

Table of Contents

Chapter 1: Introduction	1
Chapter 2: Review of Literature	9
2.1. Preconditioning process for puffing of rice:	9
2.2. Use of fluidized bed dryer for drying during preconditioning process:.....	9
2.3. Use of mathematical modeling for drying kinetics:.....	10
2.4. Study on diffusivity of moisture of soaked rice sample during fluidized bed drying process:	11
2.5. Microwave puffing of rice:	12
2.6. Genetic algorithm as an optimizing tool:.....	13
2.7. COMSOL multiphysics as a tool for studying heat and mass transfer in food:	14
2.8. Application of salt substitutes in food:	14
2.9. Use of Fuzzy logic in sensory analysis of food:	16
2.10. X-Ray diffraction method to study the effect of salt on rice structure:	17
Chapter 3: Materials and Methods	19
3.1. Material: Parboiled rice:	19
3.2. Properties of un-puffed rice:	19
3.2.1. Measurement of chemical properties of un-puffed rice:	19

3.2.1.1. Mineral (Ash) content:	19
3.2.1.2. Crude fibre	19
3.2.1.3. Protein content	21
3.2.1.4. Total fats content	21
3.2.1.5. Starch content	21
3.2.2. Measurement of physical properties of un-puffed and puffed rice:	21
3.2.2.1. Rice dimension:	21
3.2.2.2. Expansion ratio (ER):	21
3.2.2.3. Percentage puffing (PP):	22
3.3. Study of traditional process of rice puffing in rural area:	22
3.4. Industrial mechanical process of puffing rice:	24
3.5. Microwave heating process of rice puffing:	25
3.5.1. Details of microwave processing of puffed rice production:	25
3.5.1.1. Preconditioning of rice:	25
3.5.1.2. Microwave puffing of pre conditioned rice:	27
3.6. Optimization of processing condition during precondition of rice:	30
3.6.1. Rotatable central composite design for drying experiment in fluidized bed dryer:	30
3.6.2. Genetic algorithm as a tool for optimization of processing conditions:	33
3.6.2.1. Selection:	33
3.6.2.2. Reproduction:	33
3.6.2.3. Crossover:	34
3.6.2.4. Mutation:	34
3.6.3. Modeling genetic algorithm for optimization of the drying process:	35
3.7. Modeling drying kinetics of preconditioning process.	39
3.7.1. Fluidized bed drying procedure during preconditioning of microwave puffed rice:	39
3.7.2. Measurement of equilibrium moisture content:	39
3.7.3. Mathematical models used for studying the drying kinetics:	39

3.7.3.1. Newton model:	41
3.7.3.2. Page model:	41
3.7.3.3. Modified Page model:	41
3.7.3.4. Henderson and Pabis model:	41
3.7.3.5. Geometric model:	42
3.7.3.6. Wang and Singh model:	42
3.7.3.7. Two term exponential model:.....	42
3.7.3.8. Diffusion approach model:	42
3.7.4. Diffusivity study:.....	43
3.8. Physical properties of rice during fluidization process of drying:.....	45
3.8.1. Physical properties of un-puffed rice:	45
3.8.2. Minimum fluidizing velocity of un-puffed rice during drying in fluidized bed dryer:...	46
3.9. Thermal properties of un-puffed rice:.....	47
3.10. Use of COMSOL multiphysics for modeling moisture movement in rice kernel:.....	49
3.10.1. Constant parameters used for designing the model in COMSOL:.....	50
3.10.2. Variable parameters used for describing the process:.....	50
3.11. Salt substitution in microwave puffed rice product:.....	52
3.11.1. Application of mixture design for salt substitution:.....	52
3.11.2. Sensory analysis of salt substituted microwave puffed rice for consumer acceptance: 53	
3.11.2.1. Parameters for sensory analysis:.....	54
3.11.3. Use of Fuzzy logic as a tool for analysis of sensory results:.....	54
3.11.3.1. Triplets for sensory score of the samples:	54
3.11.3.2. Triplets for sensory score of quality attribute:.....	55
3.11.3.3. Triplets for relative weight age of quality attribute.....	55
3.11.3.4. Triplets for relative weight age of quality attribute:.....	56
3.11.3.5. Triplet for overall sensory score of the sample:	56
3.11.3.6. Values of membership function of standard fuzzy scale:.....	56

