D	:	Three dimensional
Adj-R <sup>2</sup>	:	Adjusted regression coefficient
Anon.	:	Anonymous
ANOVA	:	Analysis of variance
AOAC	:	Association of Official Analytical Chemists
B. Tech	:	Bachelor of Technology
CCRD	:	Central Composite Rotatable Design
CD	:	Critical difference
cm	:	Centimetre
cm <sup>3</sup>	:	Centimetre cube
CRD	:	Completely Randomized Design
CV	:	Coefficient of variance
DNPH	:	2, 4 - Dinitrophenylhydrazine
<i>et al.</i>	:	et alia (and other)
<i>etc.</i>	:	Etcetera (and the rest)
Fig.	:	Figure
g	:	Gram
g/100 g	:	Gram per hundred gram
g/cc or g/cm <sup>3</sup>	:	Gram per cubic centimetre
GC-MS	:	Gas chromatography mass spectrometry
GDP	:	Gross Domestic Product
g/kg	:	Gram per kilogram
g/ml	:	Gram per millilitre
GMS	:	Glycerol mono stearate
h	:	Hour
H <sub>2</sub> SO <sub>4</sub>	:	Hydrogen disulphide
HB	:	Hand blender
<i>i.e.</i>	:	That is
kcal	:	Kilocalorie
kg/m <sup>2</sup> h	:	Kilogram per meter square hour
kJ/mol	:	Kilo joule per mole
Ltd.	:	Limited

m <sup>2</sup>	:	Meter square
m <sup>2</sup> /s	:	Meter square per second
m <sup>3</sup> /min	:	Meter cube per minute
MC	:	Methyl cellulose
mg	:	Milligram
mg/100 g	:	Milligram per hundred gram
mg/g	:	Milligram per gram
min	:	Minute
ml	:	Millilitre
mm	:	Millimetre
MR	:	Moisture ratio
m/s	:	Meter per second
MT	:	Million tonne
M. Tech	:	Master of Technology
Na <sub>2</sub> S <sub>2</sub> O <sub>5</sub>	:	Sodium meta bisulphite
nm	:	Nanometer
No.	:	Number
NS	:	Non significant
OD	:	Osmotic distillation
p	:	Probability
pH	:	Hydrogen ion concentration
pp	:	Pages
Pred-R <sup>2</sup>	:	Predicted regression coefficient
Pvt.	:	Private
R <sup>2</sup>	:	Regression co-efficient
rpm	:	Revolution per minute
RSM	:	Response Surface Methodology
s	:	Second
S.Em	:	Standard error of mean
SPI	:	Soy protein isolate
SPME	:	Solid phase micro extraction
TSS	:	Total soluble solids
USA	:	United States of America

<i>viz.</i>	:	Namely
W	:	Watt
WAI	:	Water absorption index
wb	:	Wet basis
WPI	:	Whey protein isolate
WSI	:	Water solubility index
WT	:	Whipping time
w/w	:	Weight per weight

---

## LIST OF SYMBOLS

---

₹	Rupees
%	Per cent
/	Per
>	Greater than
<	Smaller than
+	Plus
-	Minus
°C	Degree Celcius
°Brix	Degree Brix
±	Plus or minus
<b>θ</b>	Theta
*	Interaction
≤	Less than or equal to
β	Beta
μ	Micro
x	Multiplication
μg	Microgram
μm	Micrometer
:	Colon

# CHAPTER I

## INTRODUCTION

---

Banana (*Musa paradisiac* L.) is one of the most important crops of the tropical plants. It belongs to the family *Musaceae* and the genus *Musa sapientum*. It originated from the tropical region of Southeast Asia, the Malay Archipelago and Australia and is cultivated throughout the tropics today (Oladiji *et al.*, 2010). In India, the area under banana cultivation was 8.84 lakh hectares and annual production of 308.08 lakh MT during 2017-18 (Anon., 2018a). The most important banana growing states in India are Gujarat, Tamil Nadu, Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Bihar, Uttar Pradesh, West Bengal and Assam. As far as area under cultivation and production of banana are concerned, Gujarat occupies first position in the country. Production of banana in Gujarat was about 44.72 lakh MT over an area of 0.68 lakh hectares during the year 2017-18 (Anon., 2018a). In Gujarat, banana is mostly grown in the districts of Bharuch, Anand, Narmada, Surat, Vadodara, Kheda, Junagadh, Tapi, Valsad, *etc.* District wise production of banana fruit in Gujarat is presented in Appendix – A (Anon., 2018b). The Dwarf Cavendish, Grand Naine, Lacatan, Harichhal (Lokhandi) and Gandevi Selection are the major cultivars grown in Gujarat. The Grand Naine has become one of the most popular varieties for commercial plantations in Gujarat. Its characteristic medium height and large fruit yields make it ideal for commercial agriculture. It is a highly successful commercial cultivar grown extensively for table and processing purpose (Tak *et al.*, 2015).

Our country is exporting fresh banana fruits to United Arab Emirates, Saudi Arabia, Iran, Kuwait, Bahrain, Qatar, Oman, Nepal, Maldives and United states. The export performance of fresh banana has been stunning from 2014-15 to 2017-18. The total export of banana in the year 2014-15 were 63274.39 MT of ₹ 24,194.77 lakh which raised in 2017-18 of about 101314.37 MT of ₹ 34877.39 lakh (Anon., 2018a).

Banana is considered a common man's fruit and is rightly called the 'dessert fruit for million' or 'champion fruit' or 'poor man's apple'. Banana is a rich source of carbohydrate, potassium, phosphorus, calcium, magnesium and vitamins like vitamin B. Fruit is free from fat with high calorific value (Tapas *et al.*, 2016). It also contains iron, niacin and antioxidants. Banana is valued for its characteristics flavour, fleshy

texture as well as medicinal and nutritional qualities. It helps in reducing risk of heart diseases when used regularly consumed and is recommended for patients suffering from high blood pressure, arthritis, ulcer, gastroenteritis and kidney disorders (Palmei *et al.*, 2017). Other advantages of banana consumption include; vision improvement, stronger bones and even weight loss. Bananas are also considered by some to be starchy foods, which can be used to give energy.

Banana being a tropical fruit is perishable and undergoes qualitative and quantitative losses between harvest and consumption. After ripening, banana fruit is highly susceptible to deterioration. The fully mature fruits of cavendish banana have a shelf life of 6-9 days depending upon the ambient temperature (Narayana, 2015). During the market glut, the prices crash down and the farmers suffer heavy losses due to distress sale. Due to poor transportation and storage facilities, a sizeable quantity of this fruit is wasted due to its perishable nature. Its considerable amount is wasted due to lack of efficient processing techniques that are unique to ripe banana. The post harvest losses of banana in India are estimated to be more than 25% (Srivastav and Kumar, 2002).

Harvested banana fruit is generally consumed as a fresh fruit. Very few processed products are available in the market, primarily due to difficulty in retaining the characteristics colour, flavour and texture during the processing of ripe banana. Though India is the largest producer of banana, but the processing of banana is less than 2%. Banana is available throughout the year in tropical countries, like India, so there is a vast need to utilize for proper processing techniques (Srivastav and Kumar, 2002). Some of the processing of banana into several value added products like fig (dehydrated banana), jam, jelly, fruit bar, wine, vinegar, puree, baby food, pickle and can be used in formulation of health food, baby food, tonics, instant banana juice powder, breakfast cereals and flavourings, which can fetch profit both in domestic as well as in foreign market (Mishra *et al.*, 2016).

Changing consumer habits have helped to spur growth of value added food products. The increasing demand for high quality processed food products for internal consumption and for export has boosted the food industry. To meet the increasing expectations of consumers, food must be safe, consistently good quality and sensory

attributes, healthy and inexpensive and should have a good shelf life (Kilcast and Subramaniam, 2000).

Drying is one of the most important and widely practiced methods for perishable fruits into value added products that retain its colour, flavour and nutrients with longer shelf life. The drying extends shelf life and reduces water activity of food products. It prevents microbial spoilage and undesirable enzymatic reactions. It reduces bulk and volume of product and minimizes packaging, storage and transportation costs (Fumagalli and Silveira, 2005; Falade and Solademi, 2010). The fluid materials may be dried by being physically supported on a tray, drum or moving belt; by being wiped on a heated surface; or dispersed in an air stream as in spray drying (Hertzendorf *et al.* 1970). The problem associated in belt/tray drying method is colour change, protein denaturation and poor rehydration quality (Sangamithra *et al.*, 2014). Fruit powder is highly hygroscopic in nature and undergoes colour changes during storage besides experiences other changes in quality if proper drying is not adopted. Freeze drying of liquid product yields excellent product quality with good rehydration and colour; however, the higher operation and set up costs restricted the use of freeze drying for only high quality products.

Foam mat drying is considered cheaper than vacuum, spray and freeze drying for the production of food powders (Kadam *et al.*, 2010a). The liquid is whipped to form stable foam and dehydrated by thermal means. The larger surface area of the foam accelerated the drying process for the rapid moisture removal from the high moisture feed (Sangamithra *et al.*, 2014). This process can be used for largescale production of fruit powders because of its suitability for all types of juices, rapid drying at lower temperature, retention of nutritional quality, easy reconstitution and cost effective for producing easily reconstitutable juice powders. A high quality food powder can be obtained by the proper selection of foaming method, foaming agents, foam stabilizers, time taken for foaming, suitable drying method and temperature. Fruit juice powder obtained through this process is one of the ways to add value to the product with much longer shelf life.

Banana powder is rich in nutrient and used as food ingredient and natural flavouring agent in other products during off season. Many processed products can be made from banana powder *i.e.* infant food, noodle, and energy drink. It can be used in

bakery and confectionery industries, in treatment of coeliac disease and in intestinal disorders. Banana powder is used in cake, bread, cookies, baby food, ice-cream, flavoured milk, shrikhand, chocolates *etc.* It is also used for disintegrating agents in pharmaceutical preparation (Sahoo *et al.*, 2014). Owing to the high health consciousness among consumers with increasing awareness regarding the health benefits of banana powder, it is expected that its market will grow at a rapid pace during the forecast period.

### **Practical utility of the research problem**

Banana, being perishable due to climacteric fruit, has a limited post-harvest shelf life. Transportation of fresh fruit to distant places is very difficult and costly. Preparation of good quality banana powder by drying is one of the ways to add value to the product with longer shelf life. The simplest and most economical method of dehydration of fruit is conventional tray drying. Major problems associated with air dehydration are the considerable shrinkage caused by cell collapse during the water loss, the poor rehydration characteristics of the dried product and the unfavourable changes in colour, texture, flavour and nutritive value caused by drying (Mazza, 1983). Due to the dense tissue structure, banana drying is one of the most critical steps as it consumes large amount of energy which leads to poor quality of the dried products. The most relevant method to overcome this problem is foam mat drying from fruit pulp to produce a free flowing and fine powder which gives a good reconstitutions characteristic (Palmei *et al.*, 2017). Foam mat drying is relatively simple and alternative method which facilitates the removal of water from fruit juice and vegetable puree. This method allows the dehydration of heat sensitive, high sugar content and viscous foods, which are difficult to dry and sticky under relatively mild conditions without change in quality (Sangamithra *et al.*, 2014). Foam mat drying which leads to increase of drying rate and significant reduction in drying time; improved the sensory, nutritional and functional properties of the product. The foam mat dried products are highly stable against deteriorative microbial, chemical and biochemical reactions (Rajkumar and Kailappan, 2006). Foam mat drying is an economical alternative to drum, spray and freeze drying for the production of food powders. Banana powder is highly hygroscopic in nature and undergoes quality changes if proper drying is not adopted. The banana

powder can be used as food ingredient and natural flavouring agent in other products during off season.

This study will explore the use of some foaming and stabilizing process with proper drying conditions to retain the quality of banana powder. Looking to the above facts, the present research work was undertaken with the following objectives.

**Objectives**

1. To optimize foaming and stabilizing process parameters for foam mat drying of ripe banana pulp
2. To study the drying characteristics of ripe banana pulp by foam mat drying
3. To evaluate the quality characteristics of foam mat dried banana powder

## CHAPTER II

### REVIEW OF LITERATURE

---

This chapter deals with the comprehensive review of foaming and drying of fruits and vegetables for the production of food powder by foam mat drying. The review of research work carried out by the investigators on different foaming properties, foam mat drying of different fruits and vegetables, drying characteristics and quality evaluation of different fruit powders in this direction have been reported here under.

#### 2.1 Nutritional composition of ripe banana

Aurore *et al.* (2008) determined the nutritional compositions of banana, *viz.*, energy, water, protein, total lipids, carbohydrate, sugars, dietary fibre, minerals, vitamins per 100 g fresh weight as shown in Table 2.1.

**Table 2.1 Nutritional composition of ripened banana pulp**

(Per 100 g edible portion, fresh weight)

Component (Unit)	Ripe Banana	Component (Unit)	Ripe Banana
Energy (kcal)	89.00	Potassium (mg)	385.00
Water (g)	74.00	Calcium (mg)	8.00
Carbohydrates (g)	21.80	Iron (mg)	0.42
Dietary fibre (g)	2.00	Magnesium (mg)	30.00
Protein (g)	1.10	Phosphorus (mg)	22.00
Total sugars (g)	17.19	Vitamin C (mg/100 g)	11.70
Sodium (mg)	1.00	Copper (mg)	0.11

(Source: Aurore *et al.* (2008))

Ripe banana has antioxidant properties and is rich in potassium (342.3 mg/100 g), carotenoids (>35 mg/100 g) and ascorbic acid (12.7 mg/100 g) (Englberger *et al.*, 2003; Wall, 2006). It is used in treating diarrhoea and in other therapeutic purposes

such as cardiovascular diseases (Clements *et al.*, 1980). It also has thaumatin like protein and lectins, which are responsible for the starch metabolism, senescence and defence mechanism. Eating ripe banana with these immunity defending proteins can boost immune response (Barre *et al.*, 2000; Peumans *et al.*, 2000; Rudiger and Gabius, 2001). Ripe banana is highly nutritive and usually consumed raw, throughout the world, for its easy digestibility, taste and aroma (Sharrock and Lustray, 2000).

Banana is highly nutritious and easily digestible than many other fruits. Digestion time of banana fruit is less (105 min) than apple (210 min). Ripe banana consists of 1.1% protein, 0.3% total lipid, 21.8% carbohydrate, 68.0%  $\beta$ -carotene and 11.7% vitamin C whereas unripe banana contains 1.4% protein, total lipid of 0.2%, carbohydrate of 28.7%, 31.0% vitamin C and 48.3%  $\beta$ -carotene. Bananas are easy to digest and, since they are similar in chemical composition to the mucus of the stomach lining, have a soothing effect in the treatment of gastric ulcers and diarrhoea (Anon., 2003).

## 2.2 Post harvest losses of fruits and vegetables

Ghazanfar *et al.* (2007) assessed post-harvest losses of banana during transport and storage. Results revealed that the total losses in banana transported from Nawabshah, Mirpur Khas and Hyderabad to Faisalabad market in the months of December, February and March amounted to 37, 39 and 43%, respectively.

Davara and Patel (2009) assessed post-harvest losses in banana grown in Gujarat. The effect of various ripening methods on post-harvest losses in five varieties *viz.* Robusta, Grand Naine, Sona, Mahalaxmi and Shreemanthi were determined. The study revealed that overall post-harvest loss in banana after harvesting till ripening was found to be 15.43%, which included losses at field level (0.77%), at trader's level comprising of transportation and handling losses (5.86%) as well as ripening losses (8.80%). Only negligible losses were observed during processing of banana. The highest loss (16.00%) was observed in the case of smoking and room temperature method of ripening, while the lowest (4.66%) was observed under ethephon and air cooled chamber method. Ethephon and ice treatment method resulted in ripening loss to the tune of 7.43%, but the method was most widely adopted in Gujarat owing to its convenience and better appearance of bananas after ripening.

Murthy *et al.* (2009) studied post-harvest losses in fruits, its implications on availability and economy. At the macro level, rough estimate indicates that India annually loses fruits worth about ₹13,569 crores (based on 30% loss). The reduction in post-harvest losses is a complementary means for increasing the production, *i.e.*, the cost of preventing losses is less than producing the same additional quantity of fruits. About 1.2% of agriculture GDP from 33.85 lakh tonnes in mango, 35.26 lakh tonnes in banana and 2.12 lakh tonnes in grape are discarded every year in India as post-harvest losses (₹ 7,618.77 crores).

Woldu *et al.* (2015) investigated to assess of banana post-harvest handling practices and losses in Ethiopia. The farm level post-harvest handling and loss data were collected from three major banana producing zones, 5 districts, 10 farmer villages and 14 large-scale commercial farms. As such a total of 150 small-scale and 14 large-scale growers, 59 wholesalers/ripeners, 53 retailers and 53 consumers were interviewed using structured questionnaires. Secondary data was also collected from written documents and focus group discussions (stakeholders) across the survey areas. Results of the study indicated that the aggregate post-harvest loss of banana was estimated to be 45.78%, of which about 15.68% was incurred at farm, 22.05% at wholesale and 8.05% at retailer or purchase to end user sale levels. Of the causes of postharvest loss accounted during banana transport from the farm gate, impact and finger breakage damages purely accounted to 20% while the remaining 80% also included physiological and other mechanical damages.

Kuyu and Tola (2018) surveyed on assessment of banana fruit handling practices in Jimma town market, southwest Ethiopia. The survey result revealed that losses of banana fruits due to spoilage and physical injury were common problems for all fruit vendors. A total of 48 fruits were purposively selected from open market, wholesalers and retailers and fruit damage, disease incidence, disease severity and identification of diseases causing fungal pathogen were conducted under laboratory. The highest fruit damage (56.2%) was recorded in sample taken from retailers' shop, and the associated disease incidence and severity were 54.2% and 34%, respectively.

## 2.3 Drying of fruits and vegetables

### 2.3.1 Foam mat drying of fruits and vegetables

#### 2.3.1.1 Foam mat drying of banana

Sankat and Castaigne (2004) studied foaming and drying behaviour of ripe banana. The foaming of ripe bananas and the forced air drying characteristics of banana foam mats were developed. Fresh banana puree with a density of 0.93 g/ml was foamed to a density of 0.50 g/ml after 12 min of whipping by the addition of 10 g/100 g soy protein as a foam inducer. Glyceryl mono stearate (GMS) did not induce foams while commercially available food ingredients such as cream whip and gelatine induced foams but such foams were not stable in subsequent drying. Banana foam mats were dried at temperatures from 45 °C to 90 °C in a forced air, cabinet dryer, to a hard, porous and brittle solid which was amenable to grinding so as to produce a dehydrated banana powder. The drying time was directly related to the thickness of the foam mats. Increasing the air velocity from 0.62 to 1.03 m/s did not profoundly influence the drying rate.

Thuwapanichayanan *et al.* (2008) developed the combination of foaming and drying as an alternative method to produce crisp banana chips. They studied the influences of whipping time and egg albumin concentration on the foam density. Banana puree with egg albumin, which was used as the foaming agent, was foamed to the densities of 0.3, 0.5 and 0.7 g/cm<sup>3</sup>. Foaming agent which was added to the banana puree were 2, 5 and 10% (wb). Banana foam mats with 5 mm thickness were then dried at 60, 70 and 80 °C and superficial air velocity of 0.5 m/s. The experimental results showed that the extensive porous structure of foams with lower densities resulted in higher drying rates, moisture diffusivities and shrinkage. Dried banana foams with lower foam densities also had lower hardness and crispness values. The drying temperature and the egg albumin concentration did not influence the textural properties of the final products, however to produce quality banana chips, the initial foam density of 0.5 g/cm<sup>3</sup> and drying temperature of 80 °C were recommended.

Falade and Okocha (2010) investigated foaming, reconstitution and sensory attributes of foam mat dried plantain and cooking banana. Plantain and banana pastes mixed with different concentrations (0.005, 0.01, 0.015 and 0.02%) of glyceryl mono stearate were whipped and the resulting foams were air dried at 60, 70 and 80 °C.

Higher glyceryl mono stearate concentration and longer whipping time resulted in lower foam densities. Generally, cooking banana foams showed lower foam density compared to plantain foam. Lower drying temperatures and concentration of glyceryl mono stearate resulted in longer drying time. The quality attributes such as pH (4.41–4.80), titratable acidity (0.06–0.08) and water absorption capacity (56.75-64.02%) of the reconstituted pastes varied with commodity, drying temperature and glyceryl mono stearate concentration. Fresh and reconstituted pastes showed comparable physical and chemical attributes, while the taste and sensory attributes of fresh plantain and banana pastes were significantly better than those of reconstituted pastes.

Thuwapanichayanan *et al.* (2012) examined the effects of foaming agents and foam density on drying characteristics and textural property of banana foams. The influences of the foam density and the types of foaming agents on the moisture diffusivity as well as the quality in terms of microstructure, texture and volatile losses of banana foams were therefore investigated. Three foaming agents, *i.e.*, fresh egg albumin, soy protein isolate and whey protein concentrate were used. Foaming agent was added to the banana puree at 2, 5 and 10% (wb). Drying thickness was taken about 5 mm on a mesh tray. Banana foams were most stable during whipping. The experimental results showed that whey protein concentrate banana foam could retain more open structure during drying. This morphology provided less sinkage and led to higher values of the effective diffusivity as compared with that of soy protein isolate and egg albumin banana foams. In terms of the textural properties, whey protein concentrate and egg albumin banana foams were spongy and less crisp than soy protein isolate banana foam.

Sharada (2013) determined the effect of various operating parameters and foaming agents for drying of guava, tomato and banana with some of the commonly used foaming agents like egg albumin and soya protein. The creation of foam resulted increased surface area for drying with the increase in surface area exposed for drying, increased the rate of drying. The low density foams dried at relatively low temperature in an ordinary forced circulation drier. The drying studies were carried out in a tray drier. The drying curves are drawn with different operating parameters and foaming agents. Falling rate was observed for the foam at different timings. Drying rates are

compared and the drying time is evaluated by drying the foam at 55 °C to 80 °C. Egg albumin was found to be the best. The foam mat dried powders were good quality and were highly reconstituted in water.

Palmei *et al.* (2018) optimized the ingredients for the production of foamed banana powder using response surface methodology. The independent variables selected were carboxy methyl cellulose (0.5, 1.5 and 2.5%) as foam stabilizer, egg albumin (3, 7 and 11%) as foaming agent, temperature (60, 70 and 80 °C) and whipping time (6, 12 and 18 min). The method of drying used for this study is foam mat drying. The dependent variable measured were foam density, foam expansion and foam stability. Foam density and foam expansion affected the foam mat drying of banana powder. Optimization of ingredients obtained by optimization of responses were carboxy methyl cellulose ( $X_1$ ) as 2.5%, egg albumin ( $X_2$ ) as 10.2%, temperature ( $X_3$ ) as 80 °C and whipping time ( $X_4$ ) as 18 min.

### 2.3.1.2 Foam mat drying of mango

Rajkumar and Kailappan (2006) optimized the process parameters for foam mat drying of *Totapuri* mango pulp. Mango pulp was foamed by adding egg albumin (5, 10 and 15%) and stabilized with methyl cellulose (0.5%). The foamed pulp was dried at four drying temperatures *viz.* 60, 65, 70 and 75 °C in a batch type cabinet dryer by maintaining three foam thicknesses *viz.* 1, 2 and 3 mm. From the drying study, it was observed that, the drying time required for foamed mango pulp was lower than non foamed pulp at all selected temperatures. Also, these biochemical changes were significantly higher in 2 and 3 mm than in 1 mm thick foam dried samples. The study also revealed that there was no significant change in other biochemical constituents such as pH, acidity and total sugar due to the increase in drying temperature and foam thicknesses. It was concluded that the mango pulp treated with egg albumin (10%) with methyl cellulose (0.5%) and dried at 60 °C with one mm foam thickness retained significantly higher quality than that of other foaming and drying treatments.

Rajkumar *et al.* (2007a) studied drying characteristics of foamed *Alphonso* mango pulp in a continuous type foam mat dryer. *Alphonso* mango pulp was formed by using egg albumin (5%, 10% and 15%) with methyl cellulose (0.5%) by maintaining three foam thicknesses such as 1, 2 and 3 mm on the Teflon mat. Then the foamed pulps

were dried at four drying air inlet temperatures of 60 °C, 65 °C, 70 °C and 75 °C in a batch type thin layer cabinet dryer. It was observed that the foamed mango pulp using egg albumin (10%) as foaming agent with methyl cellulose (0.5%) as stabilizing agent, dried at 60 °C with 1 mm foam thickness was found to be the best. The drying study showed that the time required to dry the fresh (non foamed) and foamed mango pulps were 75 and 35 min, respectively. It was observed that the changes in quality were comparatively lower in foam dried flakes than in non foam dried flakes using continuous type foam mat dryer.

Rajkumar *et al.* (2007b) carried out an experiment on foam mat drying of *Alphonso* mango pulp. The foam mat drying of *Alphonso* mango pulp using various food foaming agents, namely soy protein (0.25, 0.5, 1.0 and 1.5%) with methyl cellulose (0.5%), glycerol mono stearate (0.5, 1.0, 2.0 and 3.0%) and egg albumin (2.5, 5.0, 10 and 15%) with methyl cellulose (0.5%). Drying was carried out in a batch type thin layer at four drying temperatures (60 °C, 65 °C, 70 °C and 75 °C) on 1, 2 or 3 mm thickness foamed samples. The optimum concentrations of each foaming agent were determined to be 1% soy protein, 2% glycerol mono stearate and 10% egg albumin with 25 min whipping time. Biochemical analysis showed that the foam mat dried powder at 60 °C retained a significantly higher content of biochemical compounds than at higher temperatures. The treatment of mango pulp with 10% egg albumin and 0.5% methyl cellulose and drying at 60 °C of 1 mm foam thickness retained the highest nutritional quality characteristics than the other treatments.

Rajkumar *et al.* (2007c) studied thin layer drying of foamed mango pulp. The mango pulp (*Totapuri*) was foamed by the addition of egg albumin at different concentrations such as 5, 10 and 15% and the foam was stabilized with the addition of methyl cellulose at 0.5% concentration. The foamed pulp with three foam thicknesses *viz.*, 1, 2 and 3 mm was dried at three drying temperatures *viz.*, 60 °C, 65 °C and 70 °C in the batch type thin layer dryer. Thin layer drying study on foamed mango pulp concluded that the mango pulp treated with egg albumin (10%) and methyl cellulose (0.5%), dried at 60 °C with one mm foam thickness retained significantly higher biochemical contents than that of other foaming and drying treatments.

Sukanya (2018) optimized of process for production of *Kesar* mango leather using foam mat drying technique. The mango slices were ground in the mixer to obtain

fresh mango pulp. It was heated at 80 °C for 5 min and then cooled up to room temperature. Potassium meta bisulphate (0.1 g/ kg pulp) was added in to the mango pulp. During foaming experiment, mango foam was produced by varying process parameters as GMS concentration (0 - 4%), whipping speed (10,000 - 18,000 rpm) and whipping time (1 - 3 min) by keeping other parameters constant *i.e.* sugar (added up to 30 °Brix, citric acid and methyl cellulose of 0.5% each). Produced foamed mango pulp was analysed for its foaming properties such as foam expansion (%), foam density (g/cc) and drainage volume (ml). The experimental data was analyzed by analysis of variance and regression analysis using response surface methodology (RSM) for model fitting and to determine statistical significance of the model terms.

### 2.3.1.3 Foam mat drying of papaya

Kandasamy *et al.* (2012a) studied foam mat drying of papaya using glycerol monostearate as foaming agent. Foaming, drying, reconstitution, quality and sensory attributes of dried papaya powder were investigated. Foams were prepared from papaya pulp by adding different concentration of glycerol mono stearate (1, 2, 3 and 4%, w/w) at whipping time of 5, 10 and 15 min. The foam expansion was significantly influenced by pulp concentration and levels of the foaming agent at 1% level. The maximum stable foam formation was 90% at 3% glycerol mono stearate with 9 °Brix pulp concentration and whipping time of 10 min. The resulting foams were dried at air temperatures of 60, 65 and 70 °C with foam thickness of 2, 4, 6 and 8 mm in a batch type cabinet dryer under air flow rate of 2.25 m<sup>3</sup>/min. Lower drying temperature and higher foam thickness resulted in longer drying time. Biochemical analysis results showed a significant reduction in ascorbic acid, β-carotene and total sugars in the foamed papaya dried product at higher foam thickness (6 and 8 mm) and temperature. There was no significant change in other biochemical constituents such as pH and acidity. The sensory attributes of papaya powder juice were significantly ( $P \leq 0.01$ ) influenced by drying temperature and was compared with fresh papaya juice. The papaya powder obtained from the foam thickness of 4 mm and dried at 60 °C was found to be optimum to produce the foam mat dried papaya powder.

Kandasamy *et al.* (2012b) investigated foam mat drying of papaya pulp using egg albumin as foaming agent. The egg albumin was incorporated into papaya pulp at 5, 10, 15 and 20% (w/w) and whipped for 5, 10, 15 and 20 min in room temperature.

Foam expansion, foam stability and foam density were determined. The maximum stable foam formation was 125.62% at 15% egg albumin and whipping time of 15 min. The foam expansion was significantly influenced by levels of the egg albumin ( $p \leq 0.01$ ). The resulting foams were dried at air temperatures of 60, 65 and 70 °C with foam thickness of 2, 4, 6 and 8 mm under air flow rate of 2.25 m<sup>3</sup>/min. Biochemical analysis results showed a significant ( $p \leq 0.05$ ) reduction in ascorbic acid and total sugars in the foamed papaya dried product at higher drying temperatures (65 °C and 70 °C) and higher foam thickness (4, 6 and 8 mm) due to destruction at higher drying temperature and longer drying time. The sensory attributes of reconstituted papaya powder juice showed a significant ( $p \leq 0.01$ ) reduction in colour, flavour, taste and overall acceptability at higher temperature (65 °C and 70 °C) and significantly less as compared to fresh papaya juice. The papaya powder obtained from the foam thickness of 2 mm and dried at 60 °C was found to be optimum to produce the foam mat dried papaya powder.

Kandasamy *et al.* (2014) optimized the process parameters for production of papaya powder using foam mat drying. Papaya pulp was foamed by incorporating methyl cellulose (0.25, 0.5, 0.75 and 1%, w/w), glycerol mono stearate (1, 2, 3 and 4%, w/w) and egg white (5, 10, 15 and 20%, w/w) as foaming agents. The maximum stable foam formation was 72, 90 and 125% at 0.75% methyl cellulose, 3% glycerol mono stearate and 15% egg white, respectively with 9 °Brix pulp and whipping time of 20 min. The foamed pulp was dried at air temperature of 60, 65 and 70 °C with foam thickness of 2, 4, 6, 8 and 10 mm in a batch type cabinet dryer. The drying time required for foamed papaya pulp was lower than non foamed pulp at all selected temperatures. Biochemical analysis results showed a significant reduction in ascorbic acid,  $\beta$ -carotene and total sugars in the foamed papaya dried product at higher foam thickness (6, 8 and 10 mm) and temperature (65 °C and 70 °C). There was no significant change in other biochemical constituents such as pH and acidity. The organoleptic and sensory evaluation of the quality attributes of papaya powder obtained from the pulp of 9 °Brix added with 3% glycerol mono stearate, whipped for 20 min and dried with a foam thickness of 4 mm at a temperature of 60 °C was found to be optimum to produce the foam mat dried papaya powder.

#### 2.3.1.4 Foam mat drying of tomato

Patel (1996) developed a process technology for production of tomato powder using foam mat drying technique. The hot break extracted tomato juice was converted into stable foam (114% volume expansion) using 2% glycerol mono stearate (total solids basis) as foaming agent. Foam slabs of 3 mm thickness spread on aluminium trays were dried to 3% final moisture content using air at 62-65 °C temperature, 10-15% relative humidity and 2.0 m/s velocity for 90 min.

Kadam and Balasubramanian (2011) determined the effect of drying air temperature and foaming agent (egg albumin) for production of tomato powder using foam mat drying. Samples were prepared using tomato juice (4 °Brix total soluble solids), incorporating egg albumin as foaming agent (0, 5, 10, 15 and 20%, w/w). Foamed tomato juice ( $300 \pm 0.5$  g) was spread on rectangular trays (2.5 mm thickness) and kept in tray dryer at 60, 65 and 70 °C air temperature. Incorporation of 10% egg albumin with 5 min of whipping time was found optimum for stable foam formation. The increase in foaming agent level enhanced the drying process (up to 15% egg albumin) and thereafter followed a decreasing trend. Foamed tomato juice can be dried in 510 and 450 min at 60 °C and 70 °C drying air temperature, respectively with best acceptability.

Qadri and Srivastva (2014) studied the effect of microwave power on foam mat drying of tomato pulp. The experiments were conducted to study the effect of microwave power on drying characteristics on quality attributes of foamed tomato pulp egg albumin mixture in a microwave assisted foam mat drying system. Samples were prepared using tomato pulp by incorporating 10% egg albumin as foaming agent and whipping for 5 min. 10 mm thick layer of foamed tomato pulp was spread on a tray and dried in the dryer at different microwave power levels (0, 480, 640 and 800 W) at an inlet air temperature of 45 °C. The increase of microwave power accelerated the dehydration of the foam and it was observed that the drying time reduced about 15-16 times in case of microwave assisted foam mat drying as compared to simple foam mat drying. There was no adverse effect on colour, titratable acidity and pH of the product and the retention of ascorbic acid, in samples dried in microwave assisted foam mat drying and found better as compared to that in samples dried in air convection foam mat dried system.

### 2.3.1.5 Foam mat drying of other fruits

Karim and Wai (1999) studied foam mat drying of starfruit puree. Foams were prepared from starfruit puree by adding various concentrations of methocel. Overrun and density of the foams from various concentrations of methocel were compared. Relative stability of the foam was determined by comparing amounts of juice separated from foam at 70 °C. Drying rates at two drying temperatures (70 °C and 90 °C) were also compared. Quality of the dry and reconstituted powder was evaluated with simple sensory evaluation and Hunterlab instrument. Overrun and stability of foams increased with increasing methocel concentration until maximum value was obtained at a methocel concentration of 0.4% (w/w). Falling rate was observed for foam dried at both temperatures. Drying time could be shortened by as much as 30 min when drying temperature was increased from 70 °C to 90 °C. However, obvious colour and flavour changes were observed in the product dried at 90 °C.

Soares *et al.* (2001) carried out an experiment on dehydration of acerola pulp using foam mat drying. Several tests have been accomplished using different chemical agents to facilitate the foam formation and an experiment was chosen that most adjusted to the recommended density parameter (0.1 to 0.6). The pulp was then formulated and dehydrated in a drying hot house with air circulation at a temperature of 60 °C to 70 °C for 90 min. The product obtained was a powder with final moisture content of 7.2%. The obtained powder was immediately afterwards analysed with the purpose of identifying the new characteristics of the product. Analysis of the results obtained showed that there was an increase in the basic nutrients mainly regarding to the content of vitamin C that showed an increase 10 times higher than natural pulp.

Raharitsifa *et al.* (2006) studied on characterization of apple juice foams for foam mat drying prepared with egg white protein and methylcellulose. Foams were prepared from clarified apple juice by adding various concentrations of two foaming agents of different nature: a protein (egg white at 0.5, 1, 2 and 3% (w/w)) and a polysaccharide (methylcellulose at 0.1, 0.2, 0.5, 1 and 2% (w/w)) and whipping at different times (3, 5, and 7 min). In general, egg white foams were less stable but showed a higher degree of solidity (stronger structures), higher foaming capacity and smaller bubble average diameter than methylcellulose foams. Foam stability increased with increasing concentrations of either methylcellulose or egg white. Increasing

whipping times increased the stability of egg white foams only. Optimal concentrations to obtain the most solid foams (0.2% methylcellulose and 2% to 3% egg white, respectively) were the same concentrations required for maximum foaming capacity.

Bag *et al.* (2011) optimized process parameters for foaming of bael fruit pulp. Foams were prepared by adding different concentration of glycerol mono stearate and methyl cellulose (MC) at different whipping time (WT). Response surface methodology was used to predict the foam stability and expansion. Second order polynomial equations were developed after removing insignificant terms for predicting foam expansion ( $R^2 = 0.85$ ) and stability ( $R^2 = 0.95$ ). The optimum conditions achieved after the numerical and graphical optimization for maximum foam expansion and stability was: glycerol monostearate (3.10 g/100 g pulp), methyl cellulose (0.32 g/100 g pulp), PC (13.2 °Brix) and whipping time (2 min). The desirability of 0.712 was achieved at this optimum point. The predicted values of foam density and foam drainage volume were 0.658 g/cm<sup>3</sup> and 1.75 ml, respectively, at optimum parameters while the experimental values were  $0.635 \pm 0.02$  g/cm<sup>3</sup> and  $1.75 \pm 0.12$  ml, respectively.

Budhrani (2011) investigated thin layer drying study on foamed anola pulp. Anola pulp was prepared and foam was produced using two foaming agents *i.e.* Glycerol monostearate (5, 10 and 15%) and egg albumin (5, 10 and 15%), while methylcellulose (0.5%) was used as a stabilizing agent up to 25 min whipping time. Thereafter, each treatment sample was analysed for the determination of foaming behaviour for all the treatments undertaken in terms of foam expansion, foam stability and foam density. Among both foaming agent, GMS with 10% concentration gives maximum foam expansion as 142.00%, after 15 min of whipping, maximum foam density of 0.42 g/cm<sup>3</sup> and maximum foam stability of 70.59%. Drying was carried at 50, 60, and 70 °C and 4, 6 and 8 mm thickness. Samples prepared by drying at 60 °C with 6 and 8 mm thickness were indicating good quality powder.

Sangamithra *et al.* (2014) reviewed on foam mat drying of food materials. The larger surface area of the foam accelerated the drying process for the rapid moisture removal from the high moisture feed. A high quality food powder can be obtained by the proper selection of foaming method, foaming agents, foam stabilizers, time taken for foaming, suitable drying method and temperature. The basics of foam and its

structure, methods of foaming, types of foaming method and stabilizing agents for the production of stable foam have been analyzed. The influence of foaming agents and foaming properties on the drying characteristics of fruit juices were also studied. The application of foam drying process for different food materials, the microstructure and the quality of powders obtained by using different foaming agents.

Shekhawat (2014) studied process parameter of foam mat drying of pineapple juice. Foams were prepared from pineapple juice by adding foaming agent (egg albumin or soy isolate protein) of different quantity, methyl cellulose (0.5%) and sugar concentration of 20, 25 and 30 °Brix at air velocity of 3 m/s, whipping for 2 min at temperature 55, 65 and 75 °C. The foam expansion was significantly influenced by foaming agents and its quantity and sugar brix. The maximum foam expansion was obtained as 121% for 0.5% egg albumin foaming agent for 20 °Brix sugar at 55 °C temperature. The maximum foam stability was found to be 121% for 0.5% egg albumin foaming agent for 20 °Brix sugar at 55 °C temperature. The minimum foam density 1.0683 g/cm<sup>3</sup> was found for 0.25% egg albumin for 20 °Brix at 55.04 °C temperature. The optimized solution for soy protein isolate was concluded that optimized foam expansion 74.6944%, foam stability 80.9306% and foam density 1.13509 g/cm<sup>3</sup> was obtained for pineapple juice blended with 2% soy isolate protein with 20 °Brix sugar syrup at 55 °C. The average drying time for foam mat drying was 1440 min. The final moisture content of powdered samples was in the range of 3-11%. The sensory values for foam mat dried pineapple powder were more than 7.5 for colour, taste, appearance and overall acceptability, respectively.

Abbasi and Azizpour (2015) evaluated physicochemical properties of foam mat dried sour cherry powder. In this study, the effects of egg white (1, 2 and 3 g/100 g) and methyl cellulose (1, 1.5 and 2 g/100 g) were investigated on the density and drainage volume of sour cherry foam. Then, foamed sour cherry juice was spread on aluminum trays (3.0 ± 0.02 mm thickness) and put in drying chamber with the air temperature of 50, 65 and 80 °C. Physicochemical properties such as solubility, total anthocyanin content (TAC), pH, browning index, acidity and drying time of foam mat dried sour cherry powder were evaluated. As the concentration of methylcellulose increased, drainage volume, foam density, TAC, browning index and drying time were reduced; however solubility and pH of the samples had an increasing trend. Almost all

chemical properties (except for pH) indicated a decreasing trend with the rise in egg white levels. Furthermore, it was observed that at the drying temperature of 65 °C, sour cherry powder had the maximum solubility, TAC and pH. Browning index and drying time decreased by increasing the drying temperature. Only the effect of drying temperature on acidity was significant in a way that by the increase of drying temperature, total acidity increased.

Auisakchaiyoung and Rojanakorn (2015) determined the effect of foam mat drying conditions on quality of dried gac fruit aril. The effect of foam mat drying conditions on physico-chemical and antioxidant properties of the dried product was also investigated. Gac fruit aril mixed with methylcellulose at a respective mass concentration of 1.0, 1.5 and 2.0% was whipped for 0, 10, 20 and 25 min. The gac fruit aril foam mats (1, 2 and 3 mm thick) were dried at 60, 70 and 80 °C with a constant air velocity of 0.5 m/s. The optimum condition for forming foam was 1.5% methylcellulose after 25 min whipping. Gac fruit aril foam (1 mm thick) dried at 70 °C for 60 min exhibited the greatest amount of lycopene,  $\beta$ -carotene and total phenolic compounds as well as antioxidant.

Chandrasekar *et al.* (2015) studied the effect of foaming agent concentration and drying temperature on physio-chemical and antimicrobial properties of foam mat dried powder. Mixed vegetable juice powder was produced by foam mat drying method by varying foaming agent concentration and drying temperature. Foam properties of mixed vegetable juice, phytochemical and antimicrobial properties of powder were analysed. The foam expansion, foam stability and solubility index were increased from 79.2 to 104%, 68.7 to 97% and 79 to 92%, respectively. Foam density decreased from 0.2 to 0.17 g/cm<sup>3</sup>. Total phenol and beta-carotene content varied from 13.4 to 8.6 mg/g and 3.86 to 2.45 mg/g, respectively.

Durge *et al.* (2015) analyzed foaming behaviour of sapota pulp. Sapota pulp was formed by foaming device at various levels of pectin and egg albumin as 0.1% to 2% at 0.1% interval and 1-5% of methyl cellulose as stabilizer. The influences of pectin, egg albumin and methyl cellulose concentration on the foaming characteristics in terms of foam expansion and foam stability were subsequently evaluated. Sapota pulp foam was spread on each aluminium tray with a foam mat thickness of 2 mm and 3 mm and dried in tray dryer. The drying temperature in dryer was fixed at 50 °C as air at very

high temperatures and velocity resulted in collapse of the foam. The maximum foam expansion of 65.23% and foam stability of 80% was obtained at 2.5% pectin and 3% methyl cellulose level, respectively.

Sangamithra *et al.* (2015) optimized the foaming properties and foam mat drying of muskmelon using soy protein. The effect of concentration of soy protein isolate, carboxy methyl cellulose and whipping time on foaming properties of muskmelon pulp was investigated. The optimum conditions for foaming process were found to be 8.71% of SPI concentration, 0.54% of carboxy methyl cellulose concentration and a whipping time of 5.7 min. The muskmelon foamed at optimum conditions was dried using hot air dryer at 50, 60 and 70 °C. The drying rate was found to be high at 70 °C. The effective moisture diffusivity of foamed muskmelon pulp was determined and compared with the unfoamed muskmelon pulp.

Franco *et al.* (2016) conducted a study to develop yacon juice powder using foam-mat drying technique. Two yacon juice concentration (8 °Brix and 24 °Brix) were foamed by egg albumin and dried at different temperature (50 °C, 60 °C and 70 °C) and different sheet thickness (0.5 cm, 1.0 cm and 1.5 cm) in drying trays. Powders were analyzed for different physicochemical analysis. Density, solubility index and microstructure of powders were not affected by drying conditions while water activity and moisture content reduced. Increase in temperature and reduction in sheet thickness were found best for good quality powder.

Khodifad (2017) optimized foam mat drying of custard apple pulp. The foaming properties (foam expansion, foam density and foam stability) of custard apple pulp were carried out at concentration of egg albumin (0, 5, 10, 15 and 20%, w/w) with concentration of methyl cellulose (0.0, 0.125, 0.25, 0.375 and 0.50%, w/w) and whipping time (5, 10, 15, 20 and 25 min). The drying experiments of optimized foamed custard apple pulp were carried out at temperature 60, 65, 70 and 75 °C and at drying thickness of 2, 4, 6 and 8 mm. The different biochemical parameters, powder recovery and sensory evaluation of different drying treatments were observed during the experimental work. The compromised optimum condition for maximum expansion, stability and minimum density was obtained at egg albumin concentration, methyl cellulose concentration and whipping time of 15%, 0.37% and 17.32 min, respectively. The drying time to reach final moisture content for custard apple pulp were 90 to 140

min, 120 to 210 min, 150 to 290 min and 180 to 370 min at drying thickness of 2, 4, 6 and 8 mm, respectively for selected temperature range (60-75 °C). The maximum ascorbic acid and total sugar were 11.36 mg/100 g and 10.53 g/100 g observed at 60 °C and 65 °C with thickness of 2 and 4 mm and maximum sensory evaluation 8.25 was observed at 65 °C at thickness of 4 mm.

Qadri and Srivastava (2017) investigated microwave assisted foam mat drying of guava pulp, its drying kinetics and effect on quality parameters. The drying kinetics and quality of microwave foam mat dried guava powder was carried out using 8% egg albumin as the foaming agent. The foamed guava pulp was dried at microwave power of 480, 560, 640, 720 and 800 W; foam thickness of 3, 5 and 7 mm and inlet air temperature of 40 °C and 50 °C. Reduction in drying time was observed with increase in microwave power and decrease in foam thickness. Powdered samples were analyzed for various physico-chemical quality parameters *viz.* acidity, pH, total soluble solids (TSS), colour change and ascorbic acid content. Statistical analysis using three way analysis of variance revealed that sample of 5 mm foam thickness dried at 800 W and 50 °C was the best with 0.3584% total acid, 3.98 pH, 14 min drying time, 8 °Brix TSS, 3.263 colour change and 154.762 mg/100 g ascorbic acid content.

Rathi (2017) studied on effect of foam mat drying conditions on quality of tomato powder. For this study methylcellulose was added at concentration 0.50, 0.75 and 1.00% into tomato puree, whipped for 1, 2.5 and 5 min to produce tomato foam. Foam was categorized into 3 levels of foam density *viz.* low, medium and high for each level of methylcellulose concentration and spread on tray at foam layer thickness 3, 6 and 9 mm and dried in tray dry at air drying temperature 55, 65 and 75 °C. The study shows that foam density of the tomato ranges from 0.413 g/cm<sup>3</sup> to 0.740 g/cm<sup>3</sup> for methylcellulose concentration 0.50% and 1.00% respectively. Maximum expansion in foam was 125%. The minimum value of flowability was 9.814 s and maximum value 14.662 s. Solubility of tomato powder was found in the range of 13.218 to 23.60%. The hygroscopicity of tomato powder was found in the range of 3.149 to 7.081%. Maximum value of degree of caking 8.3% and minimum value 1.835%. Acidity of tomato powder varied from 0.256 to 0.410%. The maximum retention of ascorbic acid was found at 0.50% methylcellulose concentration, 0.413 g/cm<sup>3</sup> had foam layer thickness 3 mm dried at 65 °C temperature.

Djaeni *et al.* (2018) optimized foam mat drying of roselle extract. In this study, foaming condition of roselle was optimized using response surface methodology (RSM) and the effect of drying characteristic was investigated. Roselle extract was foamed by addition of 1-5% w/w foaming agents (ovalbumin). The foaming stabilizer, glycerol mono stearate (0-1% w/w) was used to remain mechanic and thermodynamic stability of foam. As the response foam density and drainage volume was determined. The optimum foam variable was then dried at various drying temperatures (50-70 °C). Result showed that optimum formulation was 3.31% egg albumin and 1% GMS. The constant rate of the foam mat drying (temperature 50 °C) was 3 times higher than non foam mat drying. Higher drying temperature can speed up the driving force but lead to color degradation.

Javed *et al.* (2018) reviewed on foam mat drying of fruits and vegetables to develop powders. Foam-mat drying is a new drying technique for foods which are highly heat sensitive and very sticky to dry. Foods contain a lot of compounds which are very sensitive to high temperature for long time. By using this drying technique product is dried in a very short time with minimum quality changes. Fruits and vegetables pastes are mixed with different foaming agents (egg albumin, soy protein, egg white, Lecithin etc.) and foam stabilizers (carboxy methyl cellulose, pectin etc.) in different concentration to introduce stable foams. Foams are dried in trays by application of hot air and milled to develop free flowing powders. Powders developed by this drying technique have maximum preservation of the compounds which are very heat sensitive.

Khamjae and Rojanakorn (2018) determined the effect of methyl cellulose concentration and whipping time on the properties of passion fruit aril foam. The effect of foam mat drying conditions on moisture diffusivity, physicochemical, microbiological and antioxidant properties of the dried product was also investigated. Passion fruit aril incorporated with methylcellulose at a mass concentration of 0.75, 1.5, 2.25 and 3.0% was whipped for 0, 10, 20 and 25 min. The passion fruit aril foam mats (1, 2 and 3 mm thick) were dried at 60, 70 and 80 °C with a constant air velocity of 0.5 m/s. The optimum condition for forming foam was 2.25% methylcellulose after 25 min whipping as it provided the highest foam expansion (187.25%) and stability as well as the lowest foam density (0.41 g/ml). Drying the passion fruit aril foam chiefly

occurred in the falling rate period. Effective moisture diffusivity increased with increasing temperature and foam thickness. This value ranged from  $1.06 \times 10^{-7} \text{ m}^2/\text{s}$  to  $1.01 \times 10^{-6} \text{ m}^2/\text{s}$ . Passion fruit aril foam (1 mm thick) dried at 70 °C for 90 min showed the highest amount of ascorbic acid and  $\beta$ -carotene as well as antioxidant activity. Based on microbial counts, freshly prepared foam mat dried passion fruit aril samples were considered safe.

Ng and Sulaiman (2018) developed beetroot powder using foam mat drying. The objectives of this research was to determine the effect of types (egg albumen and fish gelatine) and different concentrations of foaming agents on foam properties of foam mat drying beetroot, to evaluate the physicochemical properties (colour, pH, Brix, bulk density, water activity, hygroscopicity and moisture content) of foam dried beetroot powder, and to determine the effect of temperature on rehydration ratio and colour changes of rehydrated foam mat dried beetroot powder. Beetroot foam was spread at 3 mm thickness and hot air dried at 50 °C for 6 h in cabinet dryer. Beetroot pulp can be successfully foamed using egg albumen and fish gelatine as foaming agents, further hot air dried and grinded into powder. In this experiment, beetroot powder after foam mat drying was considered as hygroscopic food and resulted in lighter and reddish in colour. After rehydrating foam mat dried beetroot powder,  $L^*$  value decreased but  $a^*$  and  $b^*$  values increased. Generally, sample beetroot with fish gelatine had good foam expansion, foam density, hygroscopicity, water activity, and red colour's powder.

### 2.3.2 Different drying methods of fruits and vegetables

Maskan (2000) studied the microwave finish drying of banana. Banana samples ( $4.3 \pm 0.177$ ,  $7.4 \pm 0.251$  and  $14 \pm 0.492$  mm thick) were dried using the following drying regimes; convection (60 °C at 1.45 m/s); microwave (350, 490 and 700 W power) and convection followed by microwave (at 350 W, 4.3 mm thick sample) finish drying. The drying of banana slices took place in the falling rate drying period with convection drying taking the longest time. Higher drying rates were observed with the higher power level. Microwave finish drying reduced the convection drying time by about 64.3%. Microwave finish dried banana was lighter in colour and had the highest rehydration value.

Smitabhindu *et al.* (2007) carried out a study on drying of banana in solar-assisted forced convection drying system. The drying experiments were carried out at 60 °C temperature and time interval of 9 h for three days. The experimental results were compared with simulated results. The measured collector outlet air temperatures and moisture contents of bananas showed that the simulated temperatures, moisture contents agreed well with the experimental results. The optimum values of the solar collector area and the recycle factor were found to be 26 m<sup>2</sup> and 90%, respectively.

Wang *et al.* (2007) compared the volatiles of banana powder dehydrated by vacuum belt drying, freeze drying and air drying. Volatiles were extracted from dried banana powder with solid phase micro extraction (SPME), and separated and identified by gas chromatography mass spectrometry (GC–MS). The main components detected in banana powder responsible for its fruity odour were 3-methylbutanoic acid 3-methylbutyl ester, 3-methylbutyl acetate and butanoic acid 3-methylbutyl ester. Basing on the principal component analysis of statistical analysis system, it can be inferred that the preferred method for producing banana powder with the optimum aroma was freeze drying, followed by vacuum belt drying and then air drying.

Hassanain (2009) investigated simple solar drying system for banana fruit. For experiments, ripe banana was cut to slices of 5-10 mm. Horizontal and vertical two types of drying chambers were used. The horizontal dryer chamber was speeding banana drying over the vertical one for both of the active and passive modes. Drying system efficiency for the forced convection was higher for the first day comparing with the following days due to the fast drying in the moisture falling stage.

Antala (2011) determined the effect of osmotic-air dehydration on quality of guava powder. Guava powder was prepared by partial osmotic dehydration followed by tray drying. Guava slices (10 mm thickness) were pretreated with 0.1% potassium meta bisulphite and 0.1% citric acid solution. Guava slices were immersed into sucrose solution of 50, 60 and 70 °Brix with sample to solution ratio of 1:5 (w/w). The prepared samples were kept at room temperature and 50 °C temperature in the B.O.D. incubator for 6 h and 12 h without any agitation. The highest water loss to solid gain ratio (5.28%) of guava slices during osmotic dehydration was found in treatment 60 °Brix sucrose solution + 6 h immersion time + 50 °C process temperature. All the samples of osmotic dehydrated guava slices were further dehydrated in a tray dryer at 60 ± 2 °C

and 2.5 m/s air velocity up to 4-5% (db) moisture content. The powder was prepared by grinding guava slices and sieved using 300 mesh sieve size. The results revealed that water solubility index (86.68%), water absorption index (516.63%), titratable acidity (0.26%), ascorbic acid (146.17 mg/100 g) and overall acceptability (8.4) were found maximum for guava slices immersed in 60 °Brix sucrose solution for 6 h immersion time at 50 °C process temperature which required 6 h for tray drying.

Cholera and Patel (2016) prepared sapota powder by osmo freeze drying. Osmotic dehydration of 4 mm sapota slices was carried out at different osmotic variables, *viz.*, osmotic solution concentration (60 °Brix and 70°Brix), immersion time (5 and 10 h), process temperature (30, 40 and 50 °C) and sample to solution ratio (1:5). Osmotically dehydrated sapota slices were freeze dried at -20 °C and -40 °C temperature at a constant vacuum pressure of 1 torr using freeze dryer. The powder was prepared by grinding sapota slices and sieved using 100 $\mu$  sieve size. The highest values of rehydration ratio (4.56), water solubility index (89.15%), water absorption index (701.82%), titratable acidity (0.26%), ascorbic acid content (54.66 mg/100 g), overall acceptability (8.33) as well as lowest non-enzymatic browning (0.040 OD) were obtained in treatment having 60 °Brix osmotic solution + 5 h immersion time + 50 °C process temperature -40 °C freeze drying temperature which required 34 h freeze drying time.

## 2.4 Drying characteristics of fruits and vegetables

Kudra and Ratti (2006) analysed energy and cost of foam mat drying. Convective drying of both foamed and non foamed apple juice dried in a 19 mm layer at 55 °C has indicated higher drying rates for foamed juice which resulted in reduced drying time from 500 to 200 min. The energy consumption for drying of foamed apple juice was found to be 0.2 of that for drying of non foamed juice. The dryer throughput was calculated as 0.83 and 0.68 kg/m<sup>2</sup>h, respectively. Because of higher throughput and shorter drying time, the foam mat dryer can be smaller which would reduce capital costs by about 11% for a belt conveyor dryer and by 10% for a drum dryer.

Kadam *et al.* (2012a) investigated foam mat drying characteristics of mango pulp. Mango pulp from *Dussehari* variety was foam mat dried using 0, 3, 5, 7, and 9% egg white as foaming agent and then dried at air drying temperature of 65, 75 and

85 °C. Weight loss was used to estimate change in moisture ratio with respect to time and effective diffusivity. Seven thin layer drying models were fitted to get the best fit model, which was selected on the basis of various statistical parameters. Wang and Singh model was found to be best in almost all cases. Nutritional status in terms of total carotenes was estimated and it was observed that there was significant effect of drying temperatures and egg white concentration. Based on above parameters it was resolved that foam mat drying using 3% egg white at 65°C air drying temperature was the best combination.

Kabiru *et al.* (2013) determined the effect of slice thickness and temperature on the drying kinetics of mango. Mangoes were dried at 60 °C, 70 °C and 80 °C at constant thickness of 3 mm and then 3, 6 and 9 mm slice thick mangos were dried at constant drying air temperature of 70 °C. Drying information was fitted into four drying models namely: Newton, Page, Modified Page and Henderson and Pabis. The drying was discovered to have taken place during the falling rate period and Page model described the drying behaviour of the mango slices satisfactorily with  $R^2$  of 0.990. The effective moisture diffusivity coefficients increased with increasing temperature ranging between were  $3.89$  and  $6.99 \times 10^{-10}$  with activation energy of 28.95 kJ/mol.

Jethva *et al.* (2015) studied drying characteristics of custard apple. The custard apple pulp was dried in a tray dryer 60, 65, 70, 75 and 80 °C. The average elapsed drying time to remove first half moisture was decreased by 15.52, 10.20, 9.09 and 7.50% for temperature from 60-65 °C, 65-70 °C, 70-75 °C, 75-80 °C, respectively. The average drying rates for custard apple were 0.18, 0.20, 0.23, 0.24 and 0.25 g water/g dry matter/min for temperatures of 60, 65, 70, 75 and 80 °C, respectively. Two Term model reasonably suited to the thin layer drying of ripe custard apple. Estimated values for effective diffusivities for the custard apple pulp drying were  $2.13 \times 10^{-5}$ ,  $2.54 \times 10^{-5}$ ,  $2.94 \times 10^{-5}$ ,  $3.25 \times 10^{-5}$  and  $3.45 \times 10^{-5}$   $m^2/s$  at the temperatures of 60, 65, 70, 75 and 80 °C. The activation energy was 31.92 kJ/mol. The carbohydrate content, fat content, energy from carbohydrate and fat, pH and ash content of dried pulp varied from 75.39-79.68 g /100g, 0.2-0.4 g/100 g, 481.55-678.73 kcal, 4.9-6.1, and 1-2%, respectively. Custard apple dried at 60 °C obtained the highest sensory score within the experimental range of temperature.

Salahi *et al.* (2015) studied foam mat drying of cantaloupe, optimization of foaming parameters and investigating drying characteristics. Foaming conditions, namely amount of egg white powder, xanthan gum and whipping time, optimized using response surface methodology for minimizing foam density and drainage volume. Drying was carried out in a batch type thin layer dryer at three drying temperatures (40, 55 and 70 °C) on 3 and 5 mm thicknesses. Based on the statistic tests performed, Weibull distribution model can describe drying behavior of foams for all drying processes. Moreover, Fick's second law was employed to calculate the effective moisture diffusivity that varied from  $3.283 \times 10^{-9}$  to  $9.483 \times 10^{-9}$  m<sup>2</sup>/s and from  $4.053 \times 10^{-9}$  to  $1.216 \times 10^{-8}$  m<sup>2</sup>/s with activation energy values of 31.714 and 33.043 kJ/mol for foam thicknesses of 3 and 5 mm, respectively.

Branco *et al.* (2016) studied drying kinetics and quality of uvaia powder obtained by foam mat drying. Two formulations were developed (one with 3.5% albumin, 0.25% carboxy methyl cellulose and 0.25% xanthan gum, and the other containing only 7% albumin) and dried at 60 °C and 70 °C. Drying kinetics showed only a falling rate at both temperatures and formulations. Mathematical models were fitted to the experimental data to describe the drying kinetics. The Page model provided the best description of the foams. The higher temperatures reduced the drying time and increased the effective diffusivity. Compared with the fresh pulp, the uvaia powder at 70 °C exhibited decreased antioxidant activity, total phenolics and carotenoids contents.

Chauhan and Jethva (2016) studied drying characteristics of banana powder by tray drying. Carbohydrate content of dehydrated the banana powder after dehydration in tray dryer with perforated plates possessed significantly higher amount (78%) at 80 °C temperature for 7 mm slices. The fat content was highest in the tray dryer with solid plates at 80 °C temperature for 7 mm slices. Ash content of the eighteen samples was in the range of 4.1 to 5.12%. The ash content was highest in the oven at 80 °C for 7 mm slices and tray dried at 75 °C for 7 mm slices samples. The 7 mm slices dried at 75 °C in multipurpose tray dryer have obtained the highest sensory score within the experimental range of different dryers. It can be concluded from the study that multipurpose tray dryer best suitable for drying of banana slices to get good quality powder.

## 2.5 Quality of fruit powder

Silva *et al.* (2008) carried out studies on dehydration of tamarind pulp through the foam mat drying method. The foam mat drying process was studied for the tamarind pulp at 50, 60, 70 and 80 °C and the temperature effect on the tamarind powder were evaluated as regards to ascorbic acid content, total titratable acidity and colour. The best results for ascorbic acid content, titratable acidity and colour were obtained at the temperatures of 60 °C and 70 °C.

Kadam *et al.* (2010b) evaluated the biological properties of foam mat dried mango powder. The impact of drying air temperature (65, 75 and 85 °C) and milk as foaming agent in different concentration levels (0, 10, 15, 20 and 25%) were investigated on the chemical properties of foam mat dried mango juice powder. Chemical properties such as total sugars, ascorbic acid, total carotenes, minerals, total acid, pH, total soluble solids (TSS) and microbial load (fungal and bacterial) of foam mat dried mango powder were determined. Almost all chemical properties showed decreasing trend with increase in drying air temperature. Microbial load was not detected in foam mat dried mango powder. It was found that addition of 10% milk as foaming agent and drying at 65 °C temperature gave better results.

Kadam *et al.* (2012b) evaluated physicochemical and microbial quality of foam mat-dried pineapple powder. Pineapple pulp was foamed using two foaming agents, tri calcium phosphate (0, 0.25, 0.50, 0.75, and 1.0%) and egg white (0, 0.50, 1.0, 1.50, and 2.0%). Carboxy methyl cellulose (0.25%) was used as foam stabilizer and drying was carried out at 65, 75, and 85 °C in tray drier followed by pulverising the dried foam mats in to fine powder. Powdered samples were analysed for various physicochemical quality parameters *viz.* total sugars, reducing sugars, ascorbic acid, total acid, pH, iron, phosphorus and calcium content and bacterial and fungal load. Statistical analysis revealed that sample dried using 1% tricalcium phosphate at 65 °C was the best with 4.60% total sugars, 2.71% reducing sugars, 4.05 mg/100 g ascorbic acid, 0.35% total acid, 0.29 mg/100 g iron, 2.24 mg/100 g phosphorous and 6.58 g/100 g calcium and zero bacterial and fungal growth.

Chaves *et al.* (2013) characterised physico-chemical and sensory properties of purple brazilian cherry foams. The foams of purple brazilian cherry pulp made with

different additives. Characterisation was made through analyses of moisture, pH, acidity, soluble solids, density, water activity, colour, total and reducing sugars, protein and ashes. Drying was done at 55 °C for 2 h. Dried brazilian cherry juice powder was rehydrated for acceptance test. It was concluded that the physico-chemical characteristic was satisfactory and was in accordance with the Brazilian standards for agro-industrial products. Albumin was the best foaming agent that produced a good quality powder in a short period. The foam mat drying of brazilian cherry pulp using albumin and superliga as foaming agents produced a powder with good physico-chemical properties and sensory quality.

Adubofuor *et al.* (2016) evaluated nutrient composition and sensory evaluation of ripe banana slices and bread prepared from ripe banana and wheat composite flours. Two varieties of ripe banana (Gros Michel and Medium Cavendish) were sliced, pre-treated with 2% citric acid for 2 min and dried at 60 °C for 72 h using an oven dryer to obtain dry banana slices. Part of the oven dried ripe banana slices were milled using a hammer mill and sieved through a 250 microns mesh sieve to obtain flour. The ripe banana flour was incorporated into bread and studied sensory properties such as colour, aroma, mouthfeel and overall acceptability of the oven dried ripe banana slices and the bread substituted with flour. Results from the study revealed that, apart from colour, there was no significant difference between the other sensory attributes of the oven dried ripe banana. In conclusion, bread formulated from ripe banana and wheat flour had a higher nutritional value when compared with bread from all purpose flour.

Roongruangsri and Bronlund (2016) examined the use of hot-air drying in the preparation of pumpkin powder. The drying temperature was varied (50, 60 and 70 °C) to determine the effect of temperature on physicochemical properties, powder properties and sorption characteristics of pumpkin powders. The results showed that a drying temperature of 70 °C removes moisture from pumpkin slices faster than the lower drying temperatures of 50 and 60 °C. Pumpkin powder dried at 70 °C exhibited the darkest yellow color, while pumpkin powders dried at 50 and 60 °C were lighter. The results also showed that increases in drying temperature were accompanied by decreases in the water solubility, water and oil adsorption capacities of the resulting pumpkin powders. Pumpkin powder dried at 50 and 60°C had water solubilities of more than 50% and higher water adsorption and oil adsorption capacities than those dried

temperature at 70 °C. Overall, a good quality pumpkin powder can be produced by hot-air drying at a temperature of 60 °C in terms of moisture content, water activity, color characteristics, total carotenoid content, bulk density, water solubility, water adsorption, and oil adsorption capacities. When drying at a temperature of 50°C, the moisture content and water activity of pumpkin powder was higher and the dark yellow color of the powder was observed when subjected at a drying temperature of 70 °C.

Castro *et al.* (2017) evaluated physicochemical and sensory characteristics of banana pulp dehydrated in sheets. For the drying tests, a static type equipment was used and the fresh and dehydrated banana pulp was characterized taking into account its moisture content, soluble solids, pH, acidity and proximal analysis. The conservation parameters of the dehydrated pulp were satisfactory, which are favoured by the low water activity reached in the dehydrated product; the sensorial analysis showed that temperature and speed of the drying air exert a big influence in the quality of appearance and colour.

Harish *et al.* (2017) carried out feasible studies on production of banana powder. Banana powder was prepared by spray and tray drying processes at temperatures of 198 °C and 70 °C, respectively. The concentrated banana liquid feed of spray dryer maintained a 14-18 °Brix, the sliced banana, both ripe and unripe banana took same drying trend and same time (70 °C, 6-7 h) to arrive at below 10% moisture content, spray dried powders produced at 198 °C had less moisture content 3.5- 4.4% (wb) compared to tray dried powders 7.6-8.8% (wb) produced at 70 °C, the bulk density (0.41 – 0.5 g/cm<sup>3</sup>) of powder did not vary with process of making powder, the spray dried ripe banana powder was more soluble (3 min), spray dried unripe powder had more water solubility index (29.84%) and absorption index (2.4%) and spray dried and tray dried unripe powders produced at 198 °C and 70 °C had fairly a good source of vitamin C 10.5 mg/100 g.

Palmei *et al.* (2017) evaluated quality parameters of foam mat dried banana powder. The independent variables selected for this study were carboxy methyl cellulose (0.5-2.5%) as foam stabilizer, egg albumin (3-11%) as foaming agent, temperature (60-80 °C) and whipping time (6-12 min). Foam were prepared by incorporating carboxy methyl cellulose and egg albumin into the puree, the foam was then dried in cabinet air drier and finally grinded into powder. The dependent variables

measured were flowability time, solubility, hygroscopicity and degree of caking. The study showed that the minimum value of flowability time was 6.5 s and maximum value was 13.56 s. Solubility of banana powder ranges from 59.1 to 98.5%, hygroscopicity varied from 1.25 to 4% and degree of caking was in the range of 1.89 to 4.5%.

## CHAPTER III

### MATERIALS AND METHODS

---

This chapter deals with the procedure comprises study of optimization of foaming process parameters of banana pulp, effect of drying on drying characteristics of foamed banana pulp and quality characteristics evaluation of foam mat dried banana powder. Methodologies adopted for determination of physical, biochemical and sensory characteristics of foamed banana powder is presented in this chapter. The details of machineries, instruments and materials used in the experiments are also expounded here under.

#### 3.1 Experimental details

The experiment was carried out in the Department of Processing and Food Engineering, College of Agricultural Engineering & Technology, Junagadh Agricultural University, Junagadh during the year 2018-19. The experiment was consisting of selection of ripe banana fruits, peeling, cutting, rinsing in sodium meta bisulphite, washing, addition of foaming agent and stabilizer, whipping, drying, grinding, cooling, sieving and evaluation of quality parameters of banana powder. All the treatments were based on the reviews reported in chapter II. The flow chart of experimental procedure is shown in Fig 3.1.

##### 3.1.1 Selection of ripe banana

*Grand Naine, Dwarf Cavendish, Lacatan, Gandevi Selection* varieties of banana are mainly grown in Gujarat. Among them, *Grand Naine* is one of the most popular variety in Gujarat and most commonly grown in Saurashtra region due to its characteristic medium length and large fruit yields. In view of this, *Grand Naine* variety of banana was selected for the present investigation. The ripened fruits were brought from local market of Junagadh, Gujarat, India to the laboratory in plastic crates to avoid physical damage. Ripened banana of stage-5 ( $15 \pm 1$  °Brix) was selected for the experiment (Plate 3.1) due to moderate amount of starch, sugar and glycemic index.



**Plate 3.1 Ripe banana**

### **3.1.2 Cutting**

After removing peels, banana were cut into small pieces of thickness 3-5 mm for further process of pre-treatment.

### **3.1.3 Pre-treatment**

Banana slices were rinsed properly with 1% sodium meta bisulphite. Banana slices were kept in 1% (w/w) sodium meta bisulphite solution for 2 min (Plate 3.2) and then rinsed with water for 30 s for preventing discoloration during foaming (Plate 3.3).



**Plate 3.2 Banana slices immersed in 1% sodium meta bisulphite**



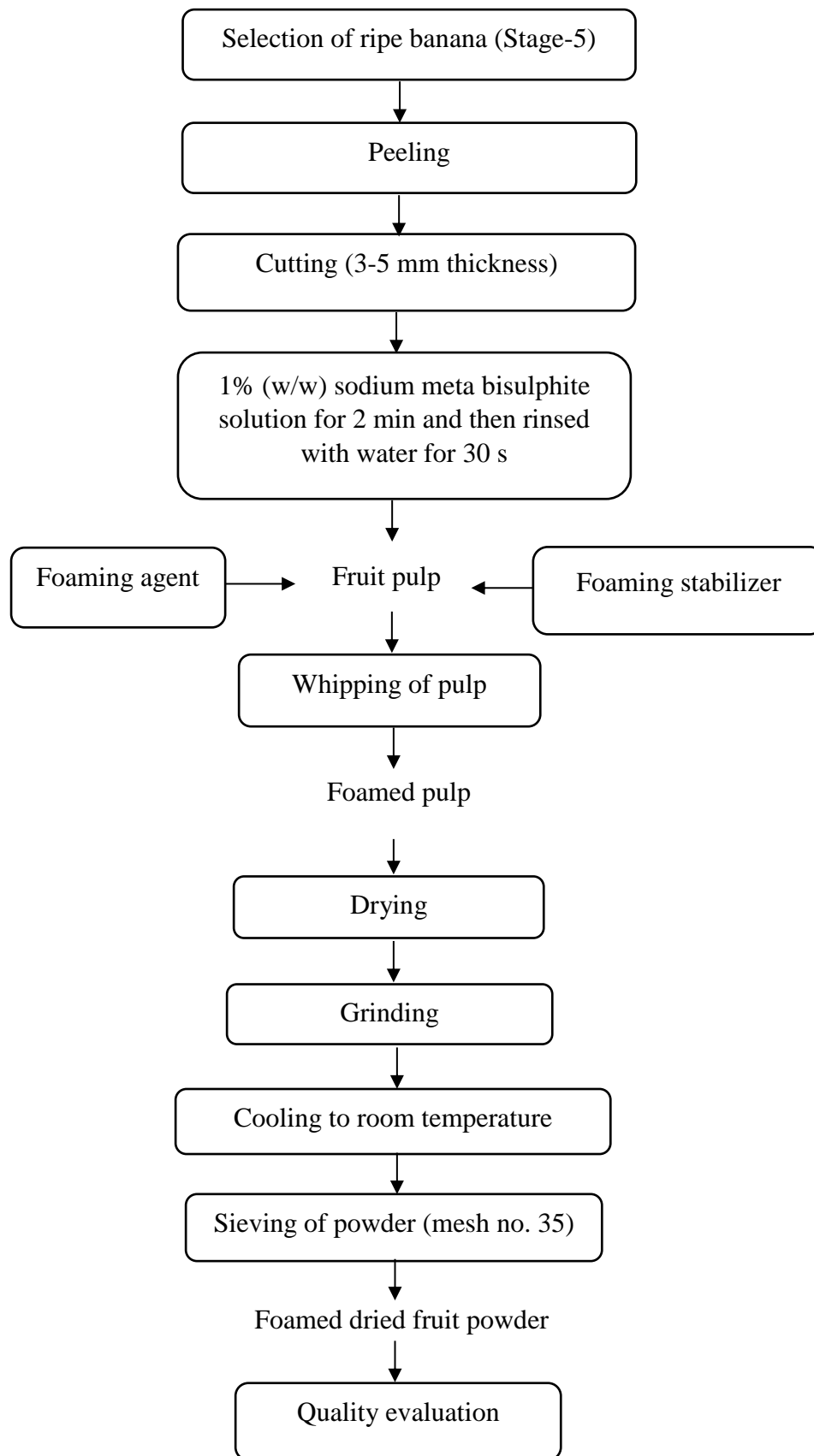
**Plate 3.3 Banana slices rinsed in water**

Whey protein isolate (WPI) and methyl cellulose (MC) were used as foaming agent and stabilizer, respectively within the limits stipulated in the Prevention of Food Adulteration Act 1955 of the Government of India and based on preliminary foaming tests conducted (Rajkumar *et al.* 2007). The concentration of whey protein isolate was kept 2.5-12.5% (w/w) with concentration of methyl cellulose 0.1-0.5% (w/w) and whipping time was kept 5-25 min.