3.11.3.7. Values of overall membership function of sensory scores on standard fuzzy scale:	57
3.11.3.8. Similarity values and ranking of puffed rice samples:	58
3.11.3.9. Similarity Values for Quality Attribute ranking of the Sample in general:	59
3.12. Study of texture of un-puffed and puffed rice during processing:	59
3.12. 1. Texture analysis by texture analyzer:	59
3.12.2. Study on effect of addition of salt in the internal structure of un-puffed rice during processing with X-ray diffraction method:	61
3.12.3. Study of internal structure of un-puffed rice sample by Scanning Electron Microscope:	63
Chapter 4: Results and Discussion:	64
4.1. Properties of un-puffed rice:	64
4.1.1. Chemical properties of un-puffed rice:	64
4.1.2. Measurement of physical properties of un-puffed rice:	64
4.2. Preconditioning process optimization of rice for microwave puffing:	64
4.2.1. RCCD for fluidized bed drying:	64
4.2.1.1. Effect of independent variables on expansion ratio:	65
4.2.1.2. Effect of independent variables in percentage puffing:	66
4.2.2. Optimization of independent variables through genetic algorithm:	66
4.3. Results of models used for drying kinetics:	68
4.3.1. Measurement of equilibrium moisture content (EMC) at different temperature:	68
4.3.2. Values of model parameters, their standard error (e_s), the reduced chi square value (χ^2) and adjusted R-square (r^2):	69
4.3.3. Drying curves for each model for different temperatures:	72
4.4. Diffusivity Study:	76
4.5. Measurement of physical properties of un-puffed rice:	78

4.6. Measurement of thermal properties of un-puffed rice:	80
4.7. Results of studies conducted with COMSOL:	80
4.8. Sensory analysis of salt substituted puffed rice using Fuzzy logic:.....	87
4.8.1. Triplet for sensory score of puffed rice samples:	87
4.8.2. Overall Membership Functions of Sensory Scores on Standard Fuzzy Scale:	88
4.8.3. Similarity Values of puffed rice samples:	89
4.8.4. Quality ranking of puffed rice in general:	90
4.9. Study of textural change in rice grain due to processing by texture analyzer:	91
4.10. Study of structural change in rice grain due to application of salt:	93
4.11. Study on the effect of rice structure during pre roasting by scanning electron microscope:.....	94
Chapter 5: Summary and conclusion:	97
Chapter 6: Bibliography:.....	101
Appendix I:	120
Appendix II:	121
Appendix III:	122

List of Tables

No.	Name of the table	P.No.
3.1:	Drying process variables and their levels	31
3.2:	Set of experiments with actual and coded values:	32
3.3	Different models with their expression:	43
3.3 a	Parameters applied for modeling the drying in fluidized bed dryer in COMSOL	51
3.4	Set of experiments with actual values:	53
3.5	Triplet associated with sensory scale	54
3.6	Parameters and Units of Instrumental Texture Profile Analysis. From Bourne, 1982.	60
4.1	Chemical composition of un-puffed rice	63
4.3	Expansion ratio and percentage puffing of the RCCD process:	64
4.4	Maximum and minimum values of independent and dependent variables	66
4.5	EMC at different temperatures	68
4.6	Newton Model	68
4.7	Geometric Model	68
4.8	Henderson and Pabis model	69
4.9	Page model	69
4.10	Modified Page model	69
4.11	Two term exponential model	69
4.12	Two term Model	70
4.13	Wang and Singh model	70
4.14	Diffusion approach model	70
4.15	All model combined with average values of parameters	70
4.16	Diffusivity values at different temperatures of drying:	76
4.17	Collected properties of rice (Das. 2005)	78
4.18	Model parameters for COMSOL at 50 ⁰ C	80
4.19	Triplet for sensory score of puffed rice sample 1	87
4.20	Sensory scores and triplets associated with quality attributes of puffed rice in general	88
4.22	Similarities value of quality attribute of puffed rice	90
4.23	Change in Textural properties during preconditioning in microwave process:	91