**Plate 3.4 Chemicals used to prepare banana pulp foam**

(1) Whey protein isolate (2) Methyl cellulose (3) Sodium meta bisulphite



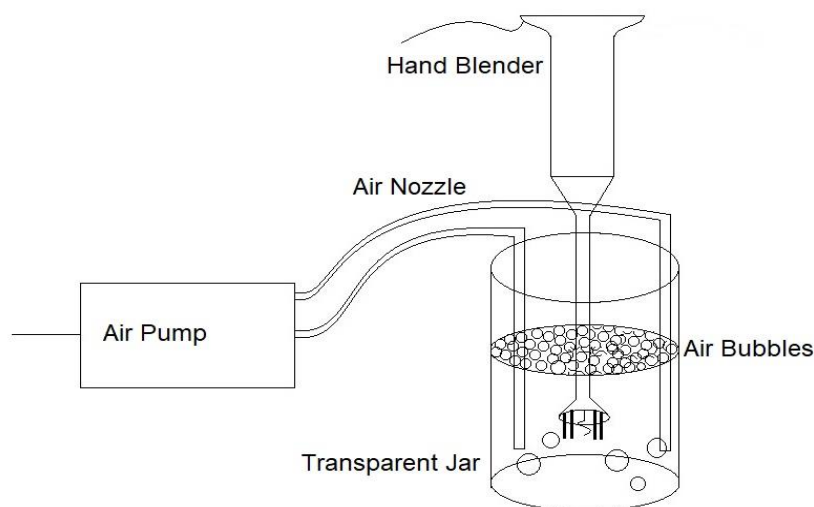
**Fig. 3.1** Experimental process flow chart for preparation of ripe banana powder by foam mat drying

Advance whey isolate is the purest whey protein available, containing over 90% protein. It has a comprehensive amino acid profile providing all the essential amino acids. It improves immunity. It is used to stabilize emulsions and as thickener or viscosity modifier.

### 3.1.4 Foaming of ripe banana pulp

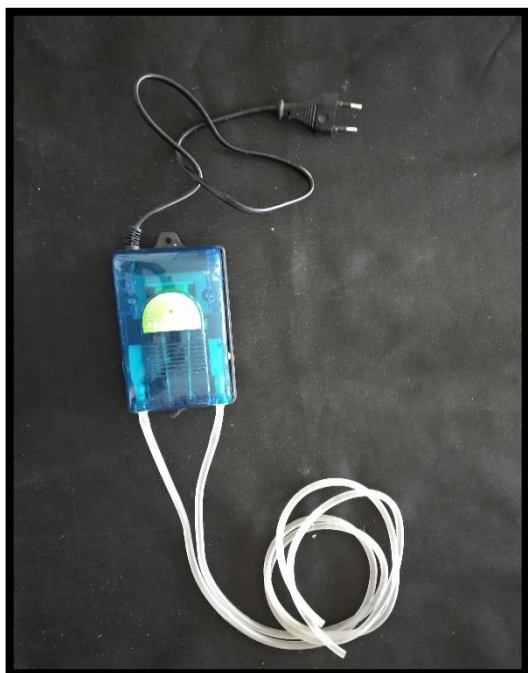
The ripe banana pulp was converted into foam for more expansion, high stability and low density with the use of foaming agent and foaming stabilizer. The air was incorporated using a foaming device.

For foaming formation, transparent cylindrical plastic vessel, air pump and hand blender were used (Fig. 3.2). Air pump (M/S AS-648A Aquarium air pump) having two air nozzles was used at flow rate 4 lit/min per nozzle for flowing air in the cylinder (Plate 3.5). The nozzles were kept about 180° angular diameter for maintaining uniformity. A portable hand blender (M/s Maharaja Whiteline Hand Blender, Model: HB-104) was used for proper mixing of air with the pulp (Plate 3.6).



**Fig. 3.2 Foaming unit**

The 100 g of sample of ripe banana pulp was taken into the vessel of foaming device. Based on preliminary experiments for formation of foam, an amount of 100 ml water was added along with pre-determined quantity of foaming agents *i.e.* sample to water ratio of 1:1 (w/w). Controlled rate of compressed air flow rate was introduced at the bottom of vessel and blending of pulp was carried out. After pre-determined time period, air flow and rotation of whipping blade were stopped simultaneously.



**Plate 3.5 Air pump**



**Plate 3.6 Hand blender**

### **3.2 Experiment No. 1: Foaming process**

Foaming experiment was conducted of ripe banana pulp using different foaming agent concentrations of whey protein isolate (5-12.5%), foaming stabilizer concentrations of methyl cellulose (0.1-0.5%) and whipping time (5-25 min) for optimization and stabilizing process parameters on foaming properties of banana pulp.

#### **3.2.1 Experimental design**

The Response Surface Methodology (RSM) is an empirical statistical modeling technique employed for multiple regression analysis using quantitative data obtained from properly designed experiments to solve multivariable equations simultaneously. It was used for designing of the experiment (Myers, 1976; Khuri and Cornell, 1987; Montgomery, 2001).

A three-factor five-level Central Composite Rotatable Design (CCRD) with quadratic model was employed (1) to study the combined effect of three independent variables, *viz.*, foaming agent ( $X_1$ ), foaming stabilizer ( $X_2$ ) and whipping time ( $X_3$ ) on

different response variables, (2) to create models between the variables, and (3) to determine the effect of these variables to optimize the selected response variables.

Five different levels for each independent variables in coded form are:

$$-\alpha, -1, 0, +1, +\alpha$$

Where,

$$\alpha = 2^{\text{No. of variables}/4} = 2^{3/4} = 1.682$$

The relationship between the coded and actual values of a factor is given by

$$\text{Coded value} = X_i = x_i - x_{cp} / \Delta x_i$$

Where,

$x_i$  = Real value of an independent variable

$x_{cp}$  = Real value of an independent variable at centre point

$\Delta x_i$  = Step change of real value of the variable  $i$  corresponding to a variation of a unit for the coded value of the variable  $I$ .

The selected levels for the independent parameters along with their coding are presented in Table 3.1.

**Table 3.1 Independent parameters and their coded and actual values employed for foaming properties of banana pulp**

Parameters		Coded variables				
		-1.68	-1	0	+1	+1.68
Foaming agent (%)	(X <sub>1</sub> )	2.5	4.53	7.5	10.47	12.5
Foaming stabilizer (%)	(X <sub>2</sub> )	0.1	0.18	0.3	0.42	0.5
Whipping time (min)	(X <sub>3</sub> )	5	9	15	21	25

As per the CCRD, total number of treatment combinations

$$= (2)^{\text{No. of variables}} + (2 \times \text{No. of variables}) + \text{Central points}$$

Here, number of variables : 3

Hence, total number of treatment combinations

$$= 2^3 + (2 \times 3) + 6 = 8 + 6 + 6 = 20$$

Hence, a total of 20 combinations including eight factorial points, six central points and six extra axial points were carried out in random order according to a CCRD

configuration for the three chosen variables. The experimental design matrix in coded (X) form and at the actual level of variables is presented in Table 3.2.

**Table 3.2 Matrix of experimental central composite rotatable design for foaming banana pulp**

Run	Treatment	Coded variables			Uncoded variables		
		X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Foaming agent (%)	Foaming stabilizer (%)	Whipping time (min)
1	2	1	-1	-1	10.47	0.18	9.00
2	16	0	0	0	7.50	0.30	15.00
3	17	0	0	0	7.50	0.30	15.00
4	18	0	0	0	7.50	0.30	15.00
5	12	0	1.68	0	7.50	0.50	15.00
6	7	-1	1	1	4.53	0.42	21.00
7	1	-1	-1	-1	4.53	0.18	9.00
8	5	-1	-1	1	4.53	0.18	21.00
9	15	0	0	0	7.50	0.30	15.00
10	14	0	0	1.68	7.50	0.30	25.00
11	11	0	-1.68	0	7.50	0.10	15.00
12	3	-1	1	-1	4.53	0.42	9.00
13	19	0	0	0	7.50	0.30	15.00
14	9	-1.68	0	0	2.50	0.30	15.00
15	8	1	1	1	10.47	0.42	21.00
16	6	1	-1	1	10.47	0.18	21.00
17	4	1	1	-1	10.47	0.42	9.00
18	20	0	0	0	7.50	0.30	15.00
19	13	0	0	-1.68	7.50	0.30	5.00
20	10	1.68	0	0	12.50	0.30	15.00

The response function (Y) was related to the coded variables by a second degree polynomial equation as given below:

$$Y = b_0 + \sum_{i=1}^j b_i X_j + \sum_{i=1}^j b_{ij} X_i^2 + \sum_{i \neq j=1}^j b_{ij} X_i X_j$$

Where,

$b_0$  is the constant,  $b_i$  the linear coefficient,  $b_{ii}$  the quadratic coefficient and  $b_{ij}$  the interactive coefficient,  $X_i$  and  $X_j$  are the levels of the independent variable.

So, the second order polynomial function for the experiment can be given as under.

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3$$

Where  $Y$  is the response calculated by the model;  $X_1$ ,  $X_2$  and  $X_f$  are the code of independent variables, i.e. foaming agent, foaming stabilizer and whipping time, respectively,  $b_1$  is constant term,  $b_1$ ,  $b_2$  and  $b_3$  are linear,  $b_{11}$ ,  $b_{22}$  and  $b_{33}$  are quadratic, and  $b_{12}$ ,  $b_{13}$  and  $b_{23}$  are interaction coefficients, respectively (Anderson and Whitcomb, 2005).

The second order polynomial coefficients were calculated by using the software package Design Expert version 10.0.8 (Trial version; STAT-EASE Inc., Minneapolis, MN, USA) to estimate the responses of the dependent variable.

### 3.2.1.1 Statistical analysis

The statistical analysis of the experimental data was carried out to observe the effect of selected process parameters on the various responses. The obtained data were subjected to analyze for graphical representation, analysis of variance (ANOVA) and multiple regression using the software package Design Expert version 10.0.8 (Anderson and Whitcomb, 2005). The three-dimensional (3D) response surface plots were generated by keeping one variable constant at the center point and varying the other two variables within the experimental range. The effect and regression coefficients of individual linear, quadratic and interaction terms were determined from the ANOVA tables. The significance of all the terms in the polynomial equation was judged statistically by computing the F-value at a probability ( $p$ ) value of 0.001, 0.01 or 0.05.

### 3.2.1.2 Optimization and validation of model

The optimization of process variables was carried out by using Design Expert version 10.0.8 software. The optimum values of the selected variables were analyzed by the response surface contour plots and also by solving the regression equation. The average experimental value of different response variables was used to check the validity and adequacy of the predicted models. The optimum condition to obtain the best quality foamed pulp was considered when the foam expansion and foam stability were as high as possible, whereas foam density was as low as possible.

### 3.2.2 Dependent parameters for foamed pulp

The following foaming properties of banana pulp were measured during the experiments and their analysis is reported in Chapter- IV.

#### 3.2.2.1 Foaming properties

Foaming properties such as foam expansion, foam density and foam stability were determined at different concentration of foaming agents with different whipping time.

- Foam expansion
- Foam stability
- Foam density

##### 3.2.2.1.1 Foam expansion

Foam expansion was calculated from the volume of ripe banana pulp before and after whipping using following formula reported by Durian (1995).

Foam expansion (%)

$$= \left[ \frac{\text{Final volume of foam, cm}^3 - \text{Initial volume of pulp, cm}^3}{\text{Initial volume of pulp, cm}^3} \right] \times 100 \quad \dots(3.1)$$

##### 3.2.2.1.2 Foam stability

Foam stability of ripe banana pulp was recorded by taking of foamed pulp in a transparent graduated beaker and kept for 3 h (Plate 3.7). The reduction in foam volume was measured for foam stability for every 30 min. The stable after 1 h was considered as mechanically and thermally stable foams for entire drying period (Kundra and Ratti, 2006). Foam stability was determined by using following formula:

Foam stability (%)

$$= \left[ \frac{\text{Volume of foam at 180 min, cm}^3}{\text{Initial volume of foam including the liquid volume without foaming, cm}^3} \right] \times 100 \quad \dots(3.2)$$

### 3.2.2.1.3 Foam density

The density of foamed ripe banana pulp was analyzed in terms of mass by volume (g/cc) by Falade *et al.* (2003).

Foam density(g/cc)

$$= \text{density of pulp, g/cc} \times \left[ \frac{\text{Initial volume of pulp, cm}^3}{\text{Final volume of foam, cm}^3} \right] \quad \dots(3.3)$$



**Plate 3.7 Determination of foam stability of foamed banana pulp**

### 3.3 Experiment No. 2: Foam mat drying

Optimized parameters of foaming process were selected for further drying process. Drying characteristics and quality of powder were evaluated during tray drying and after preparation of powder.

## 3.3.1 Treatment details

Table 3.3 Independent variables

1.	Drying temperature (T)	Four levels, viz., 55 °C, 60 °C, 65°C and 70°C
2.	Drying thickness (t)	Three levels, viz., 2 mm, 4 mm and 6 mm
3.	Treatment combinations	12
4.	Replications	3
5.	Statistical design	Factorial CRD

Table 3.4 Treatment combinations for foam-mat drying of banana pulp.

Sr. No.	Treatment	Drying temperature (°C)	Drying thickness (mm)
1	T <sub>1t1</sub>	55	2
2	T <sub>1t2</sub>	55	4
3	T <sub>1t3</sub>	55	6
4	T <sub>2t1</sub>	60	2
5	T <sub>2t2</sub>	60	4
6	T <sub>2t3</sub>	60	6
7	T <sub>3t1</sub>	65	2
8	T <sub>3t2</sub>	65	4
9	T <sub>3t3</sub>	65	6
10	T <sub>4t1</sub>	70	2
11	T <sub>4t2</sub>	70	4
12	T <sub>4t3</sub>	70	6

Table 3.5 Dependent variables

Sr.No.	Parameters
<b>1. Drying characteristics</b>	
a)	Drying time (min)
b)	Drying rate (g water/g dry matter – min)
c)	Moisture ratio

<b>2. Quality of banana powder by foam mat drying</b>	
<b>i. Physical properties</b>	
a)	Recovery (%)
b)	Bulk density (g/cc)
<b>ii. Biochemical properties</b>	
a)	Moisture (%)
b)	Total sugars (%)
c)	Reducing sugar (%)
d)	Non-reducing sugar (%)
e)	Titrateable acidity (%)
f)	Ascorbic acid (mg/100 g)
g)	pH
<b>iii. Functional properties</b>	
a)	Water solubility index (WSI) (%)
b)	Water absorption index (WAI) (%)
<b>iv. Sensory evaluation</b>	
a)	Appearance
b)	Texture
c)	Flavour
d)	Taste
e)	Overall acceptability

### 3.3.2 Experimental details

#### 3.3.2.1 Tray drying

A tray dryer (M/s Khera Instruments Pvt. Ltd.) was used to dry foamed banana pulp having twelve trays. Temperature of dryer ranges from 50 to 250 °C. A digital balance with readability of  $\pm 0.001$  g was used for the measurement of weight of the sample (Plate 3.8).

Optimized foamed banana pulp derived from experiment no. 1 was dried at different temperature 55, 60, 65 and 70 °C and different thickness of 2, 4, and 6 mm in tray dryer with a constant air velocity of 0.5 m/s. The sample size of foamed banana pulp for 2, 4 and 6 mm thickness was taken as 161 g, 323 g and 485 g, respectively.

The weight loss in sample with time was measured by digital weight balance and recorded at 30 min interval for all the temperature and thickness range selected for the study (Plate 3.9). For measuring the weight of the sample during experimentation, the tray with sample was taken out of the drying chamber, weighed on the digital weight balance and placed back into the chamber. Each process of weight measurement lasted with short duration of time. The drying procedure was continued to equilibrium moisture content.



**Plate 3.8 Tray dryer**



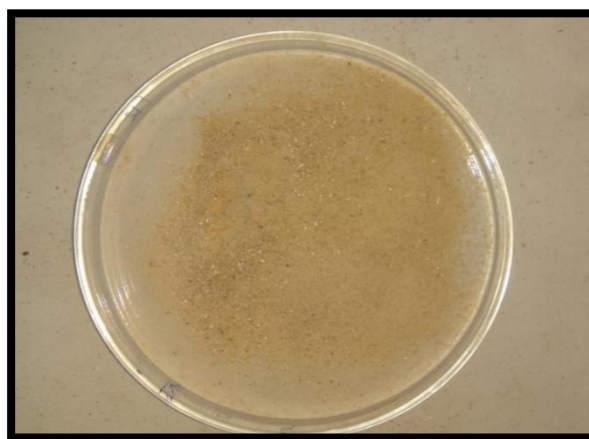
**Plate 3.9 Tray drying of foamed banana pulp**

### 3.3.2.2 Grinding of dried product

Dried matter was scraped out from stainless steel tray with use of stainless steel karchi. The collected sample was grinded in mixer (M/s Bajaj FX 11) to get powder (Plate 3.10) and further it was sieved through mesh no. 35 sieve (Plate 3.11). The powder was packed in sealed aluminium foil package having 50  $\mu\text{m}$  thickness for further quality evaluation.



**Plate 3.10 Grinding of foamed dried banana pulp**



**Plate 3.11 Sieving of banana powder**

## 3.4 Drying characteristics

### 3.4.1 Drying time (min)

Moisture lost by the foamed banana pulp in particular time interval was noted up to the weight of the drying tray in consecutive term remains constant.

### 3.4.2 Drying rate (g water/g dry matter-min)

The moisture content data recorded during experiments were analyzed to determine the moisture lost by foamed banana pulp in particular time interval. The drying rate of the samples was then calculated by equation,

DR (g water/g dry matter-min)

$$= \frac{\text{Initial weight of sample, g} - \text{Weight of sample after time } \theta, \text{ g}}{\text{Time interval, h} \times \text{Dry matter, g}} \quad \dots(3.4)$$

Where,

DR = Drying rate at time  $\theta$ , g of water removed/g of dry matter

### 3.4.3 Moisture ratio

The moisture ratio of foamed banana pulp was computed by using the initial moisture content and equilibrium moisture content. The final moisture content of the product was taken as equilibrium moisture content.

$$\text{Moisture ratio} = \frac{M - M_e}{M_o - M_e} \quad \dots(3.5)$$

Where,

M = Moisture content (% db)

$M_e$  = Equilibrium moisture content (% db)

$M_o$  = Initial moisture content (% db)

## 3.5 Quality evaluation of banana powder by foam mat drying

### 3.5.1 Physical properties

#### 3.5.1.1 Recovery (%)

Recovery of foam mat dried banana powder is analyzed by the ratio of weight of dried powder to weight of foamed banana pulp applied to the tray. The recovery of foamed dried banana powder was calculated in per cent using the following formula,

$$\text{Recovery (\%)} = \left[ \frac{\text{Weight of foamed dried powder}}{\text{Weight of foamed banana pulp on tray}} \right] \times 100 \quad \dots(3.6)$$

### 3.5.1.2 Bulk density (g/cc)

The bulk density provides an indication of the packing and arrangement of the particles, as well as the compaction profile of a material. Bulk density was determined as suggested by Wang and Kinsella (1976). A sample of 3 g of dried banana powder was put into 10 ml graduated cylinders and tapped 10 times on rubber surface. The volume of powder was recorded after 10 taps. The bulk density was calculated using the following equation.

$$\text{Bulk Density (g/cc)} = \frac{\text{Weight of powder (g)}}{\text{Volume of powder after tapping (cc)}} \quad \dots(3.7)$$

### 3.5.2 Biochemical properties

Biochemical properties such as moisture content, total sugars, reducing sugar, non-reducing sugar, titratable acidity, ascorbic acid and pH of foam dried banana powder prepared in different drying conditions were analyzed by following methods.

#### 3.5.2.1 Moisture content (%)

The moisture content (% wb) of powder was determined by hot air oven method as described by AOAC (2005). About 5-10 g of the sample was put in a pre-weighed petri dish. The weight of empty dish and dish with sample was noted separately. The sample loaded petri dishes were placed inside the hot air oven at  $105 \pm 1$  °C till it attained constant weight (Plate 3.12). The samples were cooled in a desiccator and weighed. The difference in the initial and final weight of sample was taken as the weight of water removed. The moisture content of powder was determined by the following formula,

$$\text{Moisture content (\%, wb)} = \left[ \frac{W_i - W_o}{W_i} \right] \times 100 \quad \dots(3.8)$$

Where,  $W_i$  = Initial weight of sample

$W_o$  = Final weight of sample

#### 3.5.2.2 Total sugars (%)

Total sugars estimation was performed according to the phenol sulphuric acid method as suggested by Sadasivam and Manickam (1996). One gram of banana powder was taken in a 100 ml volumetric flask in which 2 ml of lead acetate solutions was

added and kept for 10 min. The solution then de-leaded by adding 1 ml potassium oxalate solution and volume was made up to 100 ml by adding distilled water. The solution was filtered through Whatman No. 1 filter paper. The filtrate was diluted in ratio of 1:20 with distilled water and 1 ml aliquot was taken for the estimation of sugar. Then, 1 ml of 5 % phenol solution and 5 ml of 96% H<sub>2</sub>SO<sub>4</sub> was added quickly and allowed to stand for 10 min after mixing. The color of solution was read at 490 nm on spectrophotometer (Plate 3.13). The estimation of total sugar (Plate 3.13) was carried out using standard graph prepared with glucose (0-150 µg) using following equation,

Total sugars (%)

$$= \frac{\text{Sample reading} \times \text{Glucose equivalent} \left( \frac{\mu\text{g}}{\text{OD}} \right) \times \text{Volume made up}}{\text{Weight of pulp (g)} \times \text{Aliquot taken (ml)}} \times 10^{-6} \times 100 \quad \dots(3.9)$$

### 3.5.2.3 Reducing sugar (%)

Nelson-Somogyi method as reported by Sadasivam and Manickam (1996) was used for estimation of reducing sugar as shown in Plate 3.14. The filtrate obtained from the estimation of total sugar was used for determination of reducing sugar. From the collected filtrate, 0.5 ml aliquot was pipetted in test tube and final volume was made up to 2 ml with distilled water. Then, 1 ml of alkaline copper tatrte was added and boiled in water bath for 10 min and cooled. After that, 1 ml of arsenomolybdenum solution was added and volume was made up to 10 ml by adding 6 ml of distilled water and the intensity of blue colour at 620 nm on spectrophotometer was read. Standard graph was prepared using glucose (0-150 µg) and calculation was done using following relationship,

Reducing sugar (%)

$$= \frac{\text{Sample reading} \times \text{Glucose equivalent} \times \text{Volume made up}}{\text{Weight of pulp} \times \text{Aliquot taken}} \times 100 \times 10^{-6} \quad \dots(3.10)$$

### 3.5.2.4 Non-reducing sugar (%)

Non-reducing sugar for each powder sample was calculated by subtracting the reducing sugar value from the total sugar value of each powder sample as per method suggested by Ranganna (2000). Non-reducing sugar for each powder sample was calculated as per following formula,

$$\text{Non-reducing sugar (\%)} = \text{Total sugars} - \text{reducing sugar} \quad \dots(3.11)$$

### 3.5.2.5 Titratable Acidity (%)

Titrate acidity was estimated as reported by Ranganna (2000). Homogenized 10 g banana pulp was transferred to volumetric flask and the volume was made up to 100 ml by adding distilled water. The suspension was then filtered through Whatman No. 1 filter paper and filtrate was used for titration. From the collected filtrate, 5 ml aliquot was taken and titrated against standard sodium hydroxide using phenolphthalein as an indicator. The titratable acidity in terms of per cent citric acid equivalent was calculated (Plate 3.15) by using the following equation,

Titrate acidity (%)

$$= \frac{\text{Titre (ml)} \times 0.5 \text{ N NaOH (ml)} \times \text{Volume made up (ml)}}{\text{Weight of sample (g)} \times \text{Aliquot taken (ml)} \times 1000} \times 100 \quad \dots(3.12)$$

### 3.5.2.6 Ascorbic Acid (mg/100 g)

Ascorbic acid content was determined by the method described by Sadasivam and Manickam (1996). As suggested, 10-100 mg standard dehydroascorbic solution into a series of tubes was pipetted out. Similarly different aliquots (0.1-2 ml) of brominated sample extract was pipetted out. The volume in each tube was made up to 1 ml by adding distilled water. 2 ml of DNPH reagent was added which was followed by 1-2 drops of thiourea to each tube. The contents of the tubes were mixed thoroughly and incubated at 80 °C for 15 min. After incubation, the orange-red ozone crystals were dissolved which were formed by adding 5 ml of 80% sulphuric acid (Plate 3.16). The absorbance was measured at 540 nm.

Ascorbic acid (mg/100 g)

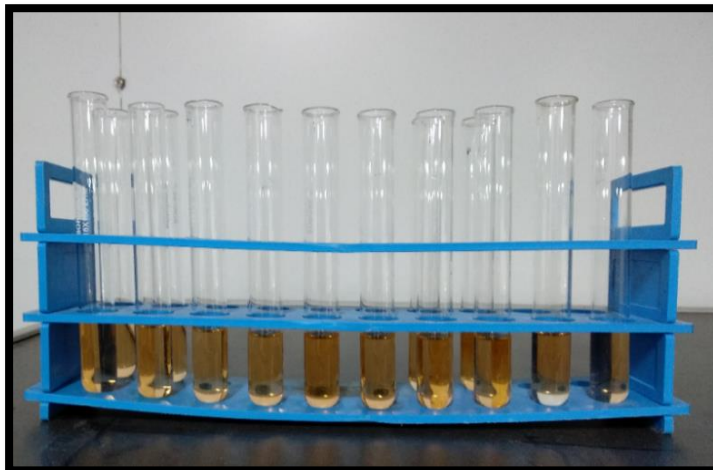
$$= \frac{\text{Titre (ml)} \times \text{Dye factor (mg/ml)} \times \text{Volume made up (ml)}}{\text{Weight of sample (g)} \times \text{Aliquot taken (ml)}} \times 100 \quad \dots(3.13)$$

### 3.5.2.7 pH

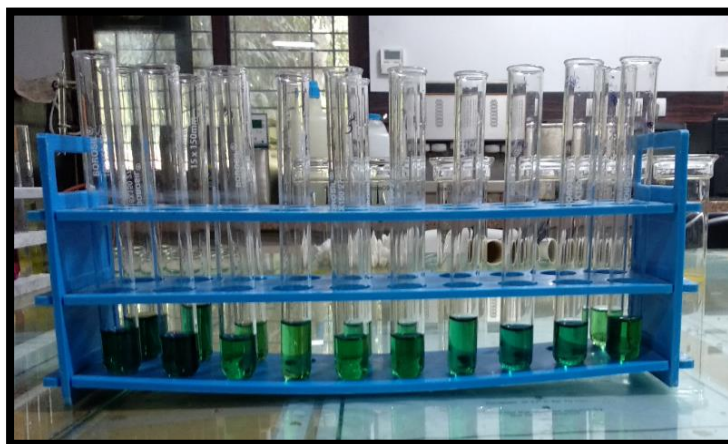
The pH is defined as a negative logarithm to the base 10 of H<sup>+</sup> ion activity of concentration. pH of the powder was measured directly using pH meter (Plate 3.17). Firstly, 10 g of sample was weighing followed by macerate with 100 ml of water, after that the mixture was to stand for 30 min and decanted the supernatant in a beaker. The pH meter was calibrated with standard buffer solution before measuring pH of powder.



**Plate 3.12** Determination of moisture content from banana powder



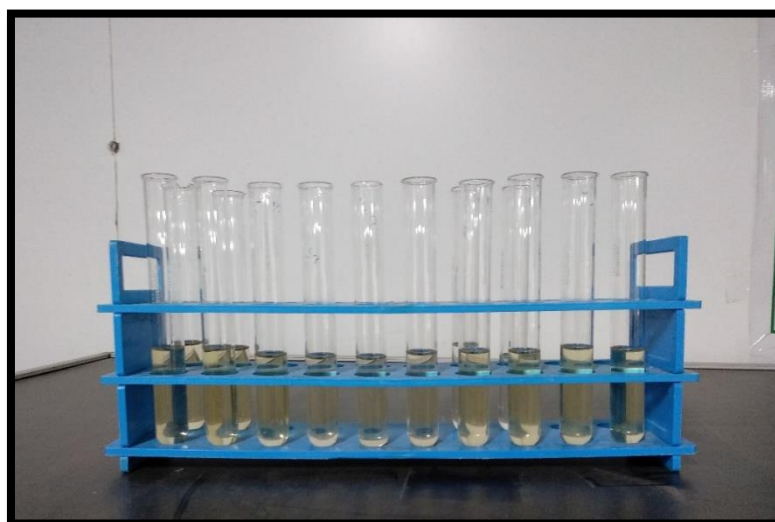
**Plate 3.13** Determination of total sugars of banana powder



**Plate 3.14** Determination of reducing sugar of banana powder



**Plate 3.15** Determination of titratable acidity of banana powder



**Plate 3.16** Determination of ascorbic acid of banana powder



**Plate 3.17** Determination of pH of banana powder

### 3.5.3 Functional properties

#### 3.5.3.1 Water solubility index (WSI) (%)

The solubility of banana powder in normal hot water was determined by the method suggested by Anderson (1982). Water solubility index (WSI) is defined as the weight of dissolved solids in supernatant per weight of dry solid powder and expressed in per cent. For determination of water solubility index 2.5 g banana powder was dispersed in 25 g of distilled water at 30 °C. A glass rod was used to break up any lumps. After stirring for 30 min, the dispersions were rinsed into tarred centrifuge tubes. The solution was then centrifuged at 3000 rpm for 10 min. The supernatant liquid was poured carefully into a tared evaporating dish. The amount of dried solid was recovered by evaporating supernatant. The water solubility index was calculated by the following equation,

$$\text{WSI (\%)} = \frac{\text{Weight of dissolve solid in supernatant}}{\text{Weight of dry solid powder}} \times 100 \quad \dots(3.14)$$

#### 3.5.3.2 Water absorption index (WAI) (%)

Water absorption index is the ratio of the weight of sediments to that of weight of dry solid powder and expressed in per cent. The sediment obtained in the estimation of water solubility index was used for determination of water absorption index and calculated by the following equation,

$$\text{WAI (\%)} = \frac{\text{Weight of sediments}}{\text{Weight of dry solid powder}} \times 100 \quad \dots(3.15)$$

### 3.6 Sensory evaluation

Sensory characteristics *viz.*, appearance, texture, flavor, taste and over all acceptability of foamed dried banana powder were evaluated by a panel of semi trained 10 judges using 9 point hedonic scale (Amerine *et al.*, 1965). A semi-trained panelist was consisting of 10 members with 9 males and 1 female, between the age group of 25 to 55 year. The panelists were the staff members of the College of Agricultural Engineering and Technology, Junagadh. Before the sensory evaluation was conducted the panel was trained for the sensory qualities to be evaluated, to get familiar with the rating method and the terminology of the attributes used. The sensory evaluation sheet is presented in Appendix - C.



**Plate 3.18 Sensory evaluation of banana powder**

### **3.7 Statistical analysis**

Statistical analysis for experiment no. 1 (foaming process) was carried out as per the Response Surface Methodology (RSM) for evaluation of foaming properties (Khuri and Cornell, 1987). The statistical analysis for experiment no. 2 (foam mat drying) was carried out as per the Factorial Completely Randomized Design (FCRD) with three replications (Panse and Sukhatme, 1985). All the treatments were compared at 5% level of significance using the critical difference test. The analysis of variance (ANOVA), standard error of mean (S.Em), critical difference (CD), coefficient of variance (CV) and mean values for dependent parameters were tabulated and the level of significance was reported.

## CHAPTER - IV

### RESULTS AND DISCUSSION

This chapter deals with the results obtained from the experiments on foaming properties of banana pulp. The banana pulp was treated with different levels of foaming agent (whey protein isolate, %), foaming stabilizer (methyl cellulose, %) and whipping time (min) and optimized by Response Surface Methodology technique. The proportion of whey protein isolate, methyl cellulose and whipping time were optimised for foam expansion, foam stability and foam density of foamed banana pulp process. The optimum parameters of foaming process were further subjected to drying at different drying temperature and foam thickness. Drying was carried out in tray dryer and drying characteristics and quality of powder were evaluated after preparation of powder. The results are presented and discussed in subsequent sections.

#### 4.1 Biochemical properties of banana pulp

The biochemical properties of ripe banana fruit (stage-5) are presented in Table 4.1. From the table, it can be observed that the mean values of biochemical properties *viz.*, moisture content, total soluble solids (TSS), total sugars, reducing sugar, titratable acidity, ascorbic acid and pH of five ripened banana fruit (stage-5) with their standard deviation was observed to be  $75 \pm 2$  (% , wb),  $15 \pm 1$  °Brix,  $17 \pm 1$ %,  $9 \pm 0.3$ %,  $0.24 \pm 0.05$ %,  $10.1 \pm 0.5$  mg/100 g and  $5.85 \pm 0.3$ , respectively.

**Table 4.1 Mean composition of fresh banana used for research work**

Properties	Value
Moisture content (% , wb)	$75 \pm 2$
TSS (°Brix)	$15 \pm 1$
Total sugars (%)	$17 \pm 1$
Reducing sugars (%)	$9 \pm 0.3$
Titratable acidity (%)	$0.24 \pm 0.05$
Ascorbic acid (mg/100 g)	$10.1 \pm 0.5$
pH	$5.85 \pm 0.3$

## 4.2 Response surface analysis

The response surface analysis of different response parameters as a function of foaming process variables was developed by multiple regression technique. It is useful to explain the interaction of different variables and to determine the optimum level of each variable. It was carried out by plotting the response surface curves for the individual response parameters. Each response surface curve explains the effect of two variables while keeping the third variable fixed at middle level. The explanation on effect of different independent variables on response parameters and their graphical presentation are given under this section.

## 4.3 Different treatments on the foam properties of banana pulp

The pre-treated banana pulp was treated with different concentration of whey protein isolate (2.5-12.5%), methyl cellulose (0.1-0.5%) for different whipping time (5-25 min). Each sample was analysed for their foaming properties *i.e.* foam expansion, foam stability and foam density. The experimental results for foamed banana pulp is presented in Table 4.2. A complete second order model 3.14 was tested for its adequacy to correlate the variation of response with independent variables. To aid visualization of variation in responses with respect to processing variables, series of three dimensional response surfaces were drawn using Design Expert Software 10.0.8. The variation of foam properties due to process parameters is discussed in separate sections as below:

### 4.3.1 Effect of foaming agent, foaming stabilizer and whipping time on foam expansion of banana pulp

It can be observed that foam expansion increased up to certain increase of foaming agent and then it slightly decreased. Maximum foam expansion was obtained in treatment number 3. Foam expansion obtained during this treatment was 138.54%. In this treatment, foaming agent was 4.53%, foaming stabilizer was 0.42% and whipping time was 9.05 min. Minimum expansion was observed in treatment number 14. In this treatment, foaming agent was 7.50%, foaming stabilizer was 0.30% and whipping time was 25 min.

The effect of foaming agent, foaming stabilizer and whipping time on foam expansion of banana pulp is presented in Table 4.2 while the response surface curves

Table 4.2 Experimental data of foam properties of banana pulp

Run	Treatment	Uncoded variables			Responses		
		Foaming agent (%)	Foaming stabilizer (%)	Whipping time (min)	Foam expansion (%)	Foam stability (%)	Foam density (g/cc)
1	2	10.47	0.18	9.05	112.56	75.42	0.48
2	16	7.50	0.30	15.00	127.62	82.49	0.45
3	17	7.50	0.30	15.00	126.67	76.12	0.45
4	18	7.50	0.30	15.00	101.90	83.72	0.50
5	12	7.50	0.50	15.00	132.38	95.00	0.44
6	7	4.53	0.42	20.95	104.39	91.78	0.50
7	1	4.53	0.18	9.05	128.29	78.45	0.45
8	5	4.53	0.18	20.95	102.44	76.43	0.50
9	15	7.50	0.30	15.00	126.19	83.05	0.45
10	14	7.50	0.30	25.00	88.57	75.81	0.54
11	11	7.50	0.10	15.00	120.48	71.82	0.46
12	3	4.53	0.42	9.05	138.54	93.71	0.43
13	19	7.50	0.30	15.00	125.24	78.55	0.45
14	9	2.50	0.30	15.00	100.50	79.18	0.51
15	8	10.47	0.42	20.95	96.28	87.29	0.52
16	6	10.47	0.18	20.95	95.81	73.22	0.52
17	4	10.47	0.42	9.05	126.51	89.45	0.45
18	20	7.50	0.30	15.00	119.52	82.55	0.46
19	13	7.50	0.30	5.00	111.90	85.86	0.48
20	10	12.50	0.30	15.00	92.27	72.11	0.53

and contour plots for foam expansion of banana pulp are shown in the Fig. 4.1 to Fig. 4.6.

**Table 4.3 Analysis of variance (ANOVA) table and regression coefficients for response surface quadratic model of different foaming properties of banana pulp**

Source	Foam expansion	Foam stability	Foam density
Intercept	120.99	80.97	0.46
<b>Linear terms</b>			
A(X <sub>1</sub> )	-4.13	-1.97*	0.009053
B(X <sub>2</sub> )	3.41	7.15***	-0.006124
C(X <sub>3</sub> )	-10.71**	-1.85	0.024***
<b>Interaction terms</b>			
AB(X <sub>1</sub> X <sub>2</sub> )	0.28	-0.31	-0.00125
AC(X <sub>1</sub> X <sub>3</sub> )	1.63	-0.051	-0.00125
BC(X <sub>2</sub> X <sub>3</sub> )	-2.72	0.016	0.00625
<b>Quadratic terms</b>			
A <sup>2</sup> (X <sub>1</sub> <sup>2</sup> )	-7.45**	-1.22	0.018**
B <sup>2</sup> (X <sub>2</sub> <sup>2</sup> )	3.17	1.53	-0.006512
C <sup>2</sup> (X <sub>3</sub> <sup>2</sup> )	-6.09*	0.61	0.015*
<b>Indicators for model fitting</b>			
R <sup>2</sup>	0.8194	0.9013	0.8552
Adj-R <sup>2</sup>	0.6569	0.8125	0.7248
Pred-R <sup>2</sup>	0.3236	0.5474	0.4691
Adeq Precision	7.998	12.016	8.868
F-value	5.04	10.15	6.56
Lack of fit	NS	NS	NS
C.V. %	7.75	3.77	3.70

A or X<sub>1</sub>= Foaming agent, B or X<sub>2</sub>= Foaming stabilizer, C or X<sub>3</sub>= Whipping time, \*\*\*Significant at p<0.001, \*\*Significant at p<0.01, \*Significant at p<0.05, NS = Non-significant

#### 4.3.1.1 Effect of foaming agent and foaming stabilizer on foam expansion

The response surface curve of variation in the foam expansion of banana as a function of foaming agent (X<sub>1</sub>) and foaming stabilizer (X<sub>2</sub>) is shown in Fig. 4.1. It represents the interactive effect of foaming agent and foaming stabilizer on the foam expansion of banana pulp, keeping the whipping time (X<sub>3</sub>) at middle level, *i.e.* 15 min.

The contour plot for foam expansion of banana pulp as a function of foaming agent and foaming stabilizer is presented in the Fig. 4.2 which indicates the increase in foam expansion as the foaming agent was increased up to 6.8% and foaming stabilizer up to up to its maximum level of 0.50%. The foam expansion at this combination was proposed to be increased up to 135.89%. With further increase in foaming agent beyond 6.8%, the foam expansion was decreased. This might be due to saturation point of foaming agent solubility under experimental conditions. Similarly, another probability of maximum foam expansion (124.41) was found at 6.47% foaming agent and 0.11% foaming stabilizer. Similar findings were also reported by Kandasamy *et al.* (2012) for foam expansion in papaya pulp.

#### 4.3.1.2 Effect of foaming agent and whipping time on foam expansion

The effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam expansion of banana pulp, keeping foaming stabilizer ( $X_2$ ) at middle level, *i.e.* 0.3% is graphically represented in the Fig. 4.3. The interaction effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam expansion of banana pulp at constant foaming stabilizer ( $X_2$ ) is presented through contour plot as shown in Fig. 4.4. This contour graph shows the increase in foam expansion with an increase in foaming agent and whipping time up to 6.38% and 9.45 min, respectively. At this combination of foaming agent and whipping time, the foam expansion of pulp was expected to be increased up to 126.74%. With further increase in foaming agent and whipping time, the foam expansion of pulp was found to be decreased. This may be due to expansion of foams increased with whipping time up to a maximum and decreased thereafter probably because excessive whipping (overbeating) could cause foam to collapse. Similar findings was also reported by Raharitsifa *et al.* (2006) on foam mat drying in apple juice foams.

#### 4.3.1.3 Effect of foaming stabilizer and whipping time on foam expansion

The effect of foaming stabilizer ( $X_2$ ) and whipping time ( $X_3$ ) on foam expansion of banana pulp at constant foaming agent ( $X_1$ ) at middle level *i.e.* 7.5% is shown in Fig. 4.5. Whereas the contour plot for foam expansion of banana pulp as a function of foaming stabilizer and whipping time is presented in the Fig. 4.6. The interaction effect showed the increase in foam expansion with an increase in foaming stabilizer up to its maximum level of 0.50% and with an increase in whipping time up to 8.37 min. At this

combination of foaming stabilizer and whipping time, the foam expansion of pulp was projected to be increased up to 144.51%. With further increase in whipping time, the foam expansion decreased. Similarly, another probability of maximum foam expansion (125.23) was found at 0.11% foaming stabilizer and 11.76 min whipping time.

The significant F-value and non-significant lack of fit indicates the fitness and reliability of the model for a given response. However, the adequacy of the model needed to be further checked by the coefficient of regression ( $R^2$ ), which is the ratio of the explained variation to the total variation and is a measure of the degree of fit (Haber and Runyon, 1977). It is also the proportion of the variability in the response variables which is accounted for the regression analysis (McLaren *et al.*, 1977). The closer the value of  $R^2$  to unity, the better is the empirical model fits the actual data. The smaller the value of  $R^2$ , the less relevant the dependent variables in the model have in explaining the behaviour variation (Little and Hills, 1978; Mendenhall, 1975). The value of  $R^2$  greater than 0.8, implies that the model indicates a good fit. (Joglekar and May, 1987). Nevertheless, some researchers suggested that a large value of  $R^2$  does not always imply that the regression model is a good one. Increasing  $R^2$  can be obtained by adding a variable to the model. Thus, it is preferred to use an adjusted  $R^2$  to evaluate the model adequacy and it should be over 0.8 (Koocheki *et al.*, 2010). Moreover, other parameters, namely predicted  $R^2$  which should be closer to 1 and adequate precision which should be greater than 4 are supportive of the significance of the model (Akesowan and Choonhahirun, 2013).

The regression analysis and ANOVA results for the foam expansion of banana pulp are shown in the Table 4.3. It can be seen from the table that, foaming agent and whipping time indicated negative linear effect while foaming stabilizer indicated positive linear effect on foam expansion of banana pulp. The quadratic effect of both, foaming agent and whipping time was negative and the quadratic effect of foaming stabilizer was positive on foam expansion. The effect of interaction between foaming agent and foaming stabilizer and interaction between foaming agent and whipping time was found positive. The effect of interaction between foaming stabilizer and whipping time was found negative for foam expansion of banana pulp.

The derived model giving the empirical relation between the foam expansion and the test variables in coded units was obtained as under:

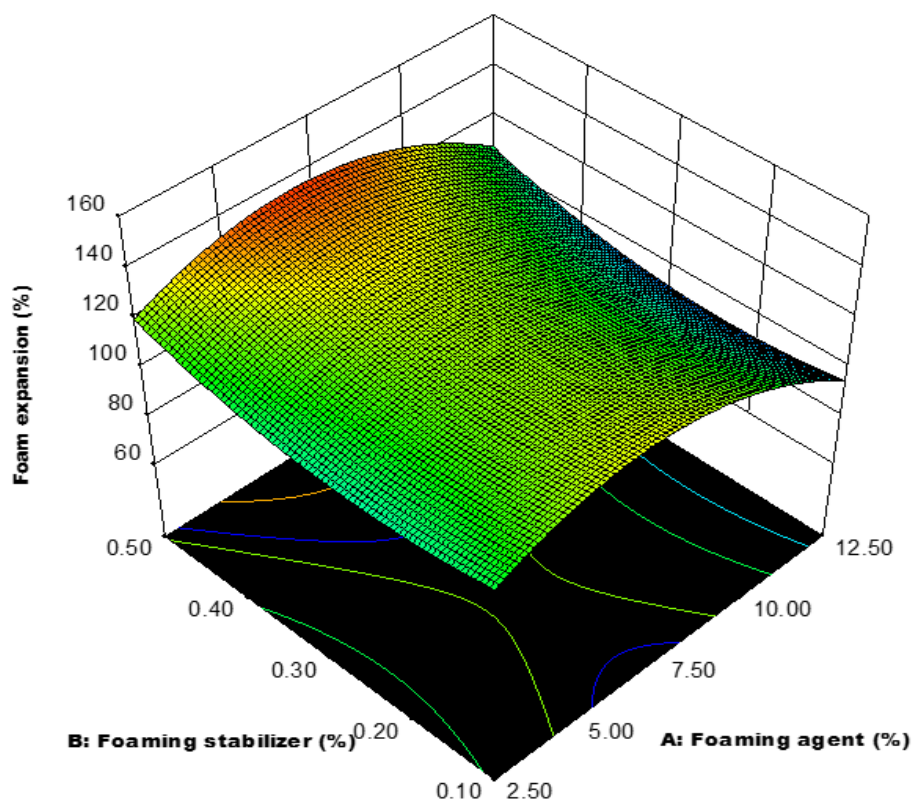


Fig. 4.1 Response surface plot for foam expansion as a function of foaming agent and foaming stabilizer

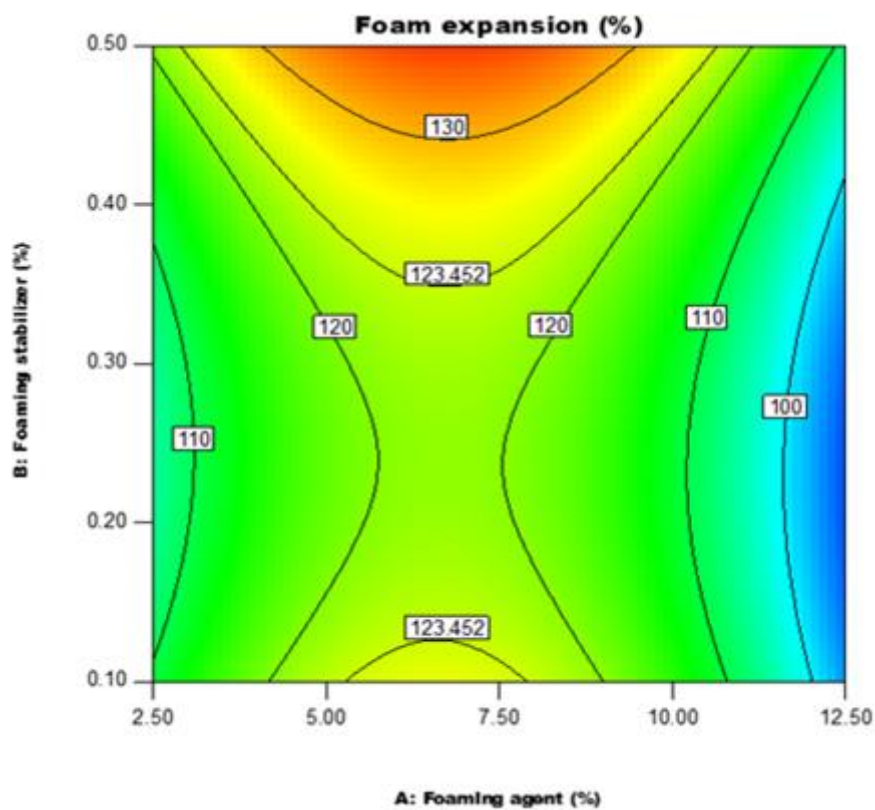
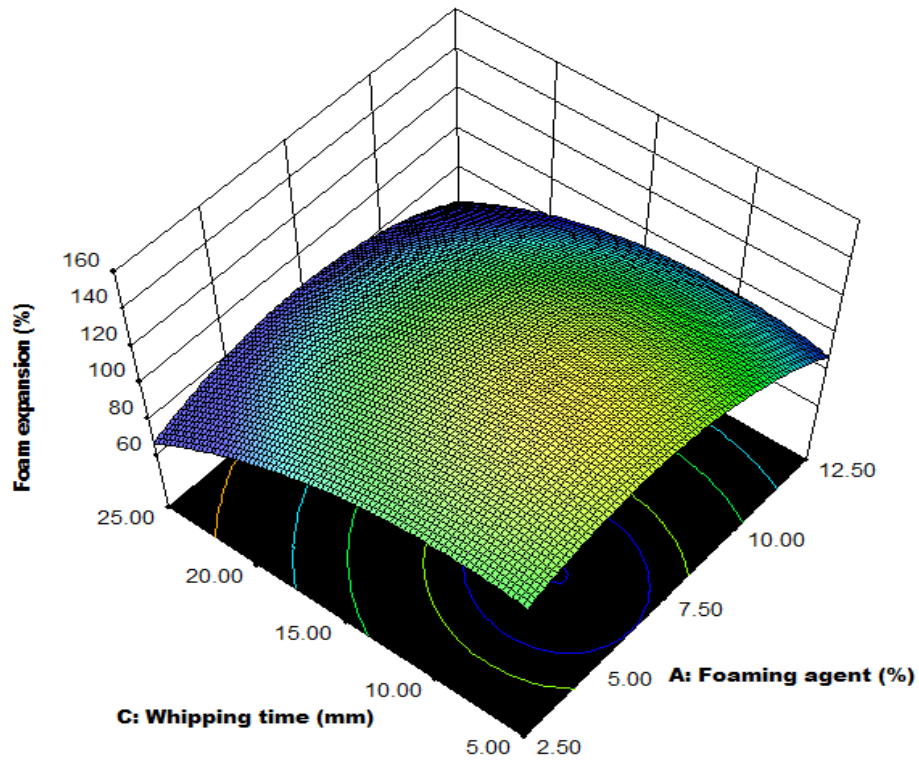
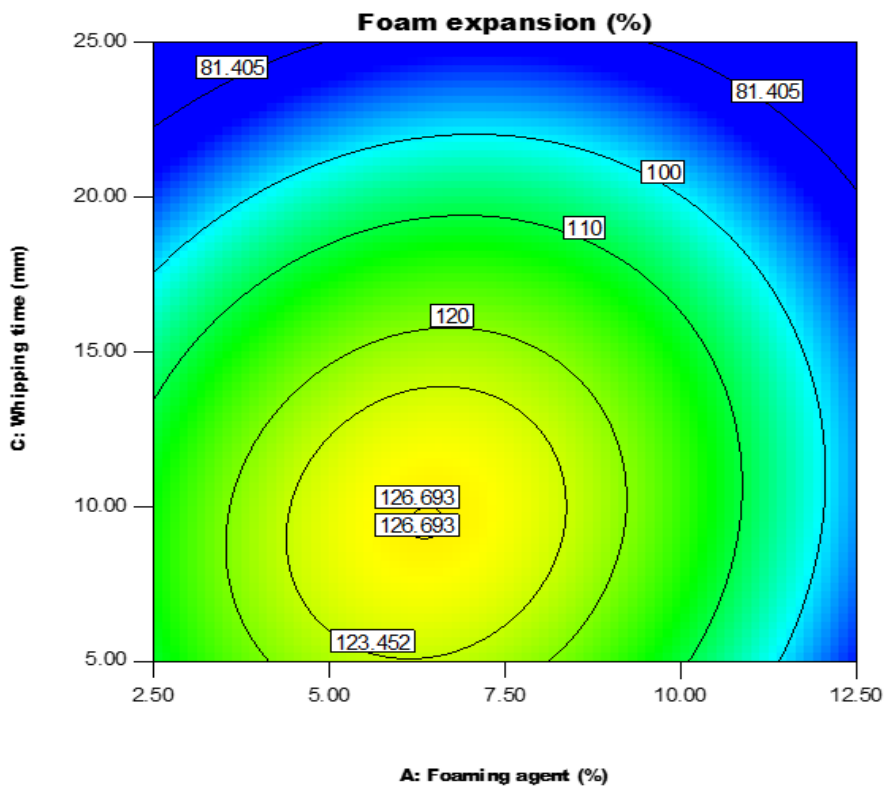


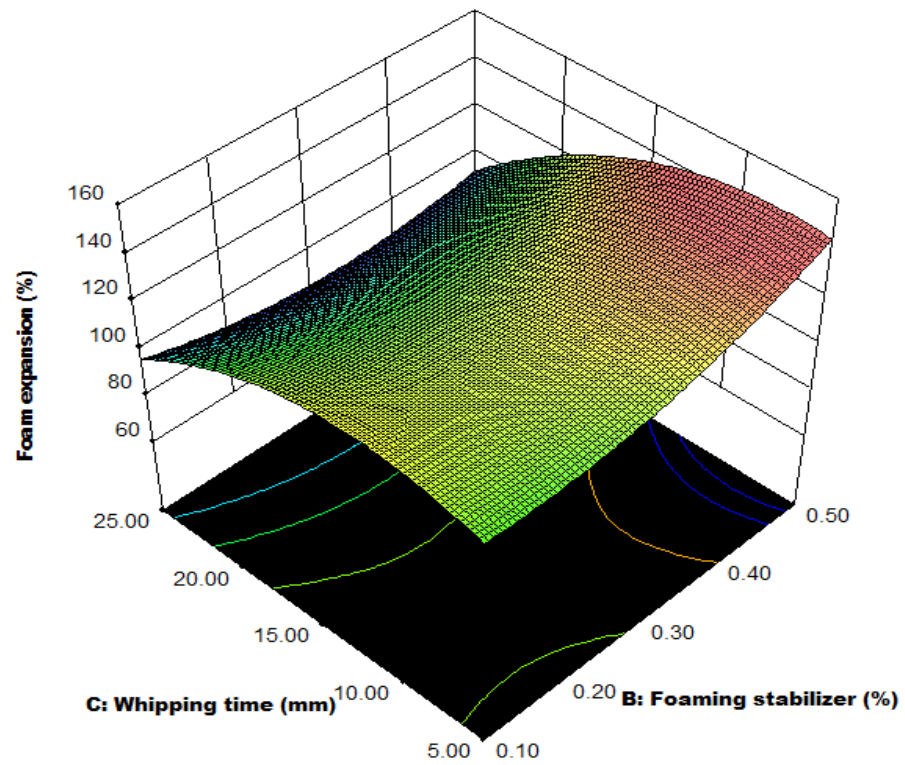
Fig. 4.2 Contour plot for foam expansion as a function of foaming agent and foaming stabilizer



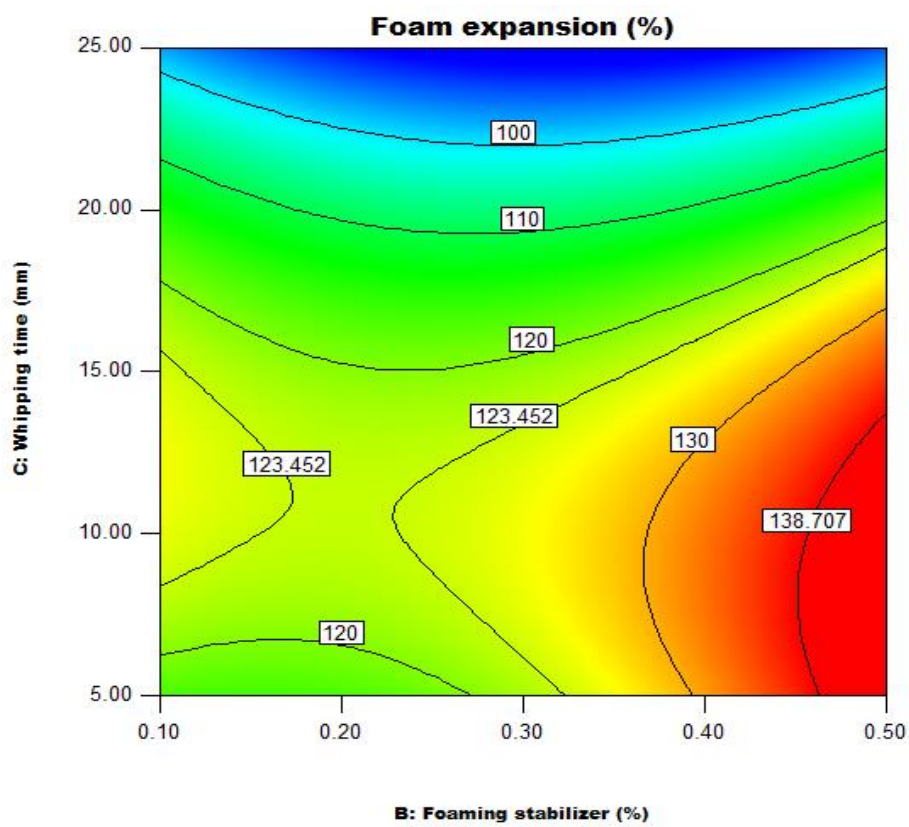
**Fig. 4.3** Response surface plot for foam expansion as a function of foaming agent and whipping time



**Fig. 4.4** Contour plot for foam expansion as a function of foaming agent and whipping time



**Fig. 4.5** Response surface plot for foam expansion as a function of foaming stabilizer and whipping time



**Fig. 4.6** Contour plot for foam expansion as a function of foaming stabilizer and whipping time

$$\text{Foam expansion} = 120.99 - 4.13 A + 3.41 B - 10.71 C + 0.28 AB + 1.63 AC - 2.72 BC - 7.45 A^2 + 3.17 B^2 - 6.09 C^2$$

Where, A, B and C are the coded factors of foaming agent, foaming stabilizer and whipping time, respectively.

The calculated F-value for foam expansion (5.04) was significant at  $p < 0.01$ . At the same time, it possessed non-significant lack of fit ( $p > 0.05$ ). These values indicated that the model for foam expansion was fitted and reliable. The  $R^2$  value and Adj- $R^2$  value for the bulk density were 0.8194 and 0.6569, respectively, indicating the adequacy, good fit and high significance of the model. The Pred- $R^2$  (0.3236) was in reasonable agreement with the Adj- $R^2$ . The high Adeq. Precision value ( $>4$ ) again supported the significance of the model for foam expansion. The small value of coefficient of variation (7.75%) for foam expansion explained that the experimental results were precise and reliable (Table 4.3).

### 4.3.2 Effect of foaming agent, foaming stabilizer and whipping time on foam stability of banana pulp

It is apparent that foam stability increased as concentration of foam stabilizers increased. Also, it depends on foaming agent and whipping time. Maximum foam stability was observed in treatment number 12. The maximum foam stability was 95.00%. In this treatment, foaming agent, foaming stabilizer and whipping time were 7.50%, 0.50% and 15.00 min, respectively. Minimum foam stability was observed in treatment number 11. Minimum foam stability reported was 71.82%. In this treatment, foaming agent, foaming stabilizer and whipping time used were 7.50%, 0.10% and 15.00 min, respectively.

The effect of foaming agent, foaming stabilizer and whipping time on foam stability of banana pulp is presented in Table 4.2 while the response surface curves and contour plots for foam stability are shown in the Fig. 4.7 to Fig. 4.12.

#### 4.3.2.1 Effect of foaming agent and foaming stabilizer on foam stability

The response surface curve of variation in the foam stability of banana as a function of foaming agent ( $X_1$ ) and foaming stabilizer ( $X_2$ ) is shown in Fig. 4.7. It represents the interactive effect of foaming agent and foaming stabilizer on the foam stability of banana pulp, keeping the whipping time ( $X_3$ ) at middle level, *i.e.* 15 min. The contour plot for foam stability of banana pulp as a function of foaming agent and foaming stabilizer is presented

in the Fig. 4.8 which indicated the increase in foam stability as the foaming agent was increased up to 4.22% and foaming stabilizer up to maximum limit of 0.5%. The foam stability at this combination was proposed to be increased up to 98.26%. With further increase in foaming agent, the foam stability of pulp decreased up to its maximum level.

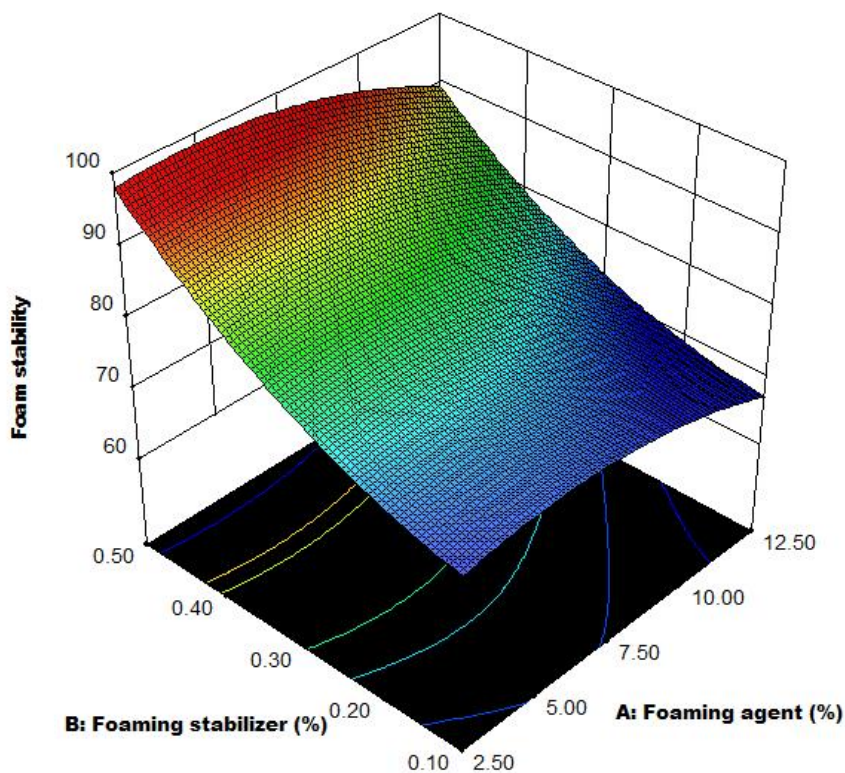
#### 4.3.2.2 Effect of foaming agent and whipping time on foam stability

The effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam stability of banana pulp at constant foaming stabilizer ( $X_2$ ) at middle level, *i.e.* 0.3% is graphically represented in the Fig. 4.9. The interaction effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam expansion of banana pulp at constant foaming stabilizer ( $X_2$ ) is presented through contour plot as shown in Fig. 4.10. This contour graph shows the increase in foam stability with an increase in foaming agent and whipping time up to 5.07% and 5.14 min, respectively. At this combination of foaming agent and whipping time, the foam stability of pulp was expected to be increased up to 86.44%. With further increase in foaming agent and whipping time, the foam stability of pulp was found to be decreased.

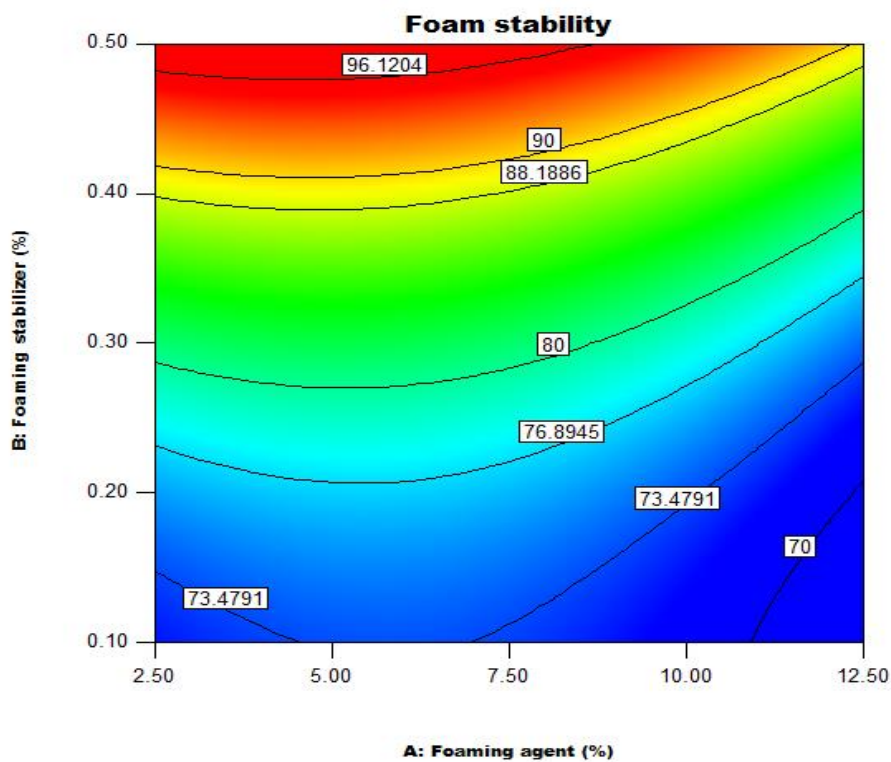
#### 4.3.2.3 Effect of foaming stabilizer and whipping time on foam stability

The effect of foaming stabilizer ( $X_2$ ) and whipping time ( $X_3$ ) on foam stability of banana pulp at constant foaming agent ( $X_1$ ) at middle level, *i.e.* 7.5% is shown in Fig. 4.11. Whereas the contour plot for foam expansion of banana pulp as a function of foaming stabilizer and whipping time is presented in the Fig. 4.12. The interaction effect showed the increase in foam stability with an increase in foaming stabilizer up to its maximum limit of 0.49% and whipping time up to 5.47 min. At this combination of foaming stabilizer and whipping time, foam stability of pulp was projected to be increased up to 101.05%. With further increase in whipping time, the foam stability of pulp decreased. Foam stability Similar result was also reported by Kandasamy *et al.* (2012) for papaya powder.

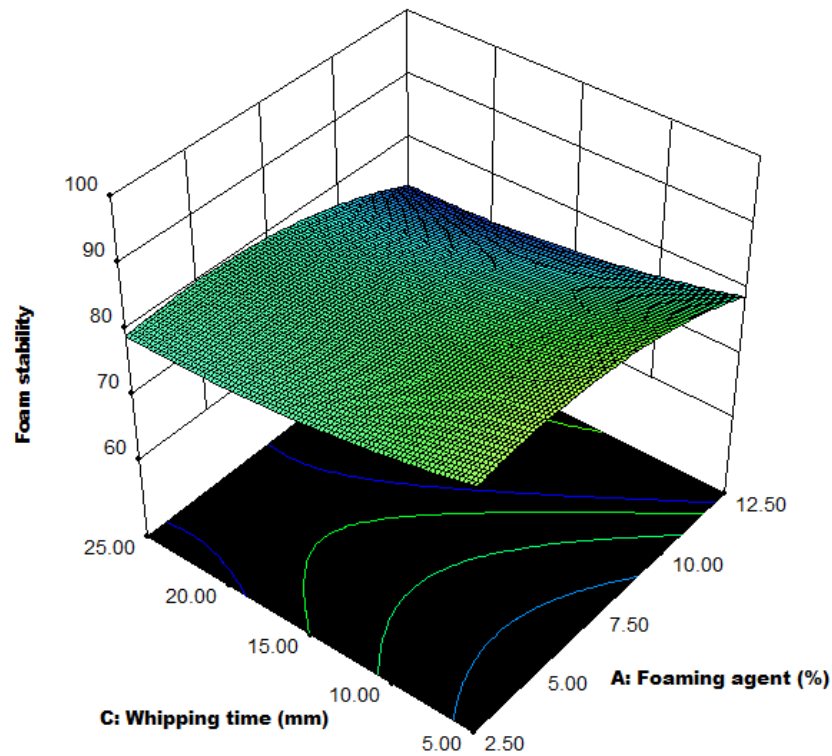
The regression analysis and ANOVA results for the foam stability of banana pulp are shown in the Table 4.3. From this table, it can be seen that, foaming agent and whipping time indicated negative linear effect while foaming stabilizer indicated positive linear effect on foam stability of banana pulp which was significant at  $p < 0.001$ . The quadratic effect of both, foaming stabilizer and whipping time was positive and the quadratic effect of foaming agent was negative on foam stability. The effect of interaction between foaming agent and foaming stabilizer and interaction between foaming agent and whipping time was found



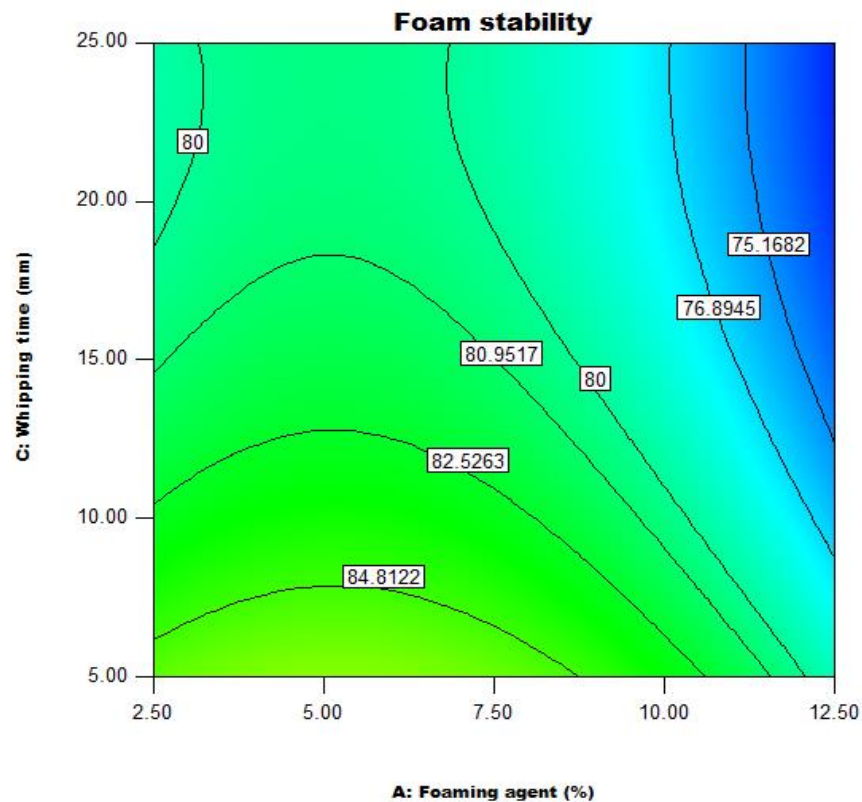
**Fig. 4.7** Response surface plot for foam stability as a function of foaming agent and foaming stabilizer



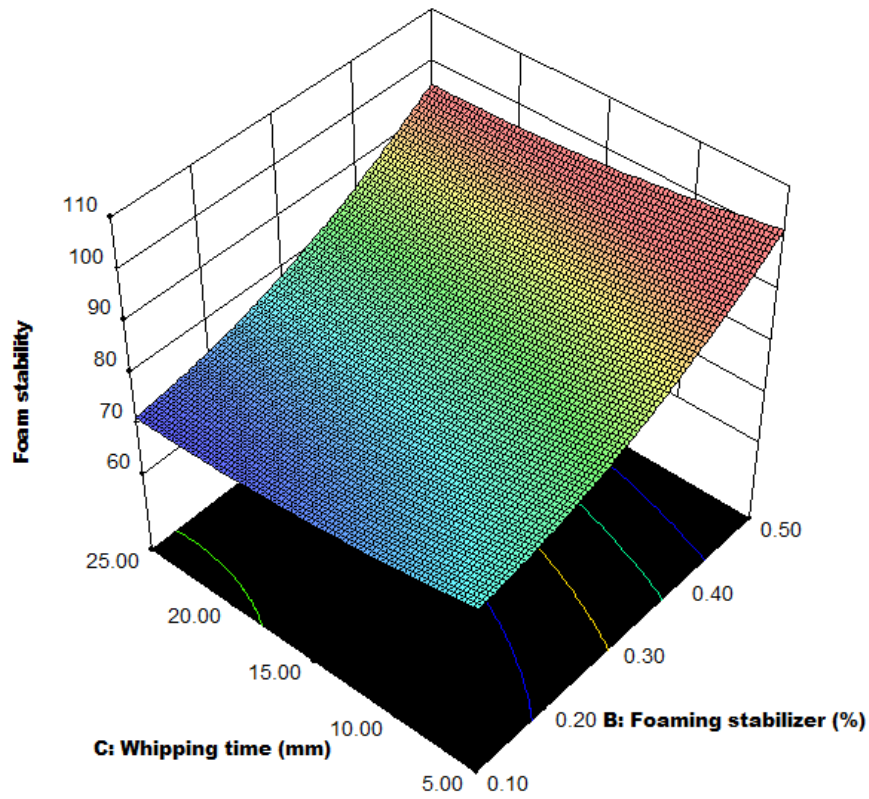
**Fig. 4.8** Contour plot for foam stability as a function of foaming agent and foaming stabilizer



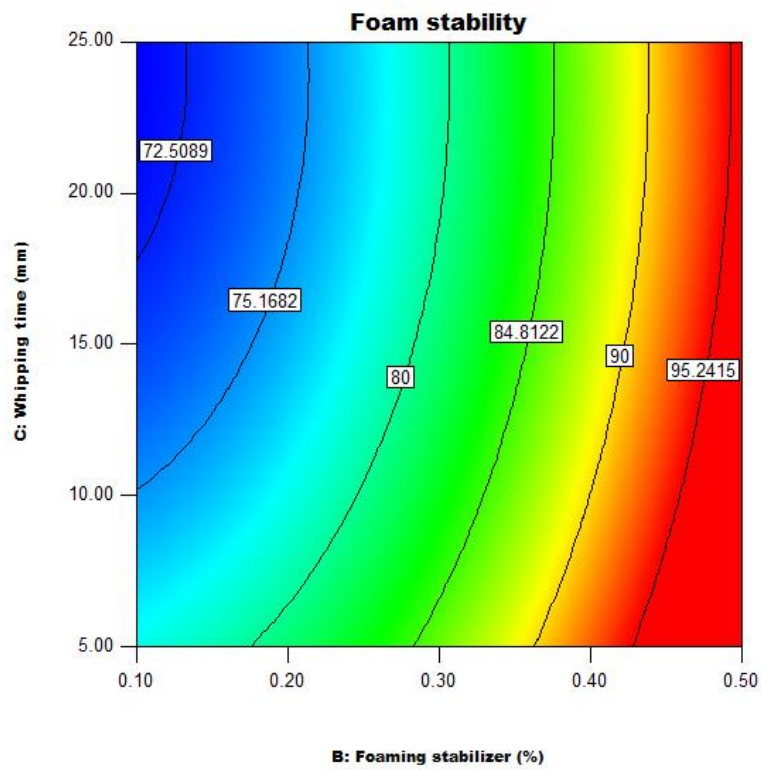
**Fig. 4.9** Response surface plot for foam stability as a function of foaming agent and whipping time



**Fig. 4.10** Contour plot for foam stability as a function of foaming agent and whipping time



**Fig. 4.11** Response surface plot for foam stability as a function of foaming stabilizer and whipping time



**Fig. 4.12** Contour plot for foam stability as a function of foaming stabilizer and whipping time

negative. The effect of interaction between foaming stabilizer and whipping time was found positive for foam stability of banana pulp.

The model as derived and giving the empirical relation between the foam stability of banana pulp and the test variables in coded units, was obtained as under:

$$\text{Foam stability} = 80.97 - 1.97 A + 7.15 B - 1.85 C - 0.31 AB - 0.051 AC + 0.016 BC - 1.22 A^2 + 1.53 B^2 + 0.61 C^2$$

Where, A, B and C are the coded factors of foaming agent, foaming stabilizer and whipping time, respectively.