4.24	Change in Textural properties during preconditioning in traditional process:	91
4.25	Texture properties of traditionally puffed and microwave puffed sample	92

List of figures

No.	Name	P. No.
3.1	<i>Swastik</i> Brand Rice sample in the market .	20
3.2	<i>Swastik</i> brand rice grains	20
3.3	Steps in traditional process of making puffed rice	
3.4	Flowchart of traditional process of puffed rice production	24
3.5	Different steps of puffed rice production in industries	27
3.6	Flowchart: Microwave puffed rice production	28
3.7	Different steps in microwave puffing of rice	29
3.8	Flowchart of genetic algorithm	38
3.9	Values of triplets associated with triangular membership distribution function for five point sensory scale.	54
3.11	Graphical representation of triplet (a b c) and its membership function	57
3.12	A generalized texture profile analysis curve from the Instron Universal Testing Machine	58
3.12	X-Ray diffractometer	61
3.13	Scanning Electron Microscope	62
4.1	Graph Newton model MR Vs Time (min).	72
4.2	Graph Henderson and Pabis model MR Vs Time (min)	72
4.3	Graph Page model MR Vs Time (min)	73
4.4	Graph Modified Page model MR Vs Time (min)	73
4.5	Graph Two term exponential model MR Vs Time (min)	74
4.6	Graph Two term model MR Vs Time (min)	74
4.7	Graph Wang and Singh model MR Vs Time (min)	75
4.8	Graph of <i>MR</i> versus time for diffusivity calculation	77
4.9	Graph for activation energy measurement	77
4.10	Moisture distribution at different time during drying at 50 ⁰ C	82
4.11	Moisture distribution at different time during drying at 60 ⁰ C	83
4.12	Moisture distribution at different time during drying at 70 ⁰ C	84
4.13	Moisture distribution at different time during drying at 80 ⁰ C	85
4.14	Fig. 4.14. Graph of hardness Vs time of rice grain during FBD drying	92
4.15	Fig. 4.15. Graph of hardness Vs time of rice grain during pre roasting	92
4.16	XRD graph of five samples	94

4.17	SEM pictures of surface of rice grain before and after preconditioning	95
4.18	SEM pictures of core of the rice grain before and after preconditioning	96

List of abbreviation and symbols

ANN	artificial neural network
d.b	Dry basis
ER	Expansion ratio
FEM	Finite element method
GA	Genetic algorithms
HTST	High-temperature short time
ER	Expansion ratio
FEM	Finite element method
GA	Genetic algorithms
MR	Moisture ratio
PP	Percentage puffing
RCCD	Rotatable central composite design
RMS	Root mean square
RSM	Response surface methodology
μ	Viscosity (Pa.s)
a, b, k,	Drying model coefficient
n	
A_r	Archimedes number
b	Breath (meter)
c_p	specific heat capacity at constant pressure ($J.kg^{-1}.^{\circ}C^{-1}$)
D_{eff}	Effective diffusivity
D_r	Equivalent diameter (meter)
g	Acceleration due to gravity
h	Heat transfer coefficient
l	Length (meter)
m	Mass (kg)
M_0	Initial moisture content
M_e	Equilibrium moisture content
M_t	Moisture content at time t
n_a	Number of experiments carried out at levels $+a_m$ and $-a_m$
n_c	Number of experiments carried out at the centre point
n_f	Number of factorial design experiments carried out at +1 and -1
t	Time (minute)
T	Temperature (Kelvin)
V	Velocity (m/s)
W	Weight
X	Independent variable
y	Coded Independent variable
Y	Dependent variable
y	Coded Dependent variable
ε	Porosity
ρ	Density
ϕ	Sphericity