The calculated F-value for foam stability (10.15) was significant at  $p < 0.001$ . At the same time, it possessed non-significant lack of fit ( $p > 0.05$ ). These values indicated that the model for foam stability was fitted and reliable. The  $R^2$  value and Adj- $R^2$  value for the foam stability were 0.9013 and 0.8125, respectively, which were higher than the 0.8, indicating the adequacy, good fit and high significance of the model. The Pred- $R^2$  (0.5474) was in reasonable agreement with the Adj- $R^2$ . The high Adeq. Precision value ( $> 4$ ) again supported the significance of the model for foam stability. The small value of coefficient of variation (3.77 %) for foam stability explained that the experimental results were precise and reliable (Table 4.3).

### **4.3.3 Effect of foaming agent, foaming stabilizer and whipping time on foam density of banana pulp**

Foam density is commonly used to evaluate whipping properties. The more air incorporated during whipping, the lower the foam density (Falade *et al.* 2003). Density of the foamed banana pulp varied from 0.43 to 0.54 g/cc (Table 4.2). Lower foam density indicated that more air was trapped in the foam. There is no much variation of foam density due to methyl cellulose concentration as its function is to stabilize the foam structure. Bikerman (1973) has suggested that high viscosity liquid would prevent the trapping of air during whipping or mechanical mixing. Maximum foam density was obtained in treatment number 14. Maximum foam density obtained was 0.54 g/cc. In this treatment, foaming agent, foaming stabilizer and whipping time were 7.50%, 0.30% and 25 min. Minimum foam density obtained was in treatment number 3. Minimum foam density was 0.43 g/cc. In this treatment, foaming agent, foaming stabilizer and whipping time were 4.53%, 0.42% and 9.05 min, respectively.

The effect of foaming agent, foaming stabilizer and whipping time on foam density of banana pulp is presented in Table 4.2 while the response surface curves and contour plots for foam density are shown in the Fig. 4.13 to Fig. 4.18.

#### 4.3.3.1 Effect of foaming agent and foaming stabilizer on foam density

The response surface curve of variation in the foam density of banana as a function of foaming agent ( $X_1$ ) and foaming stabilizer ( $X_2$ ) is shown in Fig. 4.13. It represents the interactive effect of foaming agent and foaming stabilizer on the foam stability of banana pulp, keeping the whipping time ( $X_3$ ) at middle level, *i.e.* 15 min. Whereas the contour plot for foam expansion of banana pulp as a function of foaming agent and foaming stabilizer is presented in the Fig. 4.14 which indicated the decrease in foam density as the foaming agent was increased up to 6.96% and foaming stabilizer up to its maximum limit of 0.49%. The foam density at this combination was proposed to be decreased up to 0.43 g/cc. With further increase in foaming agent, the foam density of pulp increased slightly. Similarly, another probability of minimum foam density (0.45 g/cc) was found at 6.59% foaming agent and 0.11% foaming stabilizer.

#### 4.3.3.2 Effect of foaming agent and whipping time on foam density

The effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam density of banana pulp at constant foaming stabilizer ( $X_2$ ) at middle level, *i.e.* 0.3% is graphically represented in the Fig. 4.15. The interaction effect of foaming agent ( $X_1$ ) and whipping time ( $X_3$ ) on foam density of banana pulp, keeping the foaming stabilizer ( $X_2$ ) at middle level, *i.e.* 0.3% is presented by contour plot as shown in Fig. 4.16. This contour graph shows the decrease in foam density with an increase in foaming agent and whipping time up to 6.73% and 10.01 min, respectively. At this combination of foaming agent and whipping time, the foam density of pulp was expected to be reduced up to 0.45 g/cc. With further increase in foaming agent and whipping time, the foam density of pulp was found to be increased. This might be due to the bubbles not stable at lower foaming agent concentration because the critical thickness required for the interfacial film can not be formed and the sudden increase in foam density might be due to bubble collapse and mechanical deformation during increased whipping time. Similar results were reported by Bag *et al.* (2011) in bael pulp and Falade and Okocha (2012) in plantain.

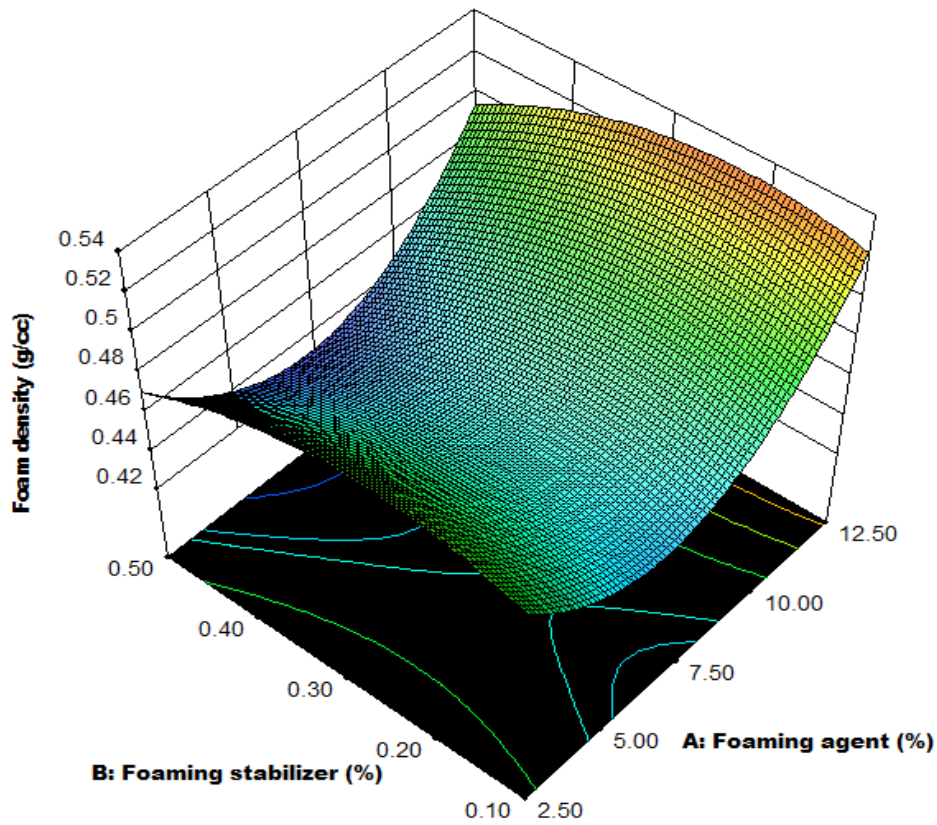


Fig. 4.13 Response surface plot for foam density as a function of foaming agent and foaming stabilizer

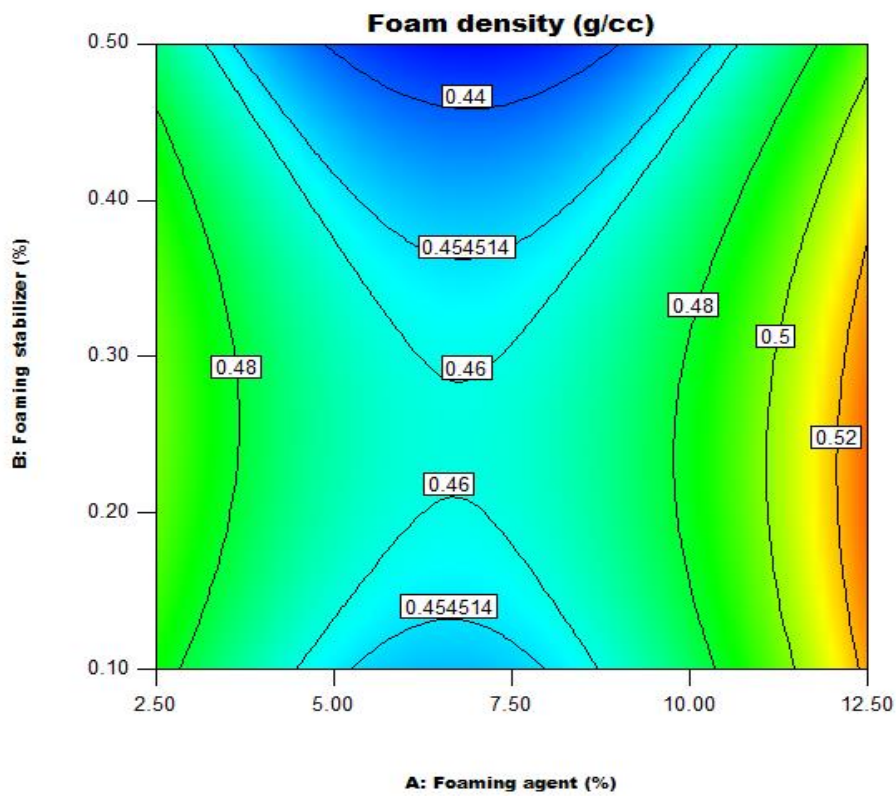
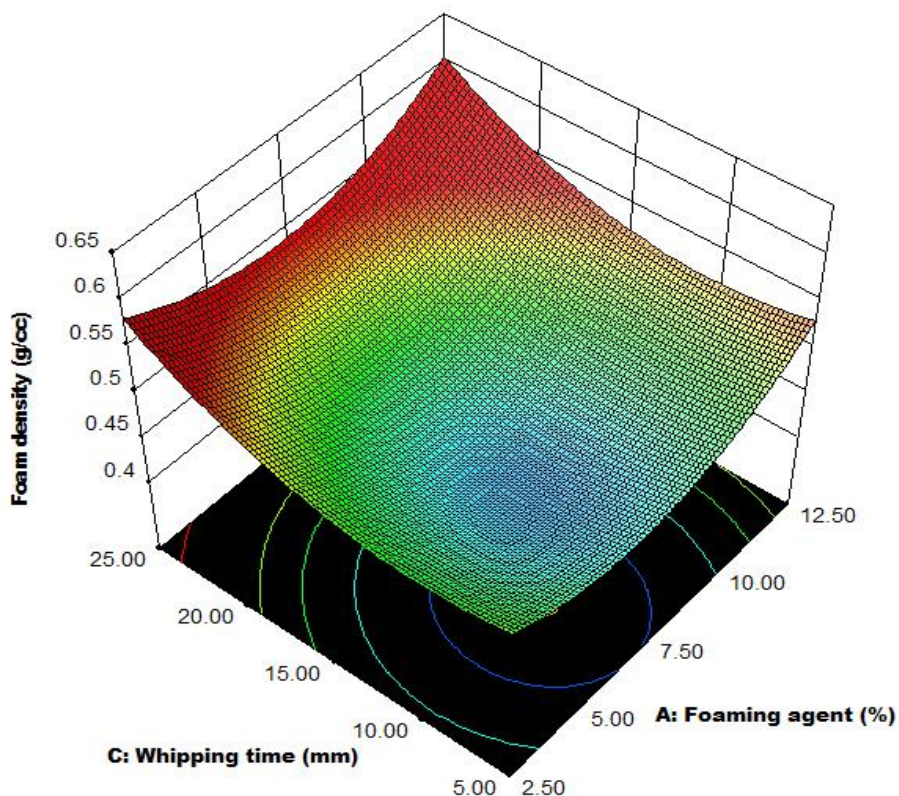
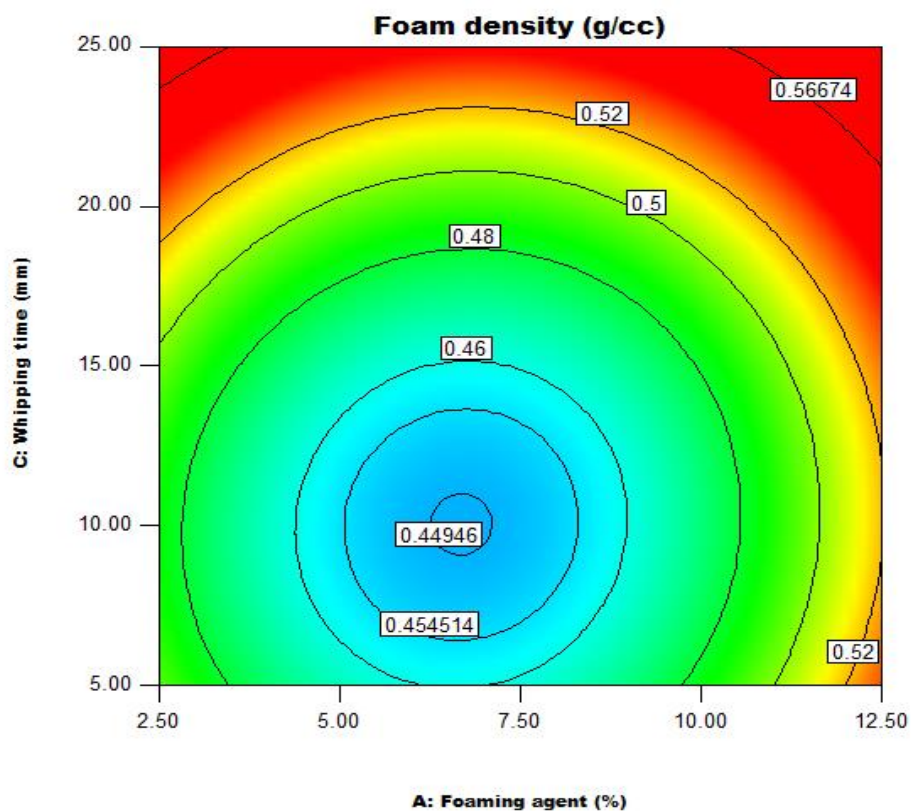


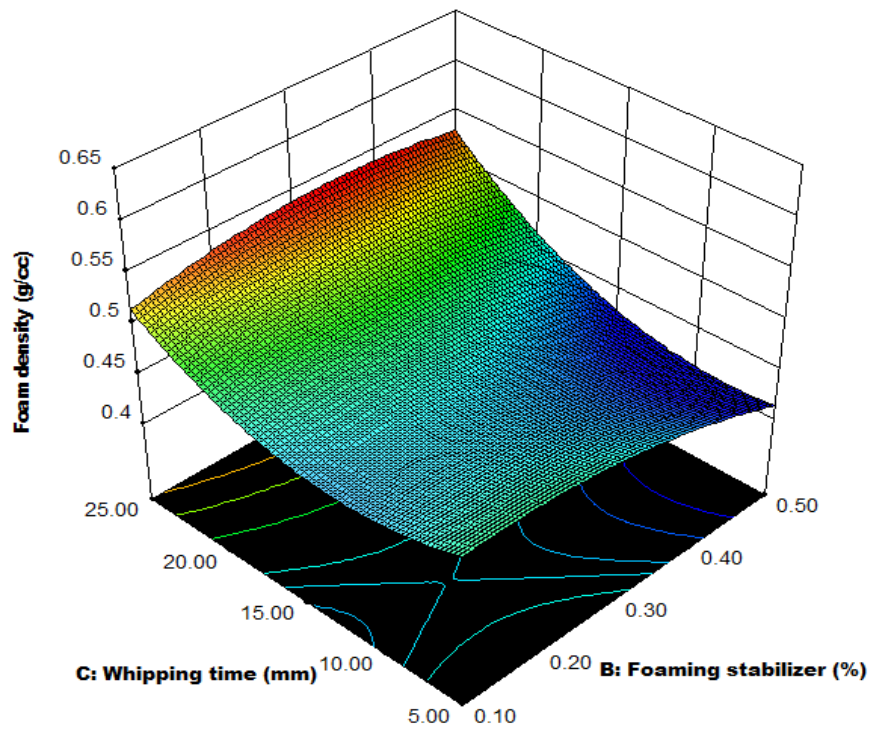
Fig. 4.14 Contour plot for foam density as a function of foaming agent and foaming stabilizer



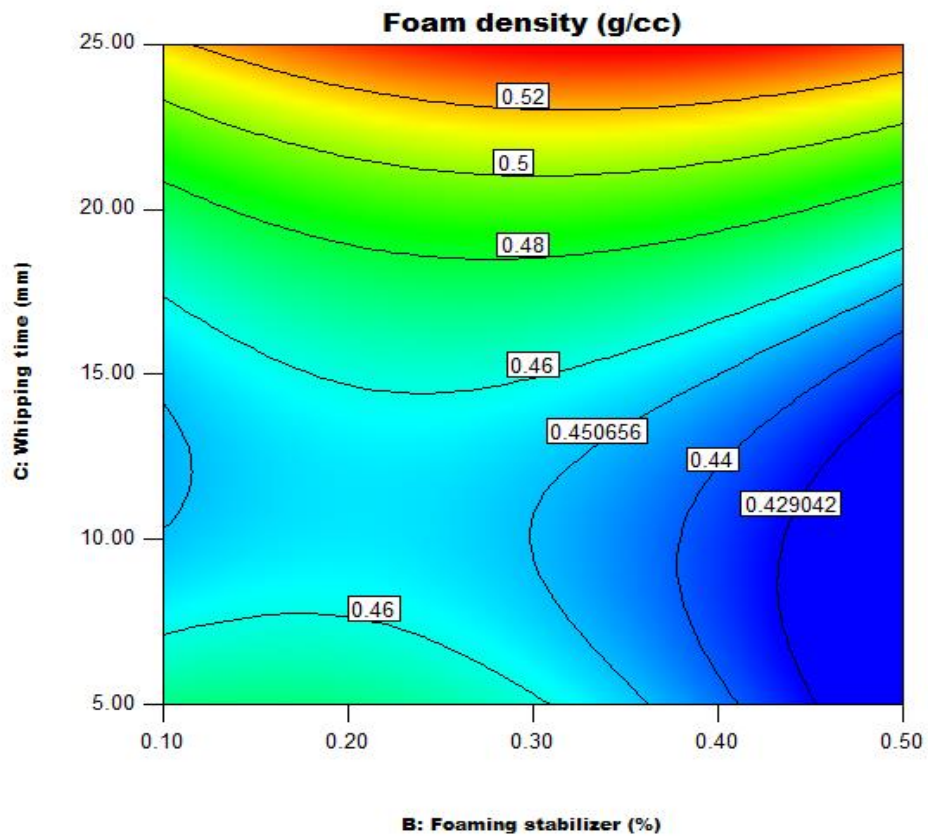
**Fig. 4.15** Response surface plot for foam density as a function of foaming agent and whipping time



**Fig. 4.16** Contour plot for foam density as a function of foaming agent and whipping time



**Fig. 4.17** Response surface plot for foam density as a function of foaming stabilizer and whipping time



**Fig. 4.18** Contour plot for foam density as a function of foaming stabilizer and whipping time

#### 4.3.3.3 Effect of foaming stabilizer and whipping time on foam density

The effect of foaming stabilizer ( $X_2$ ) and whipping time ( $X_3$ ) on foam density of banana pulp at constant foaming agent ( $X_1$ ) at middle level, *i.e.* 7.5% is shown in Fig. 4.17. Whereas the contour plot for foam density of banana pulp as a function of foaming stabilizer and whipping time is presented in the Fig. 4.18. The interaction effect showed the decrease in foam density with an increase in foaming stabilizer up to its maximum limit of 0.5% and whipping time up to 8.18 min. At this combination of foaming stabilizer and whipping time, the foam density of pulp was projected to be reduced up to 0.41 g/cc. With further increase in whipping time, the foam density of pulp increased linearly. Similarly, another probability of minimum foam density (0.45 g/cc) was found at 0.11% foaming stabilizer and 12.38 min whipping time.

The regression analysis and ANOVA results for the foam stability of banana pulp are shown in the Table 4.3. It can be seen from the table that, foaming agent and whipping time indicated negative linear effect while foaming stabilizer indicated positive linear effect on foam stability of banana pulp which was significant at  $p < 0.001$ . The quadratic effect of both, foaming stabilizer and whipping time was positive and the quadratic effect of foaming agent was negative on foam stability. The effect of interaction between foaming agent and foaming stabilizer and interaction between foaming agent and whipping time was found negative. The effect of interaction between foaming stabilizer and whipping time was found positive for foam stability of banana pulp.

The model as derived and giving the empirical relation between the foam density of banana pulp and the test variables in coded units, was obtained as under :

$$\text{Foam density} = 0.46 - 0.009053 A - 0.006124 B + 0.024 C - 0.00125 AB - 0.00125 AC + 0.00625 BC - 0.018 A^2 - 0.006512 B^2 + 0.015 C^2$$

Where, A, B and C are the coded factors of foaming agent, foaming stabilizer and whipping time, respectively.

The calculated F-value for foam density (6.56) was significant at  $p < 0.01$ . At the same time, it possessed non-significant lack of fit ( $p > 0.05$ ). These values indicated that the model for foam stability was fitted and reliable. The  $R^2$  value and Adj- $R^2$  value for the foam stability were 0.8552 and 0.7248, respectively, indicating the adequacy, good fit and high significance of the model. The Pred- $R^2$  (0.4691) was in reasonable agreement with the

Adj-R<sup>2</sup>. The high Adeq. Precision value (>4) again supported the significance of the model for foam stability. The small value of coefficient of variation (3.70%) for foam stability explained that the experimental results were precise and reliable (Table 4.3).

#### 4.4 Optimization and validation of process variables

**Table 4.4 Constraints, criteria and output for numerical optimization of foaming properties of banana pulp**

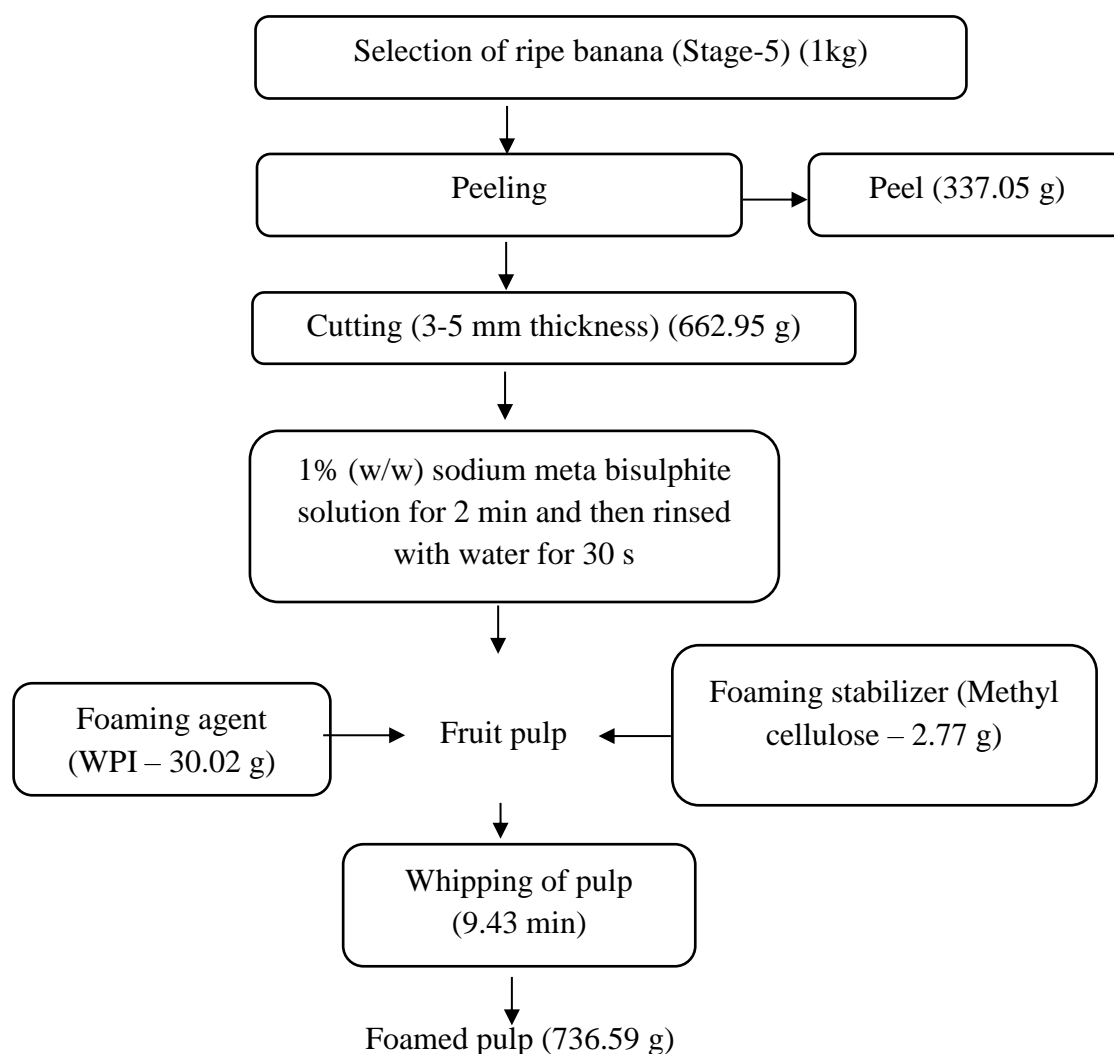
Variables					
Constraint	Goal	Importance	Optimum value		
(1)	(2)	(3)	(4)		
Foaming agent (%)	In the range	3	5.35		
Foaming stabilizer (%)	In the range	3	0.45		
Whipping time (min)	In the range	3	9.43		
Responses					
Constraint	Goal	Importance	Predicted value	Experimental value	Deviation (%)
(1)	(2)	(3)	(4)	(5)	(6)
Foam expansion	Maximum	3	138.95	142.28	2.39
Foam stability	Maximum	3	96.33	94.76	1.62
Foam density	Minimum	3	0.43	0.42	2.32

The optimum condition for the foaming properties of banana pulp was determined by the numerical optimization technique, using Design Expert software version 10.0.8 (State-Ease Inc., Minneapolis, MN, USA). The main criteria applied for constraints optimization in the study were: (a) foam expansion: maximum, (b) foam stability: maximum (c) foam density: minimum. Accordingly, the goals that were set for variables and responses to obtain the best combination are illustrated in the Table 4.4. All the independent variables and responses were given an equal importance, *i.e.* three, during optimization process. Under these constraints, the optimum treatment conditions were found to be, 5.35% foaming agent, 0.45% foaming stabilizer and 9.43 min whipping time. The analysis showed that at this combination of foaming agent, foaming stabilizer and

whipping time, it would be possible to of foaming properties of banana pulp with a foam expansion of 138.95%, foam stability of 96.33% and foam density of 0.43 g/cc (Table 4.4). Using these optimized conditions, the experiments were again conducted to find the variation in the different response variables. The results revealed that the experimental values of conducted experiments were very close to the predicted values (Table 4.4). This implied that there was a high degree of fit between the observed and predicted values from the regression models and each model was quite accurate in prediction. The closeness of the observed and predicted responses indicated the validity of developed model.

#### 4.4.1 Improved method suggested for foaming properties

As a result of studies conducted on various aspects of foaming properties of banana pulp, an improved process for better results of foaming properties of banana pulp is suggested through a process flow diagram given in Fig. 4.19.



**Fig. 4.19 Process flow chart recommended for foaming properties of banana pulp**

## 4.5 Drying of banana powder

Optimized parameters of foaming process were selected for further tray drying process of foamed banana. Foamed banana was dried at four different levels of temperatures (55 °C, 60 °C, 65 °C and 70 °C) and three different levels of foam thickness (2 mm, 4 mm and 6 mm) with a constant air velocity of 0.5 m/s. Drying characteristics of foamed banana and quality of banana powder was evaluated during drying process and after preparation of powder.

### 4.5.1 Drying characteristics of banana powder

The foamed banana pulp at optimized condition (whey protein isolate 4.53%, concentration of methyl cellulose 0.42% and whipping time 9.05 min) was dried in a tray dryer as thin layer.

The reduction in moisture content was faster during initial stage and subsequently slowed down with increase in drying time. The moisture content of foamed banana pulp reduced with the drying duration due to conversion of foamed pulp water in to vapour by increase in temperature. The moisture content dropped faster in the starting, whereas it became slow in the last phase with irrespective of treatments. It was also observed that within a certain temperature range (55-70 °C) and thickness (2-6 mm), increasing drying temperature and decreasing thickness speeds up the drying process, thus shortening the drying time.

#### 4.5.1.1 Drying time

It is evident from the Fig. 4.20 that drying time increased as foam thickness increased and drying temperature decreased. Maximum drying time (300 min) was observed at 55 °C drying temperature and 6 mm foam thickness while lowest drying time (120 min) was observed at 70 °C drying temperature and 2 mm thickness. This might be due to the fact of complete exposer and moisture migration of foamed banana pulp with high moisture migration in less foam thickness at higher drying temperature. Similar results are also reported by Kandasamy *et al.* (2012) for foamed papaya pulp and Rajkumar *et al.* (2007) for foamed mango pulp. Drying time at different levels of drying conditions are presented in Appendix – D.

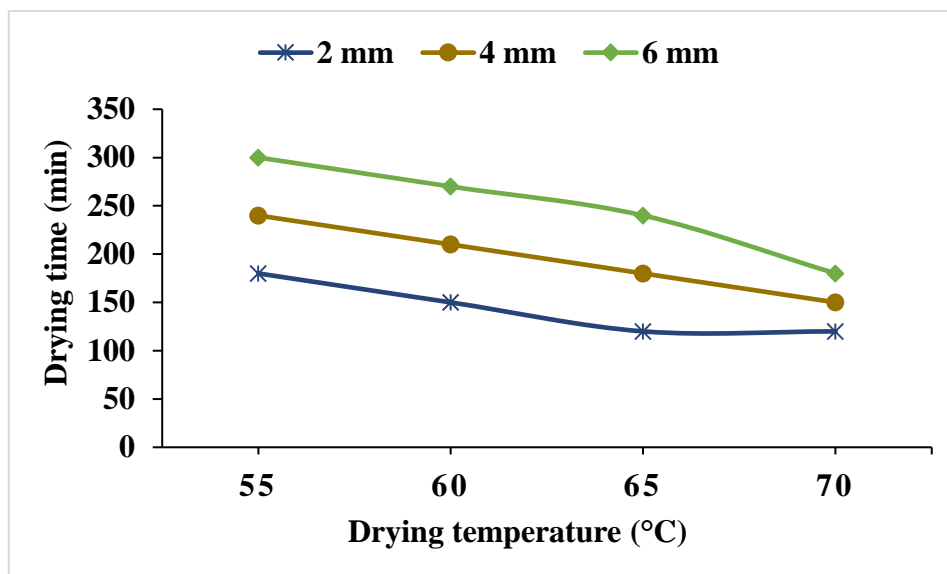


Fig. 4.20 Effect of drying conditions on drying time of foamed banana

#### 4.5.1.2 Drying rate

The drying rate versus drying time for 2 mm thickness of foamed banana is shown in Fig. 4.21. The data for drying rate are given in the Appendix – E1. From the fig., it is evident that the maximum drying rate (0.310 g water/g dry matter/min) was found for 70 °C for drying temperature and minimum (0.193 g water/g dry matter/min) was recorded for 55 °C drying temperature for 2 mm thickness of foamed banana pulp. It might be due to more moisture migration occurred at higher drying temperature.

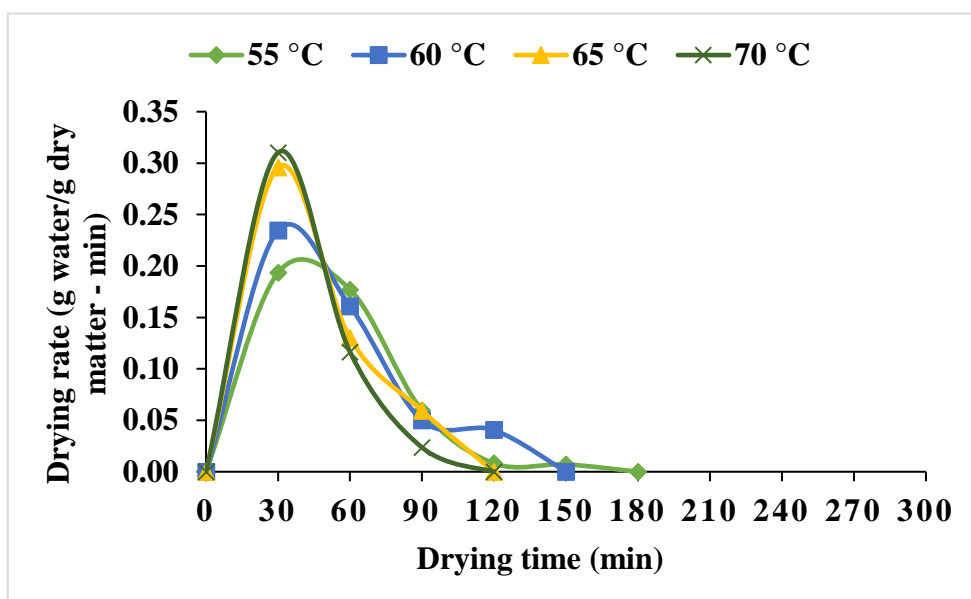


Fig. 4.21 Effect of drying conditions on drying rate for 2 mm foamed banana

The observations on drying rate versus drying time for 4 mm thickness of foamed banana is shown in Fig. 4.22. The data for drying rate are given in the Appendix – E2. From the fig., it is apparent that the maximum drying rate (0.257 g water/g dry matter/min) was found for 70 °C drying temperature and minimum (0.138 g water/g dry matter/min) was recorded for 55 °C drying temperature for 4 mm thickness of foamed banana pulp.

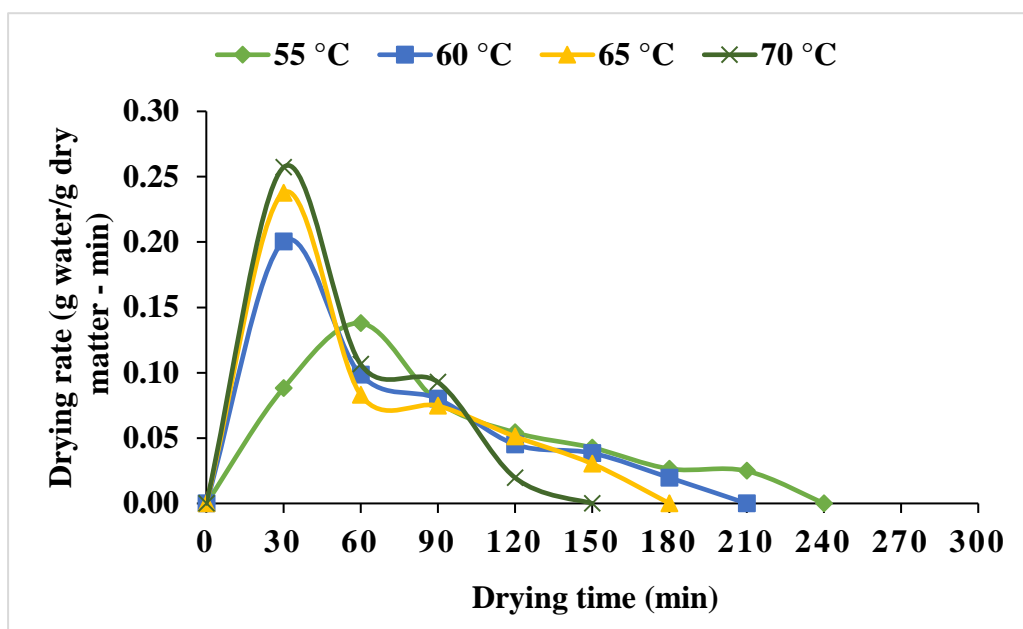


Fig. 4.22 Effect of drying conditions on drying rate for 4 mm foamed banana

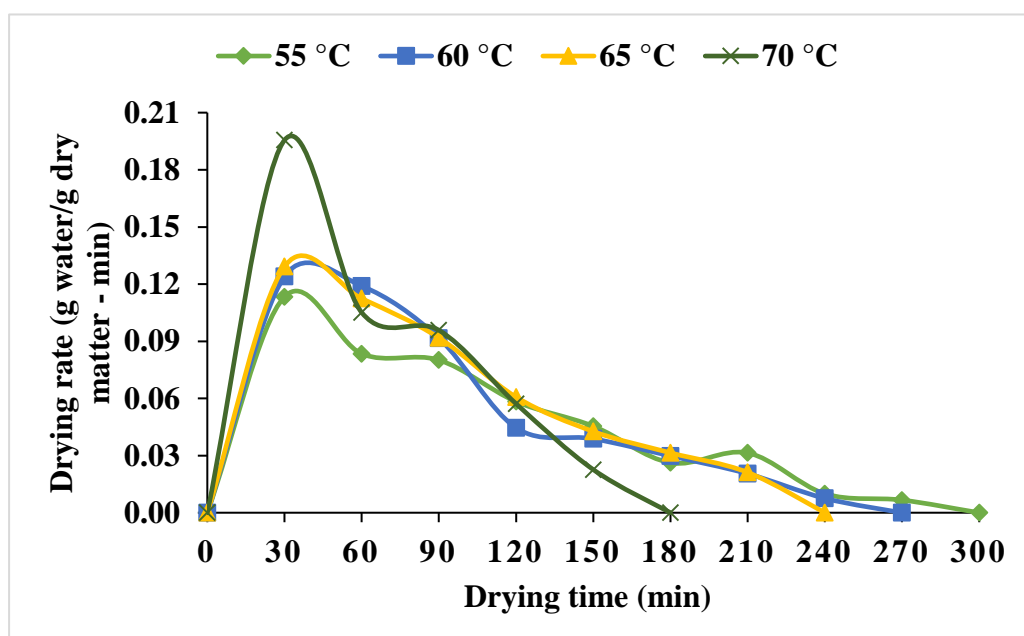


Fig. 4.23 Effect of drying conditions on drying rate for 6 mm foamed banana

The drying rate versus drying time for 6 mm thickness of foamed banana is shown in Fig. 4.23. The data for drying rate are given in the Appendix – E3. From the fig., it is

clear that the maximum drying rate (0.196 g water/g dry matter/min) was found for 70 °C drying temperature and minimum (0.113 g water/g dry matter/min) was found for 55 °C drying temperature for 6 mm thickness of foamed banana pulp.

It can be observed from Fig. 4.21 – 4.23 that the complete drying took place in falling rate for all the treatments. The drying rate decreased with increase in drying time for all the treatments. In comparison of foam thickness, maximum drying rate was found for 2 mm thickness and minimum was recorded for 6 mm thickness of foamed banana pulp irrespective of drying temperature. It can be observed that there was more considerable effect on the drying rate at initial stage of drying due to more moisture content than at the end, which was almost negligible. It was further observed that moisture loss was faster during initial stage of drying than at the end of the drying process. The reduction in the drying is mainly due to rate of migration of moisture from inner layer to outer surface decreased at the final stage of drying and hence lower drying rate at the end.

#### 4.5.1.3 Moisture ratio

The graphical representation of moisture ratio is shown in Fig. 4.24 to 4.26. The relationship shows that there was rapid decrease in moisture ratio with faster rate at initial stage of 50 to 70 min of drying in all cases, however in later stage of drying the decrease in moisture ratio was at slower rate. It can be also observed that at zero time of drying moisture ratio was one and successive drying, it decreased nonlinearly. So moisture ratio versus drying time curves could better describe the drying phenomena than the curves of moisture content verses drying time because the former had same initial value of MR (=1) but later had different initial moisture content.

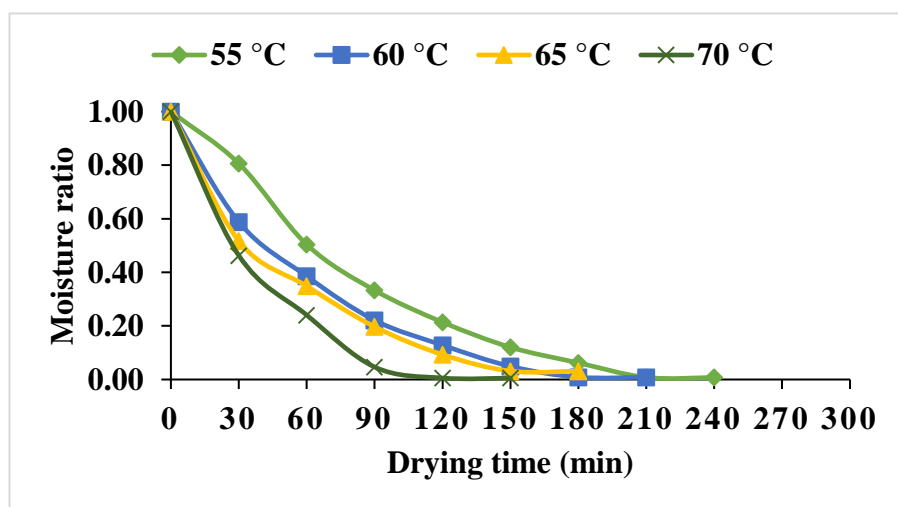


Fig. 4.24 Effect of drying conditions on moisture ratio for 2 mm foamed banana

Moisture ratio curves for all the three levels of foam thickness showed that the drying of banana foam was faster at 2 mm foam thickness due to minimum foam density. Data of moisture ratio for 2, 4 and 6 mm thickness are given in Appendix – F1, F2 and F3, respectively.

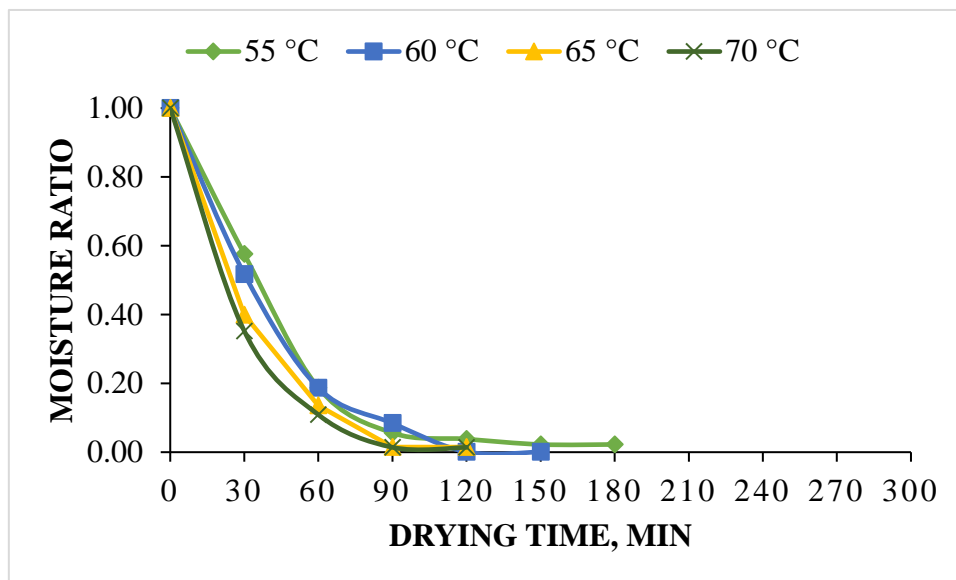
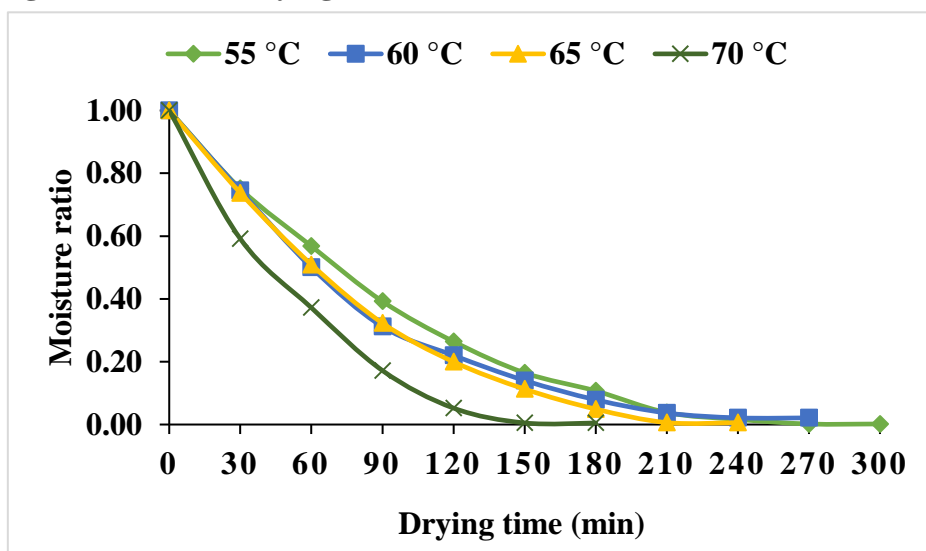


Fig. 4.25 Effect of drying conditions on moisture ratio of 4 mm foamed banana

Fig. 4.26 Effect of drying conditions on moisture ratio of 6 mm foamed banana



#### 4.6 Quality of banana powder by foam mat drying

##### 4.6.1 Physical properties

##### 4.6.1.1 Recovery (%)

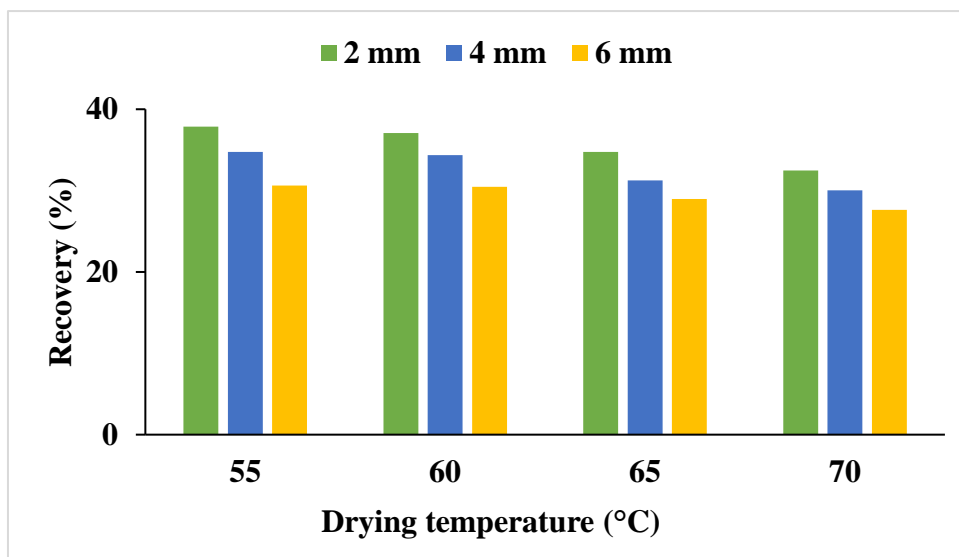
Recovery of banana powder obtained during different drying conditions is presented in Table 4.5. It can be observed that the effect of drying temperature on recovery

of banana powder was found significant. Drying temperature  $T_1$  (55 °C) resulted significantly highest recovery (34.41%) of banana powder. However, it was found at par with  $T_2$  (60 °C). Drying temperature  $T_4$  (70 °C) had significantly lowest recovery (30.04%) of banana powder. The effect of foam thickness on recovery of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly highest recovery (35.54%) of banana powder while foam thickness of  $t_3$  (6 mm) was found significantly lowest recovery (29.43%) of banana powder. The interaction between  $T*t$  was also found significant on recovery of banana powder.

**Table 4.5 Effect of drying conditions on physical properties of banana powder**

Effect	Recovery (%)	Bulk density (g/cc)
<b>Drying temperature (T)</b>		
55 °C	34.41	0.68
60 °C	33.98	0.60
65 °C	31.66	0.59
70 °C	30.04	0.54
S. Em±	0.16	0.01
CD at 5%	0.46	0.02
<b>Foam thickness (t)</b>		
2 mm	35.54	0.58
4 mm	32.60	0.60
6 mm	29.43	0.63
S. Em±	0.14	0.00
CD at 5%	0.40	0.01
<b>Interaction T*t</b>		
S. Em±	0.27	0.01
CD at 5%	0.79	NS
C.V.%	1.44	2.71

From the Fig. 4.27, it is clear that recovery of banana powder decreased with increase of temperature and foam thickness. This might be due to burning of banana foam at higher drying temperature. Mean data for recovery of banana powder are presented in Appendix – G1. The maximum recovery (37.86%) of banana powder was found for the treatment combination  $T_1t_1$  (55 °C and 2 mm). Minimum recovery (27.63%) of banana powder was found for treatment combination  $T_4t_3$  (70 °C and 6 mm). The decrease in recovery of banana powder with increase in temperature was also reported by Khodifad (2017) in custard apple powder.

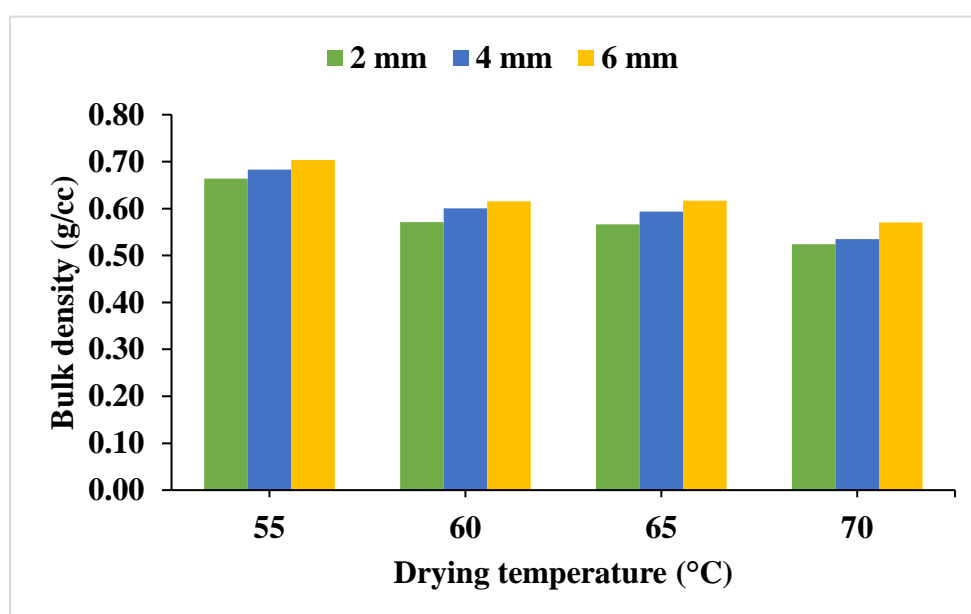


**Fig. 4.27 Effect of drying conditions on recovery of banana powder**

The best result was found in treatment combination T<sub>1t1</sub> (55 °C and 2 mm) and T<sub>2t1</sub> (60 °C and 2 mm) having highest recovery of banana powder.

#### 4.6.1.2 Bulk density (g/cc)

Bulk density of banana powder obtained during different drying conditions is presented in Table 4.5. It is evident that the effect of drying temperature on bulk density of banana powder was found significant. Drying temperature T<sub>1</sub> (55 °C) resulted significantly highest bulk density (0.68 g/cc) of banana powder while drying temperature T<sub>4</sub> (70 °C) resulted significantly lowest bulk density (0.54 g/cc) of banana powder. The effect of foam



**Fig. 4.28 Effect of drying conditions on bulk density of banana powder**

thickness on bulk density of banana powder was also found significant. Foam thickness of  $t_3$  (6 mm) resulted significantly highest bulk density (0.63 g/cc) of banana powder while foam thickness of  $t_1$  (2 mm) was found significantly lowest bulk density (0.58 g/cc) of banana powder. The interaction between  $T*t$  was found non-significant on bulk density of banana powder.

It is apparent from the Fig. 4.28 that bulk density of banana powder decreased as the drying temperature increased and foam thickness decreased. With the increase in temperature, the water evaporation rate accelerates, forming large particles with the tendency of being hollow or porous, leading to the decrease in bulk density (Walton, 2010 and Chegini *et al.*, 2005). Mean data of bulk density of banana powder is given in Appendix – G1. The maximum bulk density (0.70 g/cc) of banana powder was found for treatment combination  $T_1t_3$  (55 °C and 6 mm). Minimum bulk density (0.52 g/cc) of banana powder was found under treatment combination  $T_4t_1$  (70 °C and 2 mm). Similar result was reported by Do and Nguyen (2018) in mulberry juice powder.

The best result obtained during the drying experiment in treatment combination was  $T_1t_3$  (55 °C and 6 mm) having highest bulk density of banana powder.

Considering the physical parameters *viz.*, recovery of banana powder, treatment combination  $T_1t_1$  (55 °C and 2 mm) and  $T_2t_1$  (60 °C and 2 mm) was observed to be best among all the treatments.

## 4.6.2 Biochemical properties

### 4.6.2.1 Moisture content (%)

It is obvious from Table 4.6 that moisture content of banana powder obtained during different drying conditions was found significant. Drying temperature  $T_4$  (70 °C) resulted significantly lowest moisture content (4.21%) of banana powder while drying temperature  $T_1$  (55 °C) resulted significantly highest moisture content (5.96%) of banana powder. The effect of foam thickness on moisture content of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly lowest moisture content (4.75%) of banana powder while foam thickness of  $t_3$  (6 mm) had significantly highest moisture content (5.59%) of banana powder. The interaction between  $T*t$  was also found significant on moisture content of banana powder.

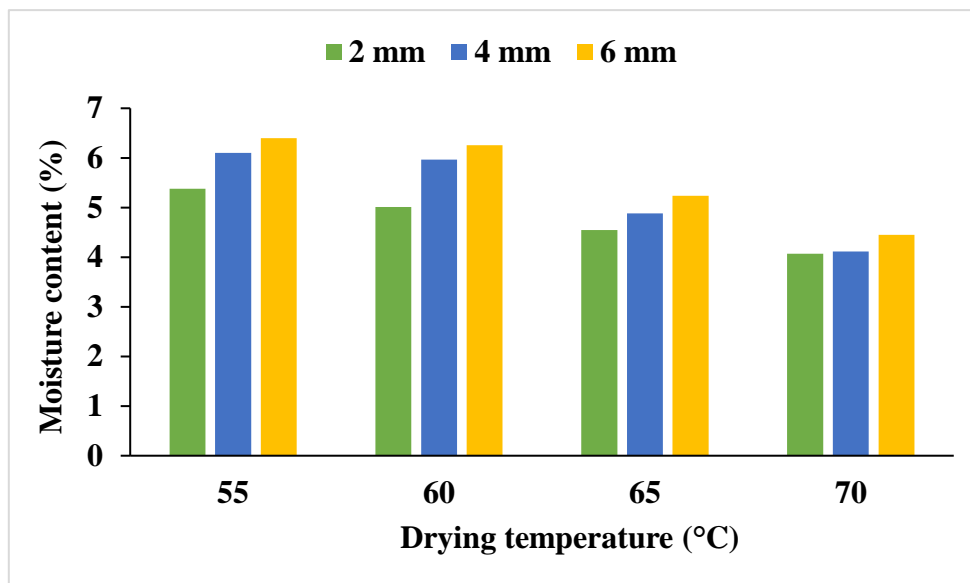
**Table 4.6 Effect of drying conditions on biochemical properties of powder**

Effect	Moisture content (%)	Total sugars (%)	Reducing sugar (%)	Non-reducing sugar (%)	Titratable acidity (%)	Ascorbic acid (mg/100 g)	pH
<b>Drying temperature (T)</b>							
55 °C	5.96	35.57	0.16	35.41	0.41	0.66	4.49
60 °C	5.75	35.16	0.17	34.97	0.47	0.65	4.43
65 °C	4.89	34.10	0.35	33.75	0.53	0.50	4.35
70 °C	4.21	30.78	0.55	30.23	0.57	0.41	4.24
S. Em±	0.02	0.30	0.00	0.30	0.01	0.01	0.01
CD at 5%	0.06	0.89	0.01	0.89	0.02	0.03	0.03
<b>Foam thickness (t)</b>							
2 mm	4.75	36.38	0.24	36.14	0.45	0.67	4.44
4 mm	5.27	33.85	0.28	33.57	0.50	0.53	4.35
6 mm	5.59	31.47	0.40	31.07	0.54	0.47	4.34
S. Em±	0.02	0.26	0.00	0.26	0.01	0.01	0.01
CD at 5%	0.05	0.77	0.01	0.77	0.02	0.02	0.02
<b>Interaction T*t</b>							
S. Em±	0.04	0.53	0.01	0.53	0.01	0.02	0.01
CD at 5%	0.10	1.53	0.02	1.54	NS	0.04	0.04
C.V.%	1.19	2.69	4.24	2.72	4.71	4.78	0.59

From the Fig. 4.29, it is clear that moisture content of banana powder decreased as the drying temperature increased and foam thickness decreased. Mean data of moisture content of banana powder is given in Appendix – G2. Minimum moisture content (4.07%) of banana powder was found for treatment combination T<sub>4</sub>t<sub>1</sub> (70 °C and 2 mm). Maximum moisture content (6.40%) of banana powder was found for treatment combination T<sub>1</sub>t<sub>3</sub> (55 °C and 6 mm). Similar results were reported by Wilson *et al.* (2014) in mango powder and Abasi *et al.* (2009) in onion powder.

The treatment combination T<sub>4</sub>t<sub>1</sub> (70 °C and 2 mm) was found to be best result during the drying experiment having lowest moisture content of banana powder. However,

moderate moisture content (5.01%) was found for treatment combination T<sub>2</sub>t<sub>1</sub> (60 °C and 2 mm).



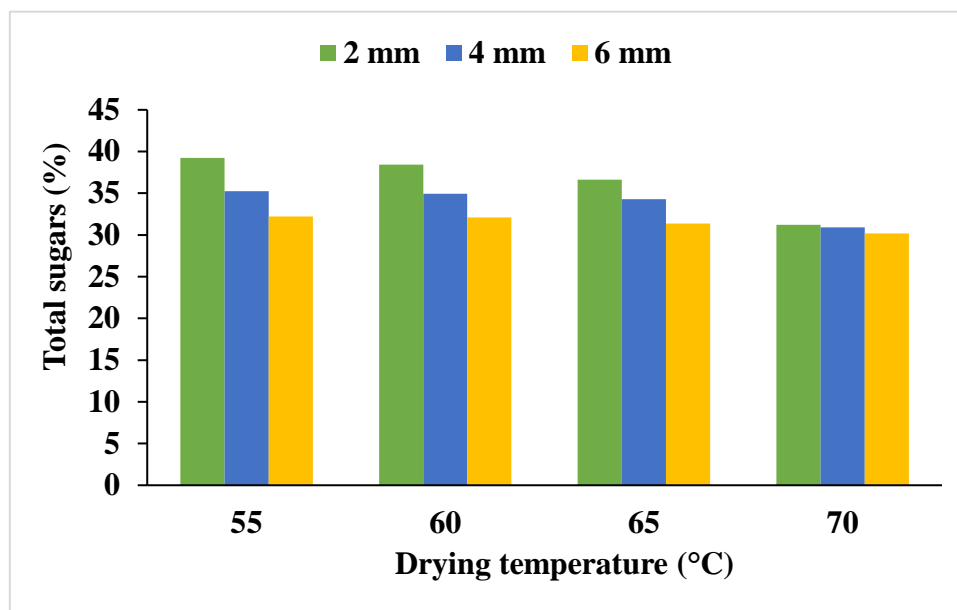
**Fig. 4.29 Effect of drying conditions on moisture content of banana powder**

#### 4.6.2.2 Total sugars (%)

Total sugars of banana powder obtained during different drying conditions carried out at different drying temperature and foam thickness is presented in Table 4.6. It is obvious that the effect of drying temperature on total sugars of banana powder was found significant. Drying temperature T<sub>1</sub> (55 °C) resulted significantly highest total sugars (35.57%) of banana powder. However, it was found at par with T<sub>2</sub> (60 °C). Drying temperature T<sub>4</sub> (70 °C) had significantly lowest total sugars (30.78%) of banana powder. The effect of foam thickness on total sugars of banana powder was also found significant. Foam thickness of t<sub>1</sub> (2 mm) resulted significantly highest total sugars (36.38%) of banana powder while foam thickness of t<sub>3</sub> (6 mm) had significantly lowest total sugars (31.47%) of banana powder. The interaction between T\*t was also found significant on total sugars of banana powder.

From the Fig. 4.30, it is clear that total sugars of banana powder decreased as the drying temperature and foam thickness increased. This might be attributed to Maillard reactions (Kadam *et al.*, 2010). Mean value of total sugars of banana powder is given in Appendix – G2. Maximum total sugars (39.25%) of banana powder was found for treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm). Minimum total sugars (30.20%) of banana powder

was found for treatment combination  $T_{4t_3}$  (70 °C and 6 mm). This results are in agreement with Kandsamy *et al.* (2012) in papaya powder and Wilson *et al.* (2014) in mango powder.



**Fig. 4.30 Effect of drying conditions on total sugars of banana powder**

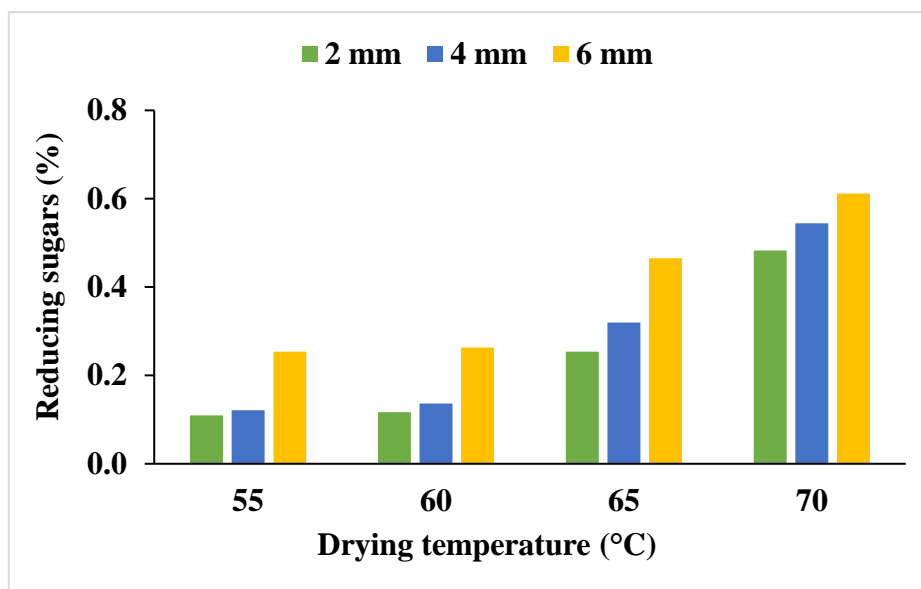
The best results were found during the different drying conditions in treatment combination  $T_{1t_1}$  (55 °C and 2 mm) and  $T_{2t_1}$  (60 °C and 2 mm) having highest total sugars of banana powder.

#### 4.6.2.3 Reducing sugar (%)

Variation in reducing sugar of banana powder obtained during different drying conditions is represented in Table 4.6. It can be observed that the effect of different drying temperature on reducing sugar of banana powder was found significant. Drying temperature  $T_1$  (55 °C) resulted significantly lowest reducing sugar (0.16%) of banana powder. However, it was found was at par with  $T_2$  (60 °C). Drying temperature  $T_4$  (70 °C) resulted significantly highest reducing sugar (0.55%) of banana powder. The effect of foam thickness on reducing sugar of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly lowest reducing sugar (0.24%) of banana powder while foam thickness of  $t_3$  (6 mm) had significantly highest reducing sugar (0.40%) of banana powder. The interaction between  $T*t$  was also found significant on reducing sugar of banana powder.

From the Fig. 4.31, it is clear that reducing sugar of banana powder increased as the drying temperature and foam thickness increased. It might be attributed to interaction of

reducing sugar readily with amino acids by Maillard reaction. Mean data of reducing sugar of banana powder is presented in Appendix – G2. Minimum reducing sugar (0.11%) of banana powder was found for treatment combination  $T_{1t_1}$  (55 °C and 2 mm) followed by  $T_{2t_1}$  (60 °C and 2 mm). Maximum reducing sugar (0.61%) of banana powder was found for treatment combination  $T_{4t_3}$  (70 °C and 6 mm).



**Fig. 4.31 Effect of drying conditions on reducing sugar of banana powder**

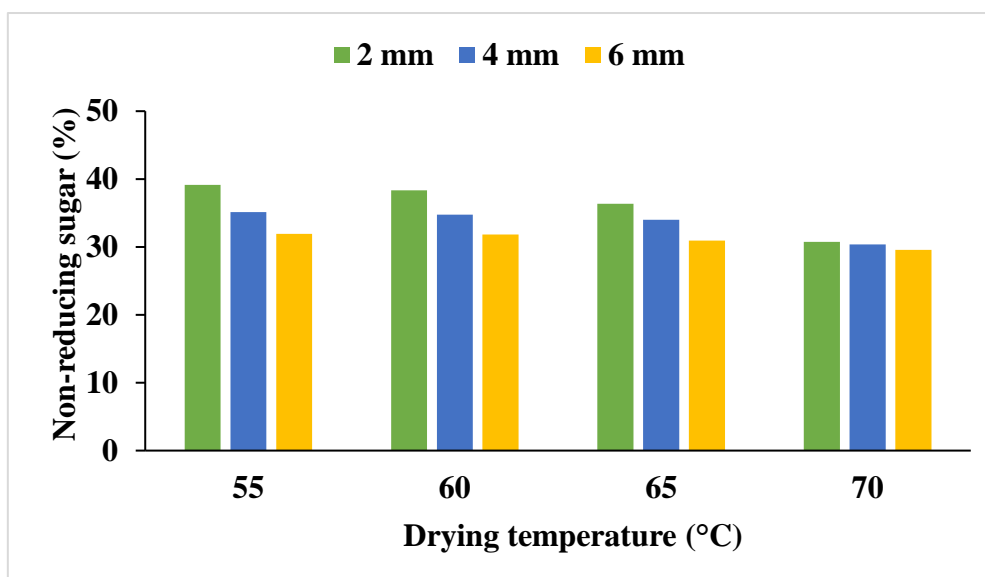
The best results was found during the different drying conditions in treatment combination  $T_{1t_1}$  (55 °C and 2 mm) and  $T_{2t_1}$  (60 °C and 2 mm) having lowest reducing sugar of banana powder.

#### 4.6.2.4 Non-reducing sugar (%)

From Table 4.6, it is apparent that effect of drying temperature on non-reducing sugar of banana powder was found significant. Drying temperature  $T_1$  (55 °C) resulted significantly highest non-reducing sugar (35.41%) of banana powder. However, it was found at par with  $T_2$  (60 °C). Drying temperature  $T_4$  (70 °C) resulted significantly lowest non-reducing sugar (30.23%) of banana powder. The effect of foam thickness on reducing sugar of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly highest non-reducing sugar (36.14%) of banana powder while foam thickness of  $t_3$  (6 mm) had significantly lowest non-reducing sugar (31.07%) of banana powder. The interaction between  $T*t$  was also found significant on reducing sugar of banana powder.

From the Fig. 4.32, it is clear that non-reducing sugar of banana powder decreased as the drying temperature and foam thickness increased. Mean value of non-reducing sugar

is given in Appendix – G2. Maximum non-reducing sugar (39.14%) of banana powder was found under treatment combination  $T_{1t_1}$  (55 °C and 2 mm). Minimum non-reducing sugar (29.59%) of banana powder was found under treatment combination  $T_{4t_3}$  (70 °C and 6 mm).



**Fig. 4.32 Effect of drying conditions on non-reducing sugar of banana powder**

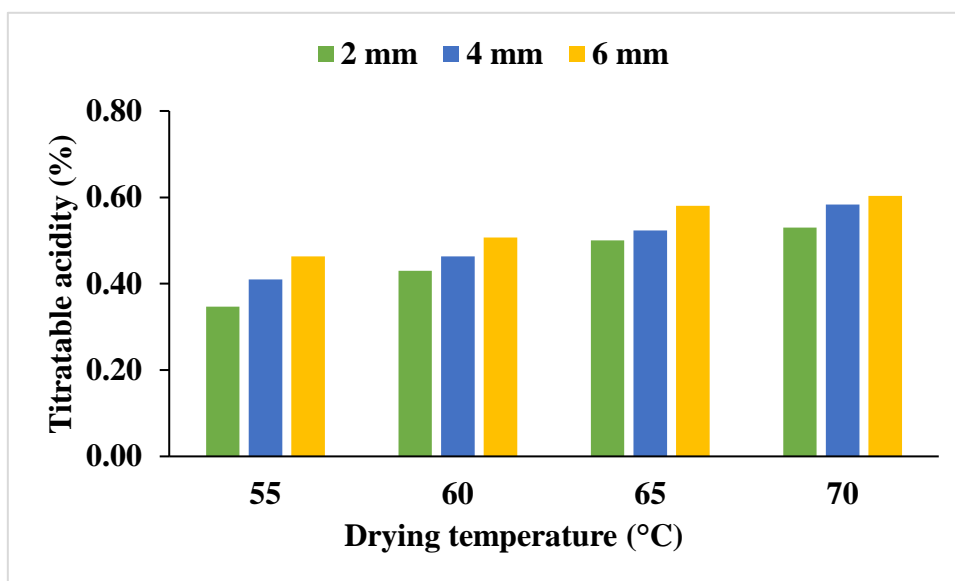
The best results was found in treatment combination  $T_{1t_1}$  (55 °C and 2 mm) and  $T_{2t_1}$  (60 °C and 2 mm) having highest non-reducing sugar of banana powder during the drying conditions.

#### 4.6.2.5 Titratable acidity (%)

It is obvious from Table 4.6 that drying temperature on titratable acidity of banana powder was found significant. Drying temperature  $T_1$  (55 °C) resulted significantly lowest titratable acidity (0.41%) of banana powder while drying temperature  $T_4$  (70 °C) resulted significantly highest titratable acidity (0.57%) of banana powder. The effect of foam thickness on titratable acidity of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly lowest titratable acidity (0.45%) of banana powder while foam thickness of  $t_3$  (6 mm) had significantly highest titratable acidity (0.54%) of banana powder. The interaction between  $T*t$  was found non-significant on titratable acidity of banana powder.

From the Fig. 4.33, it is clear that titratable acidity of banana powder increased as the drying temperature and foam thickness increased. This might be due to decrease in pH of banana powder. Mean data of titratable acidity is given in Appendix – G2. Minimum titratable acidity (0.35%) of banana powder was found for treatment combination  $T_{1t_1}$

(55 °C and 2 mm). Maximum titratable acidity (0.60%) was found for treatment combination T<sub>4</sub>t<sub>3</sub> (70 °C and 6 mm). Similar findings were reported by Yusufe *et al.* (2017) in tomato powder and Purkayastha *et al.* (2013) in tomato slices.



**Fig. 4.33 Effect of drying conditions on titratable acidity of banana powder**

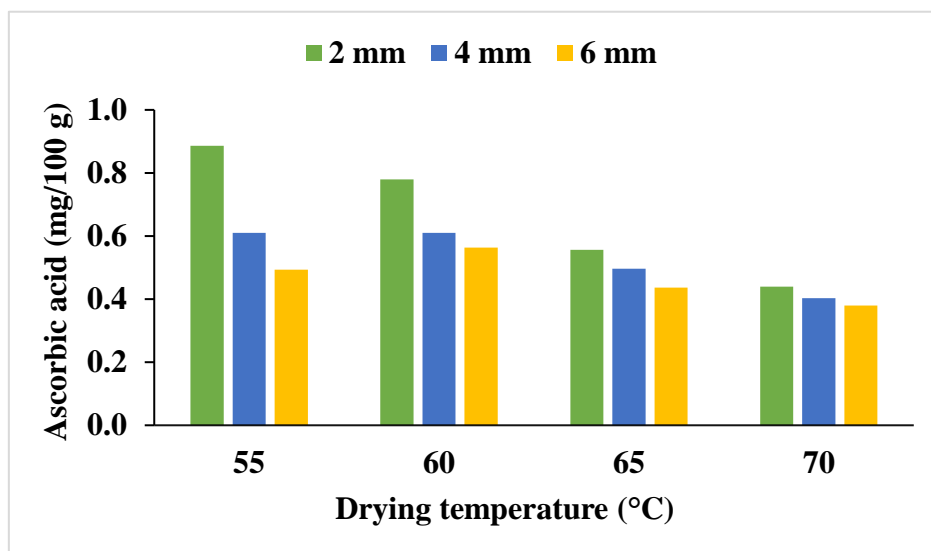
The best result was found during the drying conditions in treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) having lowest titratable acidity of banana powder.

#### 4.6.2.6 Ascorbic acid (mg/100 g)

Ascorbic acid of banana powder obtained during different drying conditions is presented in Table 4.6. It is evident that the effect of drying temperature on ascorbic acid of banana powder was found significant. Drying temperature T<sub>1</sub> (55 °C) resulted significantly highest ascorbic acid (0.66 mg/100 g) of banana powder. However, it was found at par with T<sub>2</sub> (60 °C). Drying temperature T<sub>4</sub> (70 °C) resulted significantly lowest ascorbic acid (0.41 mg/100 g) of banana powder. The effect of foam thickness on ascorbic acid of banana powder was also found significant. Foam thickness of t<sub>1</sub> (2 mm) resulted significantly highest ascorbic acid (0.67 mg/100 g) of banana powder while it was found significantly lowest ascorbic acid (0.47 mg/100 g) of banana powder for t<sub>3</sub> (6 mm). The interaction between T\*t was also found significant on ascorbic acid of banana powder.

From the Fig. 4.34, it is apparent that ascorbic acid of banana powder decreased as the drying temperature and foam thickness increased. This might be due to destructive effect at higher temperature of thermal treatment, which caused oxidation of the ascorbic acid. Mean data of ascorbic acid of banana powder is presented in Appendix – G2.

Maximum ascorbic acid (0.89 mg/100 g) of banana powder was found for treatment combination  $T_{1t_1}$  (55 °C and 2 mm). Minimum ascorbic acid (0.38 mg/100 g) of banana powder was found for treatment combination  $T_{4t_3}$  (70 °C and 6 mm). These results are in agreement with Antala (2011) in guava powder and Rajkumar *et al.* (2007) in mango powder.



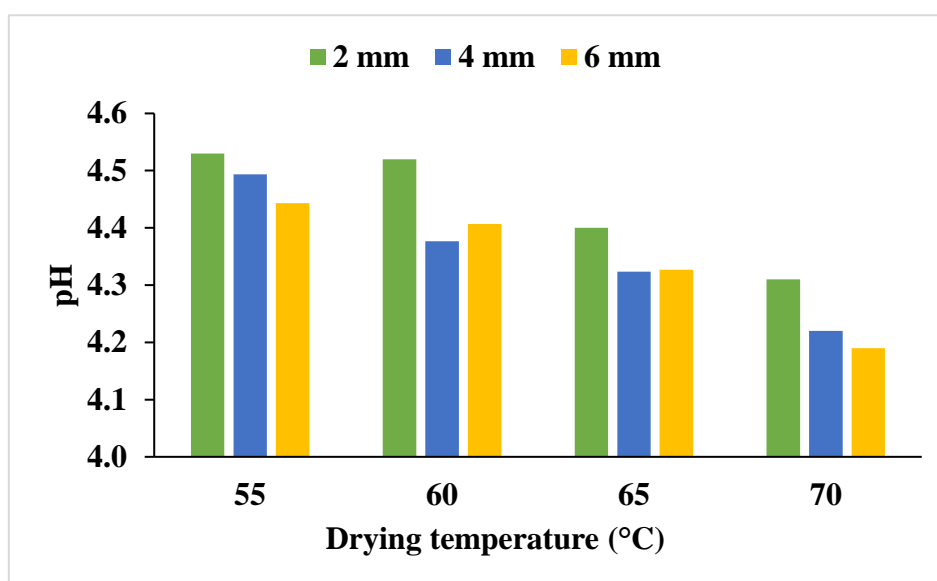
**Fig. 4.34 Effect of drying conditions on ascorbic acid of banana powder**

The best result was found during the drying experiment in treatment combination  $T_{1t_1}$  (55 °C and 2 mm) and  $T_{2t_1}$  (60 °C and 2 mm) having highest ascorbic acid of banana powder.

#### 4.6.2.7 pH

Variation in pH of banana powder at different drying conditions is presented in Table 4.6. It can be observed that the effect of drying temperature on pH of banana powder was found significant. Drying temperature  $T_1$  (55 °C) resulted significantly highest pH (4.49) of banana powder while drying temperature  $T_4$  (70 °C) had significantly lowest pH (4.24) of banana powder. The effect of foam thickness on pH of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly highest pH (4.44) of banana powder while foam thickness of  $t_3$  (6 mm) was found significantly lowest pH (4.34) of banana powder. However, foam thickness  $t_3$  (6 mm) was found at par with  $t_2$  (4 mm) for pH of banana powder. The interaction between  $T*t$  was also found significant on pH of banana powder.

From the Fig. 4.35, it is evident that pH of banana powder decreased as the drying temperature and foam thickness increased. This might be due to concentration of H<sup>+</sup> ion in solution increased with increased of temperature and thickness of foam as the ability of water to ionize increased. Mean value of pH of banana powder is presented in Appendix – G2. Maximum pH (4.53) of banana powder was found for treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm). Minimum pH (4.19) of banana powder was found under treatment combination T<sub>4</sub>t<sub>3</sub> (70 °C and 6 mm). Similar results were also reported by Yusufe *et al.* (2017) in tomato powder and Khodifad (2017) in custard apple powder.



**Fig. 4.35 Effect of drying conditions on pH of banana powder**

The best result was found during the drying experiment in treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) having highest pH of banana powder.

Considering the important biochemical properties *i.e.* maximum ascorbic acid and minimum reducing sugar of banana powder, treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) and T<sub>2</sub>t<sub>1</sub> (60 °C and 2 mm) was observed to be best among all the treatments.

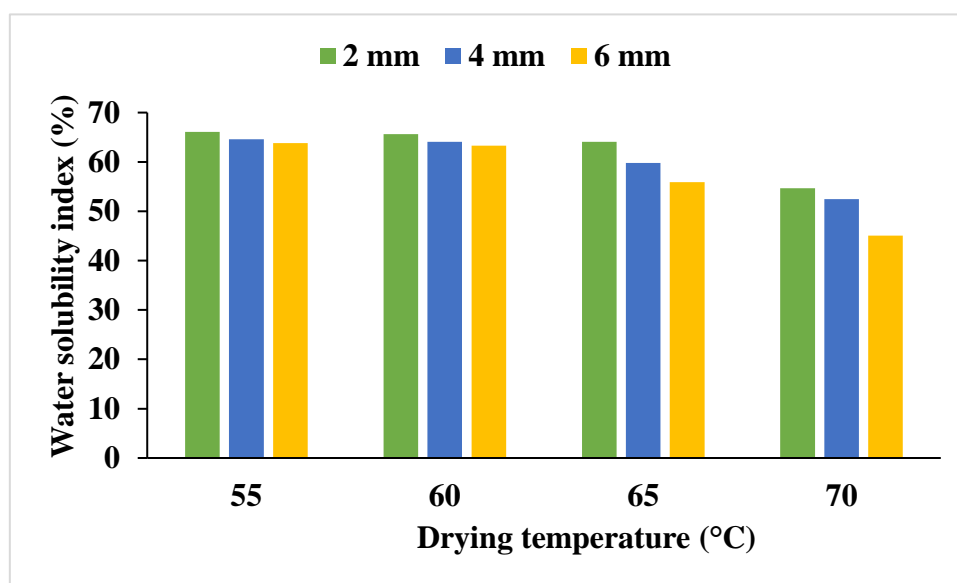
### 4.6.3 Functional properties

#### 4.6.3.1 Water solubility index (%)

Water solubility index of banana powder at different drying temperature and foam thickness is presented in Table 4.7. It is apparent that the effect of drying temperature on water solubility index of banana powder was found significant. Drying temperature T<sub>1</sub> (55 °C) resulted significantly highest water solubility index (64.85%) of banana powder. However, it was found at par with T<sub>2</sub> (60 °C). Drying temperature T<sub>4</sub> (70 °C) resulted

significantly lowest water solubility index (50.71%) of banana powder. The effect of foam thickness on water solubility index of banana powder was also found significant. Foam thickness of  $t_1$  (2 mm) resulted significantly highest water solubility index (62.62%) of banana powder while foam thickness of  $t_3$  (6 mm) was found significantly lowest water solubility index (57.02%) of banana powder. The interaction between  $T^*t$  was also found significant on water solubility index of banana powder.

From the Fig. 4.36, it is clear that water solubility index of banana powder decreased as the drying temperature and foam thickness increased. This might be due to faster collapsing of bubbles of foamed pulp at high temperature thus reduced porosity and solubility of the powder. Mean value of water solubility index of banana powder is presented in Appendix – G3. Maximum water solubility index (66.10%) of banana powder was found for treatment combination  $T_{1t_1}$  (55 °C and 2 mm). Minimum water solubility index (45.06%) of banana powder was found for treatment combination  $T_{4t_3}$  (70 °C and 6 mm). Similar findings were reported by Roongruangsri and Bronlund (2016) in pumpkin powder and Abbasi and Azizpour (2016) in cherry powder.



**Fig. 4.36 Effect of drying conditions on water solubility index of banana powder**

The best result was found during the drying experiment for treatment combination  $T_{1t_1}$  (55 °C and 2 mm) and  $T_{2t_1}$  (60 °C and 2 mm) having highest water solubility index of banana powder.

**Table 4.7 Effect of drying conditions on functional properties of powder**

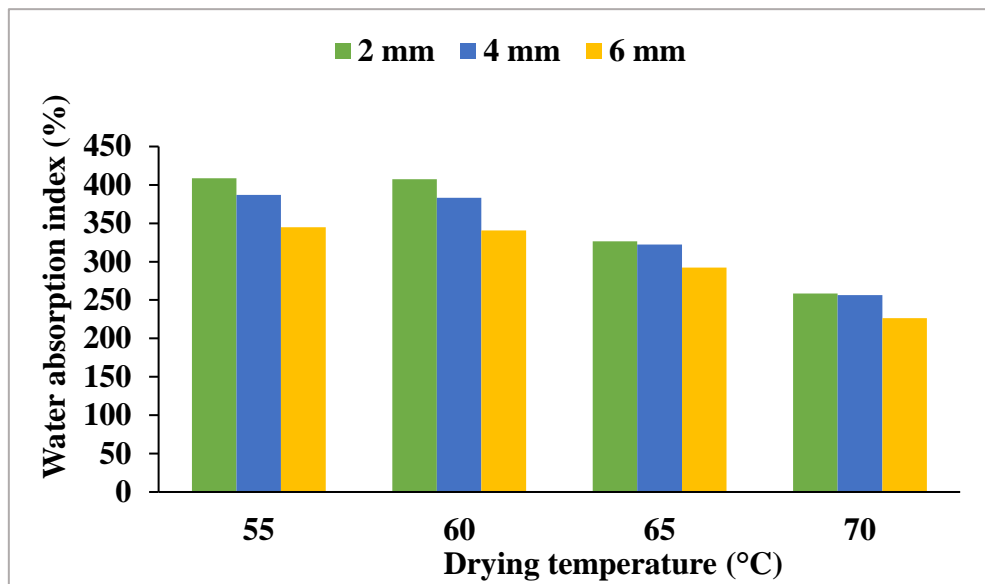
Effect	Water solubility index (%)	Water absorption index (%)
<b>Drying temperature (T)</b>		
55 °C	64.85	380.02
60 °C	64.33	377.18
65 °C	59.93	313.68
70 °C	50.71	247.13
S. Em±	0.29	1.19
CD at 5%	0.85	3.48
<b>Foam thickness (t)</b>		
2 mm	62.62	350.20
4 mm	60.23	337.27
6 mm	57.02	301.03
S. Em±	0.25	1.03
CD at 5%	0.73	3.01
<b>Interaction T*t</b>		
S. Em±	0.50	2.07
CD at 5%	1.47	6.03
C.V.%	1.45	1.09

#### 4.6.3.2 Water absorption index (%)

Water absorption index of banana powder obtained during different drying conditions is presented in Table 4.7. It is obvious that the effect of different drying temperature on water absorption index of banana powder was found significant. Drying temperature T<sub>1</sub> (55 °C) resulted significantly highest water absorption index (380.02%) of banana powder. However, it was found at par with T<sub>2</sub> (60 °C). Drying temperature T<sub>4</sub> (70 °C) resulted significantly lowest water absorption index (247.13%) of banana powder. The effect of foam thickness on water absorption index of banana powder was also found significant. Foam thickness of t<sub>1</sub> (2 mm) resulted significantly highest water absorption index (350.20%) of banana powder while foam thickness of t<sub>3</sub> (6 mm) had significantly lowest water absorption index (301.03%) of banana powder. The interaction between T\*t was also found significant on water absorption index of banana powder.

From the Fig. 4.37, it is clear that water absorption index of banana powder decreased as the drying temperature and foam thickness increased. Mean data of water absorption index is presented in Appendix – G3. Maximum water absorption index (408.48%) of banana powder was found under treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and

2 mm). Minimum water absorption index (226.46%) of banana powder was found for treatment combination T<sub>4t3</sub> (70 °C and 6 mm). Similar findings were also reported by Sangamithra *et al.* (2015) in muskmelon and Roongruangsri and Bronlund (2016) in pumpkin powder.



**Fig. 4.36 Effect of drying conditions on water absorption index of banana powder**

It may be concluded that treatment combination T<sub>1t1</sub> (55 °C and 2 mm) and T<sub>2t1</sub> (60 °C and 2 mm) was found to be best among all the treatments having highest water absorption index of banana powder.

Considering the functional properties having maximum water solubility index and water absorption index of banana powder, treatment combination T<sub>1t1</sub> (55 °C and 2 mm) and T<sub>2t1</sub> (60 °C and 2 mm) was found to be best among all the treatments.

#### 4.6.4 Sensory evaluation

The sensory evaluation *viz.*, appearance, texture, flavour, taste and overall acceptability of foam mat dried banana powder was carried out by 9-point hedonic scale. The results of different sensory attributes with their mean value are given in Appendix - H.

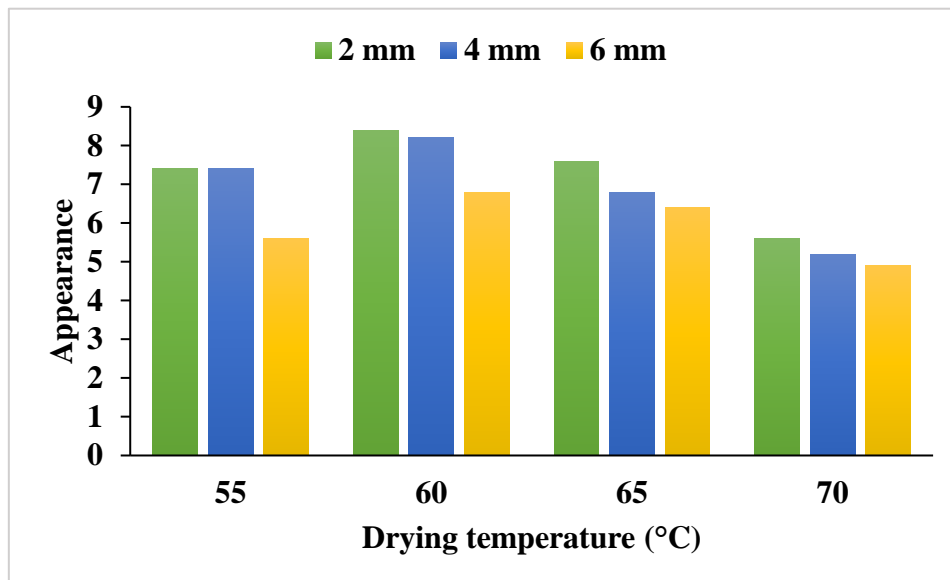
##### 4.6.4.1 Appearance

The effect of temperature and thickness on appearance of foam mat dried banana powder are graphically shown in Fig. 4.38. The maximum appearance score (8.4) was observed in treatment T<sub>2t1</sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness followed



**Plate 4.1 Appearance of banana powder prepared at different drying conditions**

by T<sub>2t<sub>2</sub></sub> *i.e.*, 60 °C drying temperature and 4 mm foam thickness. Minimum appearance score (4.9) was observed in T<sub>4t<sub>3</sub></sub> *i.e.*, 70 °C drying temperature and 6 mm foam thickness followed by T<sub>1t<sub>3</sub></sub> *i.e.*, 55 °C drying temperature and 6 mm foam thickness. This might be due to adverse effect on banana powder at higher drying temperature and more drying time.

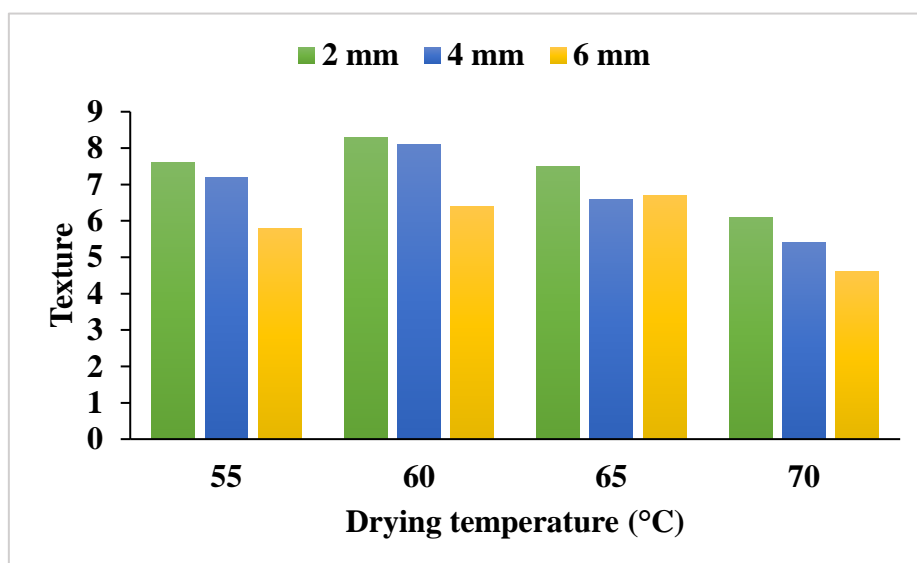


**Fig. 4.38 Effect of drying conditions on appearance of banana powder**

It can be concluded that the highest appearance score was obtained in treatment T<sub>2t<sub>1</sub></sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness among all the treatments.

#### 4.6.4.2 Texture

The effect of drying temperature and foam thickness on texture of foam mat dried banana powder are graphically shown in Fig. 4.39. Maximum texture score (8.3) was



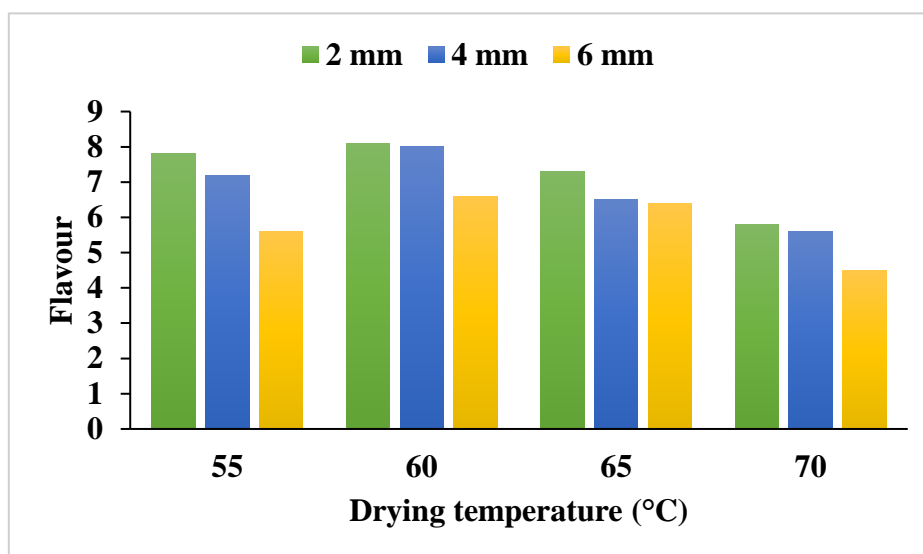
**Fig. 4.39 Effect of drying conditions on texture of banana powder**

observed in treatment T<sub>2t1</sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness, whereas minimum texture score (4.6) was observed in T<sub>4t3</sub> *i.e.*, 70 °C drying temperature and 6 mm foam thickness among all the treatments. This might be attributed to caramalization occurred at higher drying temperature.

It can be concluded that the highest texture score was recorded in treatment T<sub>2t1</sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness among all the treatments.

#### 4.6.4.3 Flavour

The effect of drying temperature and foam thickness on flavour of foam mat dried banana powder are graphically shown in Fig. 4.40. Maximum flavour score (8.1) was observed in treatment T<sub>2t1</sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness followed by T<sub>2t2</sub> *i.e.*, 60 °C drying temperature and 4 mm foam thickness. Minimum flavour score (4.5) was observed in T<sub>4t3</sub> *i.e.*, 70 °C drying temperature and 6 mm foam thickness among all the treatments.



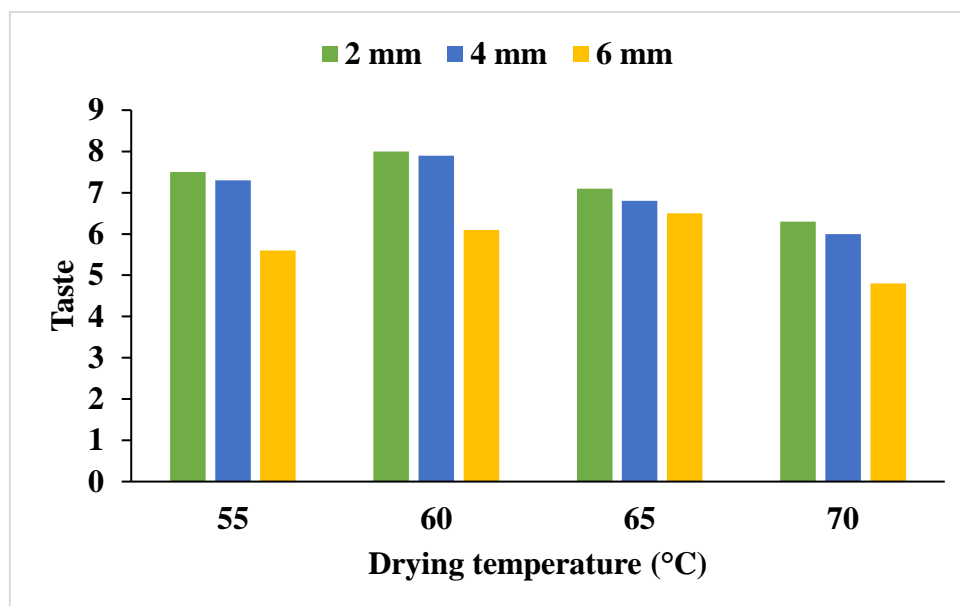
**Fig. 4.40 Effect of drying conditions on flavour of banana powder**

It can be concluded that the highest flavour score was recorded in treatment T<sub>2t1</sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness and T<sub>2t2</sub> *i.e.*, 60 °C drying temperature and 4 mm foam thickness among all the treatments.

#### 4.6.4.4 Taste

The effect of drying temperature and foam thickness on taste of foam mat dried banana powder are shown in Fig. 4.41. Maximum taste score (8.0) was observed in treatment T<sub>2t1</sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness, whereas minimum

taste score (4.8) was observed in T<sub>4t<sub>3</sub></sub> *i.e.*, 70 °C drying temperature and 6 mm foam thickness, among all the treatments.

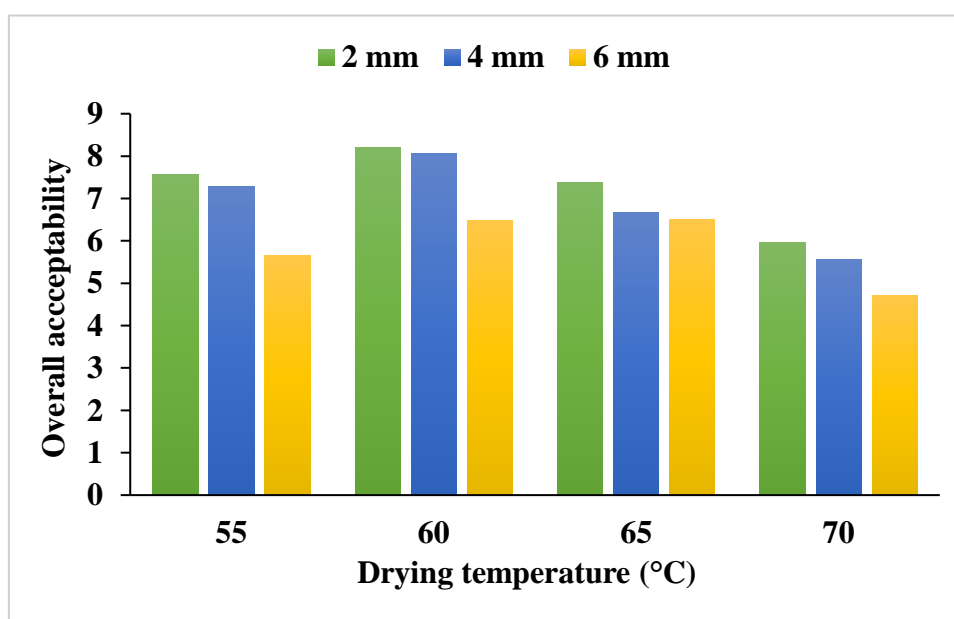


**Fig. 4.41** Effect of drying conditions on taste of banana powder

It can be concluded that the highest taste score was obtained in treatment T<sub>1t<sub>1</sub></sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness among all the treatments.

#### 4.6.4.5 Overall acceptability

The effect of drying temperature and foam thickness on overall acceptability of foam mat dried banana powder are graphically shown in Fig. 4.42. Maximum overall acceptability score (8.2) was observed in treatment T<sub>2t<sub>1</sub></sub> *i.e.*, 60 °C drying temperature and



**Fig. 4.42** Effect of drying conditions on overall acceptability of banana powder

2 mm foam thickness, whereas minimum overall acceptability score (4.7) was observed in T<sub>4t<sub>3</sub></sub> i.e., 70 °C drying temperature and 6 mm foam thickness among all the treatments.

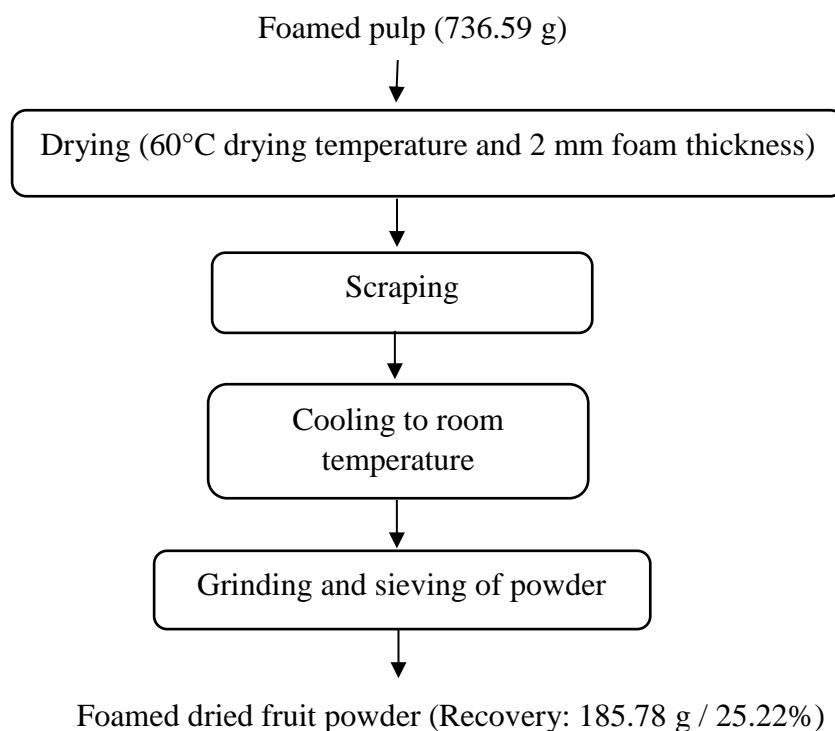
It can be concluded that the highest overall acceptability score was obtained in treatment T<sub>2t<sub>1</sub></sub>, i.e., 60 °C drying temperature and 2 mm foam thickness among all the treatments.

Thus, on the basis of sensory evaluation of foam mat dried banana powder, highest scores of appearance, texture, flavour, taste and overall acceptability was obtained in treatment T<sub>2t<sub>1</sub></sub>, i.e., 60 °C drying temperature and 2 mm foam thickness.

Considering the over all aspects of the study i.e. drying time, physico-chemical and sensory characteristics, it may be concluded that T<sub>2t<sub>1</sub></sub>, i.e., 60 °C drying temperature and 2 mm foam thickness was found to be best among all the treatments.

#### 4.6.5 Improved method suggested for drying of foamed banana

The recommended process flow chart for drying of banana foam is presented in Fig. 4.43. The recommended process flow chart for foaming as well as drying of banana foam is presented in Appendix - I.



**Fig. 4.43 Process flow chart recommended for drying conditions of banana foam**

## CHAPTER V

### SUMMARY AND CONCLUSIONS

---

India is one of the largest producers of the banana (*Musa paradisiac L.*) in the world. Banana is considered a common man's fruit and is rightly called the 'dessert fruit for million'. Banana is a fat free fruit with high calorific value. Banana is valued for its characteristics flavour, fleshy texture as well as medicinal and nutritional qualities.

Banana being a tropical fruit is perishable and undergoes qualitative and quantitative losses between harvest and consumption. After ripening, banana fruit is highly susceptible to deterioration. The fully mature fruits of banana have a shelf life of 6-9 days depending upon the ambient temperature. During the market glut, the prices crash down and the farmers suffer heavy losses due to distress sale. Due to poor transportation and storage facilities, a sizeable quantity of this fruit is wasted due to its perishable nature. Its considerable amount is wasted due to lack of efficient processing techniques that are unique to ripe banana.

Foam mat drying is one of the techniques used for preparation of food powder. This method allows the dehydration of heat sensitive, high sugar content and viscous food like ripe banana which is difficult to dry. By using this drying technique product is dried under relatively mild conditions in a very short time with minimum quality changes. Foam mat drying which leads to increase of drying rate and significant reduction in drying time; improved the sensory, nutritional and functional properties of the product. The foam mat dried products are highly stable against deteriorative microbial, chemical and biochemical reactions. The banana powder can be used as food ingredient and natural flavouring agent in other products during off season. Food processing and value addition reduce the glut in the market and farmers fetch remunerative price during harvesting season in the domestic market.

The experiment was consisting of optimizing the foaming properties of banana pulp and drying of foamed banana pulp at different drying conditions. Grand Naine variety of ripe banana at stage-5 (15 °Brix) was selected for the present investigation. The experiment was carried out in the Department of Processing and Food Engineering,

College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh during the year 2018-19.

After removing peels, banana fruits were cut into small pieces of thickness 3-5 mm. Then banana slices were kept in 1% sodium meta bisulphite solution (w/w) for 2 min and then rinsed in water for 30 s for further foaming process.

### **5.1 Experiment No. 1: Foaming properties of banana pulp**

Pre-treated banana slice of 100 g of sample was taken into the vessel of foaming device with 100 ml water *i.e.* sample to water ratio of 1:1 (w/w). For foaming formation, transparent cylindrical plastic vessel, air pump and hand blender were used. Air pump having two air nozzles was used at flow rate 4 lit/min per nozzle for flowing air in the cylinder. The nozzles were kept about 180° angular diameter for maintaining uniformity. Controlled rate of compressed air was introduced at the bottom of vessel for foaming of the pulp. Blending and whipping of pulp was carried out with a portable hand blender for proper mixing of air with the pulp. Whey protein isolate was used as foaming agent and methyl cellulose was used as foaming stabilizer. Five levels of foaming agent (2.5, 4.53, 7.5, 10.47 and 12.5%), foaming stabilizer (0.1, 0.18, 0.3, 0.42 and 0.5%) and whipping time (5, 9, 15, 21 and 25) were used as per Central Composite Rotatable Design for statistical analysis to perform the experiment.

The Response Surface Methodology (RSM) was used in designing the experiment. A three-factor five-level Central Composite Rotatable Design (CCRD) with quadratic model was employed (1) to study the combined effect of three independent variables *viz.*, foaming agent, foaming stabilizer and whipping time on different response variables, (2) to create models between the variables, and (3) to determine the effect of these variables to optimize the selected response variables. The optimum conditions obtained through response surface analysis were verified by conducting the experiments.

The following conclusions were drawn from the present investigation:

1. The mean values of biochemical properties *viz.*, moisture content, total soluble solids (TSS), total sugars, reducing sugars, titratable acidity, ascorbic acid and pH of five banana fruit with their standard deviation was observed to be  $75 \pm 2$

(%,wb),  $15 \pm 1$  °Brix,  $17 \pm 1\%$ ,  $9 \pm 0.3\%$ ,  $0.24 \pm 0.05\%$ ,  $10.1 \pm 0.5$  mg/100 g, and  $5.85 \pm 0.3$ , respectively.

2. The foam expansion varied from 88.57% to 138.54% obtained at different combination of variables. The maximum foam expansion was found in treatment number 3 having the combination of 4.53% foaming agent, 0.42% foaming stabilizer and 9.05 min whipping time, while the minimum foam expansion was found in treatment number 14 having the combination of 7.50 % foaming agent, 0.30% foaming stabilizer and 25 min whipping time.
3. The response surface equation for foam expansion was obtained as given below

$$\text{Foam expansion (\%)} = 120.99 - 4.13 A + 3.41 B - 10.71 C + 0.28 AB + 1.63 AC - 2.72 BC - 7.45 A^2 + 3.17 B^2 - 6.09 C^2$$

Where, A, B and C are the coded factors for foaming agent, foaming stabilizer and whipping time, respectively.

4. The foam stability varied from 71.82% to 95.00% obtained at different combination of variables. The maximum foam stability was found in treatment number 12 having the combination of 7.50% foaming agent, 0.50% foaming stabilizer and 15.00 min whipping time, while the minimum foam stability was found in treatment number 11 having the combination of 7.50 % foaming agent, 0.10% foaming stabilizer and 15 min whipping time.
5. The response surface equation for foam stability was obtained as given below

$$\text{Foam stability (\%)} = 80.97 - 1.97 A + 7.15 B - 1.85 C - 0.31 AB - 0.051 AC + 0.016 BC - 1.22 A^2 + 1.53 B^2 + 0.61 C^2$$

Where, A, B and C are the coded factors for foaming agent, foaming stabilizer and whipping time, respectively.

6. The foam density varied from 0.43 to 0.54 g/cc obtained at different combination of variables. The minimum foam density was found in treatment number 3 having the combination of 4.53% foaming agent, 0.42% foaming stabilizer and 9.05 min whipping time, while the maximum foam density was found in treatment number 14 having the combination of 7.50 % foaming agent, 0.30% foaming stabilizer and 25 min whipping time.
7. The response surface equation for foam density was obtained as given below

$$\text{Foam density} = 0.46 - 0.009053 A - 0.006124 B + 0.024 C - 0.00125 AB - \\ 0.00125 AC + 0.00625 BC - 0.018 A^2 - 0.006512 B^2 + \\ 0.015 C^2$$

Where, A, B and C are the coded factors for foaming agent, foaming stabilizer and whipping time, respectively.

8. The optimum foaming conditions were found to be 5.35% foaming agent, 0.45% foaming stabilizer and 9.43 min whipping time for maximum foam expansion and foam stability as well as minimum foam density.
9. The predicted value analysis showed that at this combination of foaming agent, foaming stabilizer and whipping time, it would be possible of foaming properties of banana pulp with a foam expansion of 138.95%, foam stability of 96.33% and foam density of 0.43 g/cc.
10. The experiment value analysis showed that at this combination of foaming agent, foaming stabilizer and whipping time, foaming properties of banana pulp was foam expansion of 142.28% with a deviation of 2.39%, foam stability of 94.76% with a deviation of 1.62% and foam density of 0.42 g/cc with a deviation of 2.32%.

From the above study, it can be concluded that the maximum foam expansion, maximum foam stability and minimum foam density was obtained by 5.35% foaming agent (whey protein isolate), 0.45% foaming stabilizer (methyl cellulose) and 9.43 min whipping time.

## 5.2 Experiment No. 2: Drying of foamed banana

Optimized parameters derived from experiment No. 1 for foaming properties of banana pulp for foaming agent, foaming stabilizer and whipping time was selected for further drying of foamed banana. Drying of foamed banana pulp was carried out at four levels of drying temperature (55, 60, 65 and 70 °C) and three levels of foam thickness (2, 4 and 6 mm). Drying was carried out in a tray dryer with sample size of 161 g, 323 g and 485 g for 2, 4 and 6 mm foam thickness, respectively. After drying, dried sample was scrapped, grinded and sieved through mesh no. 35 sieve. Drying characteristics *i.e.*, drying time, drying rate and moisture ratio were analysed during drying process. Physical properties like recovery and bulk density of banana powder were measured by standard method. Recovery of foam mat dried banana powder was

measured by the ratio of weight of dried powder to weight of foamed banana pulp applied on the tray. Bulk density of banana powder was determined by the ratio of weight of dried powder to volume of powder after tapping. Biochemical properties of banana powder *viz.*, moisture content, total sugars, reducing sugar, non-reducing sugar, titratable acidity, ascorbic acid and pH were measured by standard method. The moisture content of powder was determined by hot air oven method. Total sugars and reducing sugar were determined by phenol sulphuric acid method. Non reducing sugar was estimated by subtraction of reducing sugar from total sugars. Titratable acidity was estimated as reported by Ranganna (2000). Ascorbic acid content was determined by the method described by Sadasivam and Manickam (1992). pH of the powder was measured using pH meter. Functional properties such as water solubility index of banana powder was determined by the method suggested by Anderson (1982) and water absorption index is determined by the ratio of the weight of sediments to that of weight of dry solid powder. Sensory characteristics *viz.*, appearance, texture, flavour, taste and over all acceptability of foamed dried banana powder were evaluated by a panel of semi trained 10 judges using 9-point hedonic scale. The results were statistically analysed by Completely Randomized Design with three replications at 5 per cent level of significance.

The following conclusions were drawn from the present investigation:

1. Maximum drying time (300 min) was observed at 55 °C drying temperature and 6 mm foam thickness while minimum drying time (120 min) was observed at 70 °C drying temperature and 2 mm thickness. Drying time for drying temperature 60 °C and 2 mm foam thickness was found 180 min.
2. Maximum drying rate (0.310 g water/g dry matter/min) was found for 70 °C for drying temperature for 2 mm foam thickness and minimum drying rate (0.113 g water/g dry matter/min) was recorded for 55 °C drying temperature for 6 mm foamed thickness of banana pulp.
3. There was rapid decrease in moisture ratio with faster rate at initial stage of 50 to 70 min of drying in all cases, however in later stage of drying, the decrease in moisture ratio was at slower rate.
4. Physical properties *i.e.*, recovery of banana powder was found maximum (37.86%) for the treatment combination T<sub>1</sub>t<sub>1</sub> (55 °C and 2 mm) which was found

at par with treatment combination T<sub>2t<sub>1</sub></sub> (60 °C and 2 mm). Minimum recovery (27.63%) of banana powder was found for treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm). Maximum bulk density (0.70 g/cc) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 6 mm). Minimum bulk density (0.52 g/cc) of banana powder was found for treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 2 mm).

5. Biochemical properties *viz.*, Minimum moisture content (4.07%) of banana powder was found for treatment combination T<sub>4t<sub>1</sub></sub> (70 °C and 2 mm). Maximum moisture content (6.40%) of banana powder was found for treatment combination T<sub>1t<sub>3</sub></sub> (55 °C and 6 mm). Moisture content of banana powder for treatment combination T<sub>2t<sub>1</sub></sub> (60 °C and 2 mm) was found 5.01%.
6. Maximum total sugars (39.25%) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm). Minimum total sugars (30.20%) of banana powder was found for treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).
7. Minimum reducing sugar (0.11%) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm) followed by T<sub>2t<sub>1</sub></sub> (60 °C and 2 mm). Maximum reducing sugar (0.61%) of banana powder was found for treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).
8. Maximum non-reducing sugar (39.14%) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm). Minimum non-reducing sugar (29.59%) of banana powder was found under treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).
9. Minimum titratable acidity (0.35%) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm). Maximum titratable acidity (0.60%) was found for treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).
10. Maximum ascorbic acid (0.89 mg/100 g) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm) which was found at par with treatment combination T<sub>2t<sub>1</sub></sub> (60 °C and 2 mm). Minimum ascorbic acid (0.38 mg/100 g) of banana powder was found under treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).
11. Maximum pH (4.53) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm). Minimum pH (4.19) of banana powder was found under treatment combination T<sub>4t<sub>3</sub></sub> (70 °C and 6 mm).

12. Functional properties *i.e.*, maximum water solubility index (66.10%) and water absorption index (408.48%) of banana powder was found for treatment combination T<sub>1t<sub>1</sub></sub> (55 °C and 2 mm) which was found at par with treatment combination T<sub>2t<sub>1</sub></sub> (60 °C and 2 mm).
13. Maximum sensory score (8.2) in term of appearance, texture, flavour, taste and overall acceptability of foam mat dried banana powder was observed in treatment T<sub>2t<sub>1</sub></sub> *i.e.*, 60 °C drying temperature and 2 mm foam thickness, whereas minimum sensory score (4.7) was observed in T<sub>4t<sub>3</sub></sub> *i.e.*, 70 °C drying temperature and 6 mm foam thickness among all the treatments.

Considering overall quality and drying time from the above study, it can be concluded that treatment combination T<sub>2t<sub>1</sub></sub>, *i.e.*, 60 °C drying temperature and 2 mm foam thickness was found to be best among all the treatments.

## BIBLIOGRAPHY

---

---

- Abasi, S.; Mousavi, S. M.; Mohebi, M. and Kiani, S. 2009. Effect of time and temperature on moisture content, shrinkage, and rehydration of dried onion. *Iranian Journal of Chemical Engineering*, **6(3)**: 57-60.
- Abbasi, E., and Azizpour, M. 2016. Evaluation of physicochemical properties of foam mat dried sour cherry powder. *LWT - Food Science and Technology*, **68**: 105-110.
- Adubofuor, J.; Amoah, I.; Batsa, V.; Agyekum, P.B. and Buah, J. A. 2016. Nutrient composition and sensory evaluation of ripe banana slices and bread prepared from ripe banana and wheat composite flours. *American Journal of Food and Nutrition*, **4(4)**: 103-111.
- Akesowan, A. and Choonhahirun, A. 2013. Effect of enzyme treatment on guava juice production using Response surface methodology. *The Journal of Animal and Plant Sciences*, **23(1)**: 114-120.
- Amerine, J. H; Pangborn, R. M; and Rosster, E. B. 1965. Principles of sensory evaluation of food. Academic Press Inc., New York.
- Anderson, R. A. 1982. Water absorption and solubility and amylograph characteristics of roll-cooked small grain products. *Cereal Chem.*, **59(4)**: 265-269.
- Anderson, M. J. and Whitcomb, P. J. (ed). 2005. RSM Simplified - Optimizing Processes Using Response Surface Methods for Design of Experiments, Productivity Press, New York.
- Antala. 2011. Packaging and storage studies on fresh guava fruit and osmotic-air dehydrated power of guava (*Psidium guajava* L.), Ph.D. thesis (unpublished) submitted to Department of Agricultural Food Engineering, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.
- Anonymous, 2003. International network for the improvement of banana and plantain (INIBAP). Parc scientifique agropolis montpellier cedex 5, France.

- Anonymous, 2018a. Horticultural Statistics at a Glance 2018, Horticulture Statistics Division, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India : 146-396.
- Anonymous, 2018b. District-wise Area, Production and Yield of Important Food & Non-food Crops in Gujarat State (Year: 2014-15 and 2015-16), Directorate of Agriculture, Gujarat State, Gandhinagar.
- AOAC, 2005. Official methods of analysis, 18<sup>th</sup> ed., Association of Official Analytical Chemists, Washington, DC.
- Aurore, G, Parfait, B and Fahrasmane, L. 2008. Bananas, raw materials for making processed food products. *Trends in Food Science & Technology*, **20(2)**: 78-91.
- Auisakchaiyoung, T. and Rojanakorn, T. 2015. Effect of foam mat drying conditions on quality of dried gac fruit (*Momordica cochinchinensis*) aril. *International Food Research Journal*, **22(5)**.
- Bag, S. K.; Srivastav, P. P. and Mishra, H. N. 2011. Optimization of process parameters for foaming of bael (*Aegle marmelos* L.) fruit pulp. *Food and Bioprocess Technology*, **4(8)**: 1450-1458.
- Barre, A.; Peumans, W. J.; Menu-Bouaouiche, L.; VanDamme, E. J. M.; May, G. D. and Herrera, A. F. 2000. Purification and structural analysis of an abundant thaumatin like protein from ripe banana fruit. *Planta*, **211**: 791–799.
- Bikerman, J. J. 1973. Foams. New York, USA: Springer-Verlag.
- Branco, I. G.; Kikuchi, T. T.; Argandona, E. J. S.; Moraes, I. C. F. and Haminiuk, C. W. I. 2016. Drying kinetics and quality of uvaia (*Hexachlamys edulis* (O. Berg)) powder obtained by foam mat drying. *International Journal of Food Science and Technology*, **51**: 1703–1710.
- Budhrani, B. P. 2011. Thin layer drying study on foamed anola pulp. M.Tech. (Agril. Engg.) thesis (unpublished) submitted to College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

- Castro, J. K.; Cerquera, N. E. and Pastrana-Bonilla, E. 2017. Physicochemical characterization and sensory evaluation of banana pulp (*Musa Paradisiaca*) dehydrated in sheets. *ARPN Journal of Engineering and Applied Sciences*, **12(5)**: 1463-1468.
- Chandrasekar, V.; Gabriela, J. S.; Kannan, K. and Sangamithra, A. 2015. Effect of foaming agent concentration and drying temperature on physiochemical and antimicrobial properties of foam mat dried powder. *Journal of Dairying, Foods and Home sciences*, **34(1)**: 39-43.
- Chauhan, N. and Jethva, K. R. 2016. Drying characteristics of banana powder. *Indian Journal of Science*, **23(77)**: 75-88.
- Chaves, M. A.; Barreto, I. M.; Reis, R. C. and Kadam, D. M. 2013. Physicochemical and sensory properties of purple brazilian cherry (*Eugenia uniflora*, L.) foams. *International Journal of Food Science and Technology*, **48(8)**: 1688-1697.
- Cholera, S. P. and Patel, N. C. 2016. Preparation of sapota powder by osmo-freeze drying. *AGRES – An International e-Journal*, **5(3)**: 249-265.
- Clements, M. L.; Levine, M. M.; Black, R. E.; Hughes, T. P.; Rust, J. and Tome, F. C. 1980. Potassium supplements for oral diarrhea regimens. *The Lancet*, **2(8199)**: 854.
- Davara, P. R. and Patel, N. C. 2009. Assessment of post harvest losses in banana grown in Gujarat. *Journal of Horticultural Sciences*, **4(2)**: 187-190.
- Djaeni, M.; Utari, F. D. and Arifin, U. F. 2018. Optimization foam mat drying of roselle (*Hibiscus sabdariffa* L.) extract.
- Do, H. T. T and Nguyen, H. V. H. 2018. Effects of Spray-Drying Temperatures and Ratios of Gum Arabic to Microcrystalline Cellulose on Antioxidant and Physical Properties of Mulberry Juice Powder. *Beverages*, **4(4)**: 101.
- Durian, D. J. 1995. Foam mechanics at the bubble scale. *Physical review letters*, **75**: 4780-4784.

- Durge, S.; Srivastav, P. P. and Jaybhaye, R. V. 2015. Foaming behaviour of sapota pulp. *International Journal of Agricultural Engineering*, **8(2)**: 160-168.
- Englberger, L.; Darnton-Hill, I.; Coyne, T.; Fitzgerald, M. H. and Marks, G. C. 2003. Carotenoid-rich bananas - A potential food source for alleviating vitamin A deficiency. *Food and Nutrition Bulletin*, **24(4)**: 303– 318.
- Falade, F. O.; Adeyanju, K. I. and Uzo-Peters, P. I. 2003. Foam mat drying of cowpea (*Vigna unguiculata*) using glyceryl monostearate and egg albumen as foaming agents. *European Food Research and Technology*, **217(6)**: 486-491.
- Falade, K. O. and Okocha, J. O. 2010. Foam mat drying of plantain and cooking banana (*Musa spp.*). *Food and Bioprocess Technology*, **5(4)**: 1173-1180.
- Falade, K. O. and Solademi, O. J. 2010. Modelling of air drying of fresh and blanched sweet potato slices. *International Journal of Food Science and Technology*, **45**: 278–288.
- Franco, T. S.; Perussello, C. A.; Ellendersen, L. N. and Masson, M. L. 2016. Effects of foam mat drying on physicochemical and microstructural properties of yacon juice powder. *LWT-Food Science and Technology*, **66**: 503-513.
- Fumagalli, F. and Silveira, A. M. 2005. Quality evaluation of microwave-dried packham's triumph pear. *Drying Technology*, **23**: 2215–2226.
- Ghazanfar, M. A. K.; Llyas, M. B.; Khan, C. A. and Bhatti, M. A. R. 2007. Post harvest losses in apple and banana during transport and storage. *Pakistan Journal of Agricultural Sciences*, **44(3)**: 534-539.
- Haber, A. and Runyon, R. 1977. General statistics (3<sup>rd</sup> Ed.), Addison-Wesley, Reading, MA.
- Harish, N.; Vandana, K.; Dhanusha, S. K. V. and Kalpana, D. 2017. Feasible studies on production of banana powder. *International Journal of Agricultural Science and Research*, **7(4)**: 413-420.
- Hassanain, A. A. 2009. Simple solar drying system for banana fruit. *World Journal of Agricultural Sciences*, **5(4)**: 446-455.

- Hertzendorf, M. S.; Moshy, R. J. and Seltzer, E. 1970. Foam drying in the food industry. *Critical Reviews in Food Science and Nutrition*, **1**: 25-70.
- Javed, I. M.; Abbas; A.; Rafique, H.; Nawaz, F. M. and Rasool, A. 2018. A review paper on foam-mat drying of fruits and vegetables to develop powders. *MOJ Food Processing & Technology*, **6(6)**: 465-467.
- Jethva, K. R.; Kumar, S., Kumar, N. and Seth, N. 2015. A paper was presented in National Seminar on Emerging Trends in Food Quality and Safety, at Anand Agricultural University, Anand.
- Joglekar, A. M. and May, A. T. 1987. Product excellence through design of experiments. *Cereal Foods World*, **32**: 857-868.
- Kabiru, A. A.; Joshua, A. A. and Raji, A. O. 2013. Effect of slice thickness and temperature on the drying kinetics of mango (*Mangifera indica*). *International Journal of Research and Review in Applied Sciences*, **15(1)**: 41-50.
- Kadam, D. M.; Patil, R. T. and Kaushik, P. 2010a. Foam mat drying of fruit and vegetable product. *Drying of Foods, Vegetables and Fruits*, **1**: 111-124.
- Kadam, D. M.; Wilson, R. A.; Kaur, S. 2010b. Determination of biochemical properties of foam mat dried mango powder. *International Journal of Food Science and Technology*, **45(8)**: 1626-1632.
- Kadam, D. M. and Balasubramanian, S. 2011. Foam mat drying of tomato juice. *Journal of Food Processing and Preservation*, **35(4)**: 488-495.
- Kadam, D. M.; Wilson, R. A.; Chadha, S. and Sharma, M. 2012a. Foam mat drying characteristics of mango pulp. *International Journal of Food Science and Nutrition Engineering*, **2(4)**: 63-69.
- Kadam, D. M.; Wilson, R. A.; Kaur, V.; Chadha, S.; Kaushik, P.; Kaur, S.; Patil, R. T. and Rai, D. R. 2012b. Physicochemical and microbial quality evaluation of foam mat-dried pineapple powder. *International Journal of Food Science and Technology*, **47**: 1654-1659.

- Kandasamy, P.; Varadharaju, N. and Kalemullah, S. 2012a. Foam mat drying of papaya (*Carica Papaya* L.) using glycerol monostearate as foaming agent. *Food Science and Quality Management*, **9**: 17-27.
- Kandasamy, P.; Varadharaju, N.; Kalemullah, S. and Moitra, R. 2012b. Preparation of papaya powder under foam mat drying technique using egg albumin as foaming agent. *International Journal of Bio-resource and Stress Management*, **3(3)**: 324-333.
- Kandasamy, P.; Varadharaju, N.; Kalemullah, S. and Maladhi, R. 2014. Optimization of process parameters for foam mat drying of papaya pulp. *Journal of Food Science and Technology*, **51(10)**: 2526-2534.
- Karim, A. and Wai, C. 1999. Foam mat drying of starfruit (*Averrhoa carambola* L.) pure e. stability and air drying characteristics. *Food Chemistry*, **64**: 337-343.
- Kilcast, D. and Subramaniam, P. 2000. The stability and shelf-life of food. Woodhead Publishing Ltd., Cambridge.
- Khamjae, T. and Rojanakorn, T. 2018. Foam mat drying of passion fruit aril. *International Food Research Journal*, **25(1)**: 204-212.
- Khodifad, B. C. 2017. Foam mat drying of custard apple pulp and storage stability of custard apple powder. M.Tech. (Agril. Engg.) thesis (unpublished) submitted to College of Agricultural Engineering and Technology, Anand Agricultural University, Godhra.
- Koocheki, A. S.; Mortazavi, A.; Shahidi, F.; Razavi, S. M. A.; Kadkhodae, R. and Milani, J. M. 2010. Optimization of mucilage extraction from qodume shirazi seed (*Alyssum homolocarpum*) using response surface methodology. *Journal of Food Process Engineering*, **33**: 861-882.
- Khuri A. I. and Cornell, J. A. (1987) Response surface design and analysis. Marcel Dekker, Inc., New York.
- Kudra, T. and Ratti, C. 2006. Foam mat drying: Energy and cost analyses. *Canadian Biosystems Engineering.*, **48**: 3.27–3.32.

- Kuyu, C. G. and Tola, Y.B. 2018. Assessment of banana fruit handling practices and associated fungal pathogens in Jimma town market, southwest Ethiopia. *Food Science and Nutrition*, **6(3)**: 609-616.
- Little, T. M. and Hills, F. J. 1978. Agricultural experimental design and analysis, John Wiley, New York. pp. 170.
- Maskan, M., 2000. Microwave/air and microwave finish drying of banana. *Journal of Food Engineering*, **44(2)**: 71-78.
- Mazza, G. 1983. Dehydration of carrots: Effects of pre-drying treatments on moisture transport and product quality. *International Journal of Food Science and Technology*, **18**: 113-23.
- Mclaren, C. G.; Bartolome, V. I.; Carrasco, M. C.; Quintana, L. C.; Ferino, M. I. B.; Mojica, J. Z.; Olea, A. B.; Paunlagui, L. C.; Ramos, C. G. and Ynalvez, M. A. 1977. Experimental design and data analysis for agricultural research, Vol. I, Los Banos, Laguna : International Rice Research Institute.
- Mendenhall, W. 1975. Introduction to probability and statistics (4<sup>th</sup> Ed.). North Settuete, MA : Duxbury Press, pp. 273.
- Mishra, A. A.; Shukla, R. N.; Kumar, A. and Gautam, A. K. 2016. Effect of drying temperature and packaging material on quality and shelf-life of dried banana powder. *International Journal of Processing and Post Harvest Technology*, **7**: 47-52.
- Montgomery, D. C. 2001. Design and analysis of experiments, Wily, New York. pp. 416-419.
- Morgan, A. I.; Graham, R. P., Ginnette, L. F. and Williams, G. 1961. Recent developments in foam mat drying. *Food Technology*, **15**: 37–39.
- Murthy, D. S.; Gajanana, T. M.; Sudha, M. and Dakshinamoorthy, V. 2009. Marketing and post-harvest losses in fruits: Its implications on availability and economy. *Indian Journal of Agricultural Economics*, **64(2)**: 259-275.

- Myres, R. H. 1976. Response Surface Methodology, Department of Statistics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, Distributed by Edwards Brothers, Inc., Ann Arbor, Michigan.
- Narayana, C. K. 2015. Bananas and plantains - Postharvest management, storage, ripening and processing, New India Publishing Agency, New Delhi. pp. 87.
- Ng, M. L. and Sulaiman, R., 2018. Development of beetroot (*Beta vulgaris*) powder using foam mat drying. *LWT*, **88**: 80-86.
- Oladiji, A. T.; Idoko, A. S.; Abodunrin, T. P. and Yakubu, M. T. 2010. Studies on the physicochemical properties and fatty acid composition of the oil from ripe plantain peel (*Musa paradisiaca*). *African Scientist*, **11(1)**: 73-78.
- Omulo, G.; Noble, B. and Kiggundu, N. 2015. Harnessing of banana ripening process for banana juice extraction in Uganda. *African Journal of Food Science and Technology*, **6(4)**: 108-117.
- Palmei, G.; Sakare, P.; Manda, N. and Poornima, S. 2017. Development and study on quality parameters of foam mat dried banana powder. *International Journal of Agriculture Sciences*, **9(44)**: 4715-4721.
- Palmei, G.; Pandey, J. P.; Chand, K. and Shahi, N. C. 2018. Optimization of ingredients for the production of foamed banana powder using response surface methodology. *International Journal of Chemical Studies*, **6(3)**: 955-960.
- Panse, V. G. and Sukhatme, P. V. 1985. Statistical methods for agricultural workers, Fourth Editions. ICAR, New Delhi.
- Patel, S. 1996. Development of a process technology for production of tomato powder using foam mat drying technique, Ph.D. thesis (unpublished) submitted to Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur.
- Peumans, W. J.; Zhang, W. L.; Barre, A.; Astoul, C. H.; Balint-Kurti, P. J. and Rovira, P. 2000. Fruit-specific lectins from banana and plantain. *Planta*, **211**: 546–554.

- Purkayastha, M. D.; Nath, A.; Deka, B.C. and Mahanta, C.L. 2013. Thin layer drying of tomato slices. *Journal of food science and technology*, **50(4)**: 642-653.
- Qadri, O. S. and Srivastava, A. K., 2014. Effect of microwave power on foam mat drying of tomato pulp. *Agricultural Engineering International: CIGR Journal*, **16(3)**: 238-244.
- Qadri, O. S. and Srivastava, A. K., 2017. Microwave-assisted foam mat drying of guava pulp: Drying kinetics and effect on quality attributes. *Journal of Food Process Engineering*, **40(1)**: 12295.
- Raharitsifa, N.; Genovese, D.B. and Ratti, C. 2006. Characterization of apple juice foams for foam mat drying prepared with egg white protein and methylcellulose. *Journal of Food Science*, **71(3)**: E142– E151.
- Rajkumar, P. and Kailappan, R. 2006. Optimizing the process parameters for foam mat drying of Totapuri mango pulp. *The Madras Agricultural Journal*, **93(1-6)**: 86-98.
- Rajkumar, P.; Kailappan, R.; Viswanathan, R. and Raghavan, G.S.V. 2007a. Drying characteristics of foamed alphonso mango pulp in a continuous type foam mat dryer. *Journal of Food Engineering*, **79**: 1452–1459.
- Rajkumar, P.; Kailappan, R.; Vishwanathan, R.; Parvathi, K.; Raghavan, G. and Ratti, C. 2007b. Foam mat drying of Alphonso mango pulp. *Drying Technology*, **25**: 357-365.
- Rajkumar, P.; Kailappan, R.; Vishwanathan, R.; Parvathi, K. and Raghavan, G. 2007c. Thin layer drying study on foamed mango pulp. *Agricultural Engineering International: the CIGR e Journal Manuscript*, **9**: 224-238.
- Ranganna, S. 2000. Handbook of analysis and quality control for fruit and vegetable products. (6<sup>th</sup> ed.). New Delhi: Tata McGraw-Hill Publishing Co. Ltd.
- Rathi, N. 2017. Effect of foam-mat drying conditions on quality of tomato powder. M. Tech. thesis (unpublished) submitted to G. B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand.

- Roongruangsri, W. and Bronlund, J. E. 2016. Effect of air-drying temperature on physico-chemical, powder properties and sorption characteristics of pumpkin powders. *International food research journal*, **23(3)**: 962-972.
- Rudiger, H. and Gabius, H. J. 2001. Plant lectins: Occurrence, biochemistry, functions and applications. *Glycoconjugate Journal*, **18**: 589–613.
- Sadasivam, S. and Manickam, A. 1996. Biochemical methods. New Age International Pvt. Ltd.,New Delhi: 6-11.
- Sahoo, A. K.; Sonkamble, A. M. and Patil, S. R. 2014. Effect of drying methods on quality of banana powder. *The Asian Journal of Horticulture*, **9(2)**: 500-502.
- Salahi, M. R.; Mohebbi, M. and Taghizadeh, M. 2015. Foam-mat drying of cantaloupe (*Cucumis melo*): Optimization of foaming parameters and investigating drying characteristics. *Journal of Food Processing and Preservation*, **39(6)**: 1798-1808.
- Sangamithra, A.; Venkatachalam, S.; Swamy, G. J. and Kuppuswamy, K. 2014. Foam mat drying of food materials: A review. *Journal of Food Processing and Preservation*, **39**: 3165-3174.
- Sangamithra, A.; Sivakumar, V.; Kannan, K. and John, S. G., 2015. Foam mat drying of muskmelon. *International Journal of Food Engineering*, **11(1)**: 127-137.
- Sankat, C. K. and Castaigne, F. 2004. Foaming and drying behaviour of ripe bananas. *LWT- Food Science and Technology*, **37**: 517–525.
- Sharada, S. 2013. Studies on effect of various operating parameters and foaming agents-drying of fruits and vegetables. *International Journal of Modern Engineering Research*, **3(3)**: 2249-6645.
- Sharrock, S. and Lustry, C. 2000. Nutritive value of banana. Annual report, INIBAP. Montpellier, France.
- Shekhawat, S. 2014. Study on process parameter of foam mat drying of pineapple juice. M.Tech. thesis (unpublished) submitted to College of Technology and

Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

- Silva, A. S. A.; Gurjão, K. C. D. O.; Almeida, F. D. A. C.; Bruno, R. D. L. A. and Pereira, W. E. 2008. Dehydration of tamarind pulp through the foam mat drying method. *Ciência e Agrotecnologia*, **32(6)**: 1899-1905.
- Smitabhindu R.; Janjai, S. and Chankong, V. 2007. Optimization of a solar assisted drying system for drying bananas. *Renewable Energy*.
- Soares, E. C.; Oliveira, G. S. F. D.; Maia, G. A.; Monteiro, J. C. S. and Silva Jr, A. 2001. Dehydration of acerola pulp (*Malpighia Emarginata Dc*) by foam mat drying process. *Food Science and Technology*, **21(2)**: 164-170.
- Srivastav R. P. And Kumar S. 2002. Fruit And vegetable preservation: Principles and practices. 3<sup>rd</sup> Edn., Army printing press, Lucknow, India, pp 11-20.
- Sukanya, S. H. 2018. Optimization of process for production of *Kesar* mango leather using foam mat drying technique. Ph.D. (Agril. Engg.) thesis (unpublished) submitted to College of Agricultural Engineering and Technology, Vasanttrao Naik Marathwada Krishi Vidhyapeeth, Parbhani.
- Tak, M. K.; Kumar, V.; Attar, S.; Revale, A. K. and Patel, R. 2015. Correlation of banana cv Grand Naine with growth and yield aspect. *Journal of Plant Development Sciences*, **7**: 1-5.
- Tapas, S.; Joshi, V.; Sarkar, T. and Sayan, S. 2016. Effect of post-harvest treatments on shelf life and quality of banana cv. Grand Naine. *Journal of Agriculture Sciences*, **8(61)**: 3505-3509.
- Thuwapanichayanan, R.; Prachayawarakorn, S. and Soponronnarit, S. 2008. Drying characteristics and quality of banana foam mat. *Journal of Food Engineering*, **86(4)**: 573-583.
- Thuwapanichayanan, R.; Prachayawarakorn, S. and Soponronnarit, S. 2012. Effects of foaming agents and foam density on drying characteristics and textural property of banana foams. *Food Science and Technology*, **47**: 348-357.

- Wall, M. M. 2006. Ascorbic acid, vitamin A and mineral composition of banana (*Musa sp.*) and papaya (*Carica papaya*) cultivars grown in Hawaii. *Journal of Food Composition and Analysis*, **19**: 434–445.
- Wang, J. C. and Kinsella, B. P. 1976. Functional properties of novel proteins: Alfalfa leaf protein. *Journal of Food Science*, **41**: 286.
- Wang, J.; Li, Y. Z.; Chen, R. R.; Bao, J. Y. and Yang, G. M. 2007. Comparison of volatiles of banana powder dehydrated by vacuum belt drying, freeze-drying and air-drying. *Food Chemistry*, **104(4)**: 1516-1521.
- Wilson, R. A.; Kadam, D. M.; Chadha, S.; Grewal, M. K. and Sharma, M. 2014. Evaluation of Physical and Chemical Properties of Foam-Mat Dried Mango (*Mangifera indica*) Powder during Storage. *Journal of food processing and preservation*, **38(4)**:1866-1874.
- Woldu, Z.; Mohammed, A.; Belew, D.; Shumeta, Z. and Bekele, A. 2015. Assessment of banana postharvest handling practices and losses in Ethiopia. *Journal of Biology, Agriculture and Healthcare*, **5(17)**: 82-96.
- Yusufe, M.; Mohammed, A. and Satheesh, N. 2017. Effect of Duration and Drying Temperature on Characteristics of Dried Tomato (*Lycopersicon esculentum* L.) Cochoro Variety. *Acta Universitatis Cibiniensis. Series E: Food Technology*, **21(1)**: 41-50.

**APPENDIX - A****District wise production of banana fruit in Gujarat state during the year 2015-16.**

<b>Name of District</b>	<b>Area (ha)</b>	<b>Production (MT)</b>
Bharuch	76.55	5538.40
Anand	64.96	4699.86
Narmada	61.45	4445.91
Vadodara	27.70	2004.10
Surat	8.87	641.75
Kachchh	2.47	178.80
Navsari	1.16	83.93
Chhotaudepur	0.95	68.73
Junagadh	0.15	10.85
Amreli	0.08	5.79
Kheda	0.05	3.62
<b>Total</b>	<b>244.39</b>	<b>17681.64</b>

(Source: Directorate of Agriculture, Gujarat State, Gandhinagar, 2018)

## APPENDIX – B

ANOVA for model statistics for the dependent variables of foaming properties

<b>Model Terms</b>	<b>Foam expansion (%)</b>	<b>Foam stabilizer (%)</b>	<b>Foam density (g/cc)</b>
<b>F value</b>	5.04	10.15	6.56
<b>p&gt;F</b>	0.0093	0.0006	0.0035
<b>Std. Dev.</b>	8.83	3.08	0.018
<b>Mean</b>	113.90	81.60	0.48
<b>C.V. %</b>	7.75	3.77	3.70
<b>R squared</b>	0.8194	0.9013	0.8552
<b>Adjusted R squared</b>	0.6569	0.8125	0.7248
<b>Predicted R squared</b>	0.3236	0.5474	0.4691
<b>Adequacy precision</b>	7.998	12.016	8.868
<b>Lac of fit</b>	NS	NS	NS

NS – not significant

**APPENDIX - C****Sensory Card****Sensory evaluations for foam mat dried banana powder**

Please follow the numerical system with respect to the stated quality using the following scales.

1. Samples are to be judged by inter comparison.
2. Rinse your mouth with water after every evaluation.
3. Do not change the order of the samples.

**Score Card**

<b>Sr. No.</b>	<b>Treatment</b>	<b>Appearance</b>	<b>Texture</b>	<b>Taste</b>	<b>Flavour</b>	<b>Overall acceptability</b>
<b>1</b>	<b>T<sub>1t1</sub></b>					
<b>2</b>	<b>T<sub>1t2</sub></b>					
<b>3</b>	<b>T<sub>1t3</sub></b>					
<b>4</b>	<b>T<sub>2t1</sub></b>					
<b>5</b>	<b>T<sub>2t2</sub></b>					
<b>6</b>	<b>T<sub>2t3</sub></b>					
<b>7</b>	<b>T<sub>3t1</sub></b>					
<b>8</b>	<b>T<sub>3t2</sub></b>					
<b>9</b>	<b>T<sub>3t3</sub></b>					
<b>10</b>	<b>T<sub>4t1</sub></b>					
<b>11</b>	<b>T<sub>4t2</sub></b>					
<b>12</b>	<b>T<sub>4t3</sub></b>					

**Hedonic Scale**

<b>Grade</b>	<b>Score</b>
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

Name:

Date:

Signature

## APPENDIX - D

## Drying time of banana foam at different drying conditions

Treatments	Drying time (min)
T <sub>1t1</sub>	180
T <sub>1t2</sub>	240
T <sub>1t3</sub>	300
T <sub>2t1</sub>	150
T <sub>2t2</sub>	210
T <sub>2t3</sub>	270
T <sub>3t1</sub>	120
T <sub>3t2</sub>	180
T <sub>3t3</sub>	240
T <sub>4t1</sub>	120
T <sub>4t2</sub>	150
T <sub>4t3</sub>	180

## APPENDIX – E1

**Drying rate of banana foam at 2 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t<sub>1</sub></sub></b>	<b>T<sub>2t<sub>1</sub></sub></b>	<b>T<sub>3t<sub>1</sub></sub></b>	<b>T<sub>4t<sub>1</sub></sub></b>
<b>0</b>	0.000	0.000	0.000	0.000
<b>30</b>	0.193	0.234	0.296	0.310
<b>60</b>	0.177	0.161	0.130	0.116
<b>90</b>	0.060	0.050	0.059	0.024
<b>120</b>	0.008	0.041	0.000	0.000
<b>150</b>	0.007	0.000	-	-
<b>180</b>	0.000	-	-	-
<b>210</b>	-	-	-	-
<b>240</b>	-	-	-	-
<b>270</b>	-	-	-	-
<b>300</b>	-	-	-	-

**APPENDIX – E2**

**Drying rate of banana foam at 4 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t2</sub></b>	<b>T<sub>2t2</sub></b>	<b>T<sub>3t2</sub></b>	<b>T<sub>4t2</sub></b>
<b>0</b>	0.000	0.000	0.000	0.000
<b>30</b>	0.088	0.200	0.238	0.257
<b>60</b>	0.138	0.098	0.083	0.106
<b>90</b>	0.078	0.080	0.075	0.093
<b>120</b>	0.054	0.045	0.051	0.020
<b>150</b>	0.027	0.038	0.030	0.000
<b>180</b>	0.025	0.020	0.000	-
<b>210</b>	0.000	0.000	-	-
<b>240</b>	-	-	-	-
<b>270</b>	-	-	-	-
<b>300</b>	-	-	-	-

## APPENDIX – E3

**Drying rate of banana foam at 6 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t3</sub></b>	<b>T<sub>2t3</sub></b>	<b>T<sub>3t3</sub></b>	<b>T<sub>4t3</sub></b>
<b>0</b>	0.000	0.000	0.000	0.000
<b>30</b>	0.113	0.124	0.129	0.196
<b>60</b>	0.083	0.119	0.112	0.105
<b>90</b>	0.080	0.092	0.092	0.096
<b>120</b>	0.058	0.045	0.061	0.057
<b>150</b>	0.045	0.039	0.043	0.023
<b>180</b>	0.026	0.030	0.031	0.000
<b>210</b>	0.031	0.020	0.021	-
<b>240</b>	0.010	0.008	0.000	-
<b>270</b>	0.007	0.000	-	-
<b>300</b>	0.000	-	-	-

**APPENDIX – F1**

**Moisture ratio of banana foam at 2 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t3</sub></b>	<b>T<sub>2t3</sub></b>	<b>T<sub>3t3</sub></b>	<b>T<sub>4t3</sub></b>
<b>0</b>	1.000	1.000	1.000	1.000
<b>30</b>	0.576	0.518	0.399	0.352
<b>60</b>	0.187	0.187	0.136	0.109
<b>90</b>	0.056	0.084	0.015	0.059
<b>120</b>	0.038	0.001	0.015	0.059
<b>150</b>	0.022	0.001	-	-
<b>180</b>	0.022	-	-	-
<b>210</b>	-	-	-	-
<b>240</b>	-	-	-	-
<b>270</b>	-	-	-	-
<b>300</b>	-	-	-	-

## APPENDIX – F2

**Moisture ratio of banana foam at 4 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t3</sub></b>	<b>T<sub>2t3</sub></b>	<b>T<sub>3t3</sub></b>	<b>T<sub>4t3</sub></b>
<b>0</b>	1.000	1.000	1.0000	1.000
<b>30</b>	0.806	0.588	0.517	0.463
<b>60</b>	0.504	0.386	0.349	0.240
<b>90</b>	0.333	0.221	0.197	0.047
<b>120</b>	0.214	0.128	0.093	0.006
<b>150</b>	0.120	0.049	0.031	0.006
<b>180</b>	0.062	0.009	0.031	-
<b>210</b>	0.008	0.009	-	-
<b>240</b>	0.008	-	-	-
<b>270</b>	-	-	-	-
<b>300</b>	-	-	-	-

**APPENDIX – F3**

**Moisture ratio of banana foam at 6 mm foam thickness and different drying temperature**

<b>Treatments</b>	<b>T<sub>1t3</sub></b>	<b>T<sub>2t3</sub></b>	<b>T<sub>3t3</sub></b>	<b>T<sub>4t3</sub></b>
<b>0</b>	1.000	1.000	1.000	1.000
<b>30</b>	0.751	0.745	0.738	0.591
<b>60</b>	0.568	0.500	0.509	0.372
<b>90</b>	0.392	0.312	0.323	0.172
<b>120</b>	0.264	0.220	0.200	0.052
<b>150</b>	0.165	0.140	0.113	0.005
<b>180</b>	0.107	0.079	0.049	0.005
<b>210</b>	0.038	0.037	0.006	-
<b>240</b>	0.016	0.021	0.006	-
<b>270</b>	0.002	0.021	-	-
<b>300</b>	0.002	-	-	-

## APPENDIX – G1

## Mean data of physical properties of banana powder

<b>Treatments</b>	<b>Recovery (%)</b>	<b>Bulk density (g/cc)</b>
<b>T<sub>1t1</sub></b>	37.86	0.66
<b>T<sub>1t2</sub></b>	34.75	0.68
<b>T<sub>1t3</sub></b>	30.64	0.70
<b>T<sub>2t1</sub></b>	37.09	0.57
<b>T<sub>2t2</sub></b>	34.38	0.60
<b>T<sub>2t3</sub></b>	30.46	0.62
<b>T<sub>3t1</sub></b>	34.76	0.57
<b>T<sub>3t2</sub></b>	31.25	0.59
<b>T<sub>3t3</sub></b>	28.98	0.62
<b>T<sub>4t1</sub></b>	32.46	0.52
<b>T<sub>4t2</sub></b>	30.01	0.53
<b>T<sub>4t3</sub></b>	27.63	0.57

## APPENDIX – G2

## Mean data of biochemical properties of banana powder

Treat-ments	Moisture content (% <i>, wb</i> )	Total sugars (%)	Reducing sugar (%)	Non-reducing sugar (%)	Titrateable acidity (%)	Ascorbic acid (mg/100 g)	pH
<b>T1t1</b>	5.38	39.25	0.11	39.14	0.35	0.89	4.53
<b>T1t2</b>	6.10	35.26	0.12	35.14	0.41	0.61	4.49
<b>T1t3</b>	6.40	32.20	0.25	31.95	0.46	0.49	4.44
<b>T2t1</b>	5.01	38.45	0.12	38.33	0.43	0.78	4.52
<b>T2t2</b>	5.97	34.93	0.14	34.77	0.46	0.61	4.38
<b>T2t3</b>	6.26	32.09	0.26	31.82	0.51	0.56	4.41
<b>T3t1</b>	4.55	36.61	0.25	36.36	0.50	0.56	4.40
<b>T3t2</b>	4.88	34.30	0.32	33.98	0.52	0.50	4.32
<b>T3t3</b>	5.24	31.39	0.47	30.92	0.58	0.44	4.33
<b>T4t1</b>	4.07	31.23	0.48	30.74	0.53	0.44	4.31
<b>T4t2</b>	4.11	30.91	0.54	30.37	0.58	0.40	4.22
<b>T4t3</b>	4.45	30.20	0.61	29.59	0.60	0.38	4.19

## APPENDIX – G3

## Mean data of functional properties of banana powder

<b>Treatments</b>	<b>Water solubility index (%)</b>	<b>Water absorption index (%)</b>
<b>T1t1</b>	66.10	408.48
<b>T1t2</b>	64.63	386.86
<b>T1t3</b>	63.84	344.72
<b>T2t1</b>	65.65	407.60
<b>T2t2</b>	64.07	383.22
<b>T2t3</b>	63.28	340.74
<b>T3t1</b>	64.10	326.40
<b>T3t2</b>	59.79	322.40
<b>T3t3</b>	55.89	292.22
<b>T4t1</b>	54.64	258.33
<b>T4t2</b>	52.44	256.60
<b>T4t3</b>	45.06	226.46

**Appendix - H**

**Details of the mean value of sensor evaluation of different foam mat dried banana powder**

Sr. No.	Treatment	Sensory evaluation				
		Appearance	Texture	Flavour	Taste	Overall acceptability
1	T <sub>1t1</sub>	7.4	7.6	7.8	7.5	7.6
2	T <sub>1t2</sub>	7.4	7.2	7.2	7.3	7.3
3	T <sub>1t3</sub>	5.6	5.8	5.6	5.6	5.7
4	T <sub>2t1</sub>	8.4	8.3	8.1	8.0	8.2
5	T <sub>2t2</sub>	8.2	8.1	8.0	7.9	8.1
6	T <sub>2t3</sub>	6.8	6.4	6.6	6.1	6.5
7	T <sub>3t1</sub>	7.6	7.5	7.3	7.1	7.4
8	T <sub>3t2</sub>	6.8	6.6	6.5	6.8	6.7
9	T <sub>3t3</sub>	6.4	6.7	6.4	6.5	6.5
10	T <sub>4t1</sub>	5.6	6.1	5.8	6.3	6.0
11	T <sub>4t2</sub>	5.2	5.4	5.6	6.0	5.6
12	T <sub>4t3</sub>	4.9	4.6	4.5	4.8	4.7

**Appendix - I****Recommended flow chart for preparation of banana powder by foam mat drying**