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OPTIMIZATION OF NUTRITIONALLY RICH INSTANT PORRIDGE WITH SPROUTED LEGUMES, MALTED MILLETS AND PAPAYA AND ITS COMPARISON WITH CONVENTIONAL PORRIDGE IN TERMS OF TEXTURAL, RHEOLOGICAL AND PARTICLE SIZE PROPERTIES

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ABSTRACT

Nutrient dense instant porridge was prepared with flours from corn, whole wheat, malted finger millet, sprouted whole green gram, soy protein isolates, unsalted roasted peanuts, dairy whitener and dried papaya in different ratios to make the multi-nutrient mix. Processing parameters viz. Flour Concentration (FC):10-20%, Sugar Concentration (SC): 50-75% and Cooking Time (CT): 1-5 min were optimized for development of porridge from multi-nutrient mix. Significant ($p<0.05$) second order model predicted the optimized condition for the porridge as FC: 17.9%, SC: 69% and CT: 1.8min. The water absorption index (2.5 g/unit g sample) and water solubility index (20.8%) was higher for multi-nutrient flour mix as compared to wheat flour (2.3 g/unit g sample and 8.3%) indicating better porridge forming ability.Response surface methodology showed that FC, SC and CT significantly affected the organoleptic quality, textural and rheological properties of porridge. Among the three process parameters, FC and CT had the most significant effect on evaluated porridge quality parameters. Fat and protein content of optimized porridge (OP) was significantly higher and particle size significantly lower than the control wheat porridge (CWP) indicating an improved capacity of the nutrients to be absorbed by the body. Porridges showed shear-thinning behavior and apparent viscosity values at all shear rates were higher for OP than CWP. From rheological studies it was observed that mean apparent viscosity and yield stress was lower for OP due to significant difference in the particle size and particle size distribution of the two samples. Both the porridge samples were comparable on account of storage modulus, loss modulus and complex viscosity.

Key words: Multi-nutrient porridge, RSM, Optimization, Back extrusion, Rheology, particle size.

INTRODUCTION

A healthy food is well balanced with respect to quality and quantity of ingredients from different food groups and not just concentrating on one food group, giving rise to the concept of multi-grain foods. Apart from health significance, convenience foods are also a recent trend in the food market. Owing to the present demand for these foods there is a need to develop convenient yet healthy multi-grain food products.

Porridge produced from various cereals and coarse cereals like wheat, oats, maize, sorghum etc. are widely consumed owing to their ease of making and acceptability among all age groups. Porridges are used as breakfast foods for adults as well as complimentary foods for infant and are also dietary adjuncts for convalescents (Michaelsen, 1998; Ojijo and Shimoni, 2004). At present porridges are made only from cereals only, thereby limiting their nutritional benefits. However due to their ease in preparation, versatility it terms of ingredients used, and convenience in terms of time taken for cooking and serving they can offer unique advantage to incorporate multigrain concept in ready-to-eat, wholesome food. In the present study efforts have been made to develop multi- nutrient porridge using cereals, millets, pulses, dairy product, oilseeds and tropical fruits. The formulated multi-nutrient porridge though rich in nutritional and functional attributes its acceptance is mainly dominated by its sensorial acceptability. Among the sensory factors, textural attributes like firmness and consistency of semi-solid products like porridge are of paramount importance. Thus, for the development of unacceptable porridge, optimization of product conditions (flour concentration, sugar concentration) and process conditions (time of cooking)has to be carried out especially if it has to be prepared in large quantities for service in community kitchens or mid-day meal programs in developing countries. Optimization of porridge was carried out using response surface methodology (RSM) by central composite rotatable design (CCRD), for its speed and economy ineffective process optimization (Carley *et al.*, 2004; Nazni and Karuna Thara, 2011; Akesowan, 2010; Nazni and Gracia, 2014, Nazni and Gracia, 2014, Nazni and Bhuvaneswari, 2011; Parameswari and Nazni, 2012, Shemi George and Nazni, 2012). Independent variables were the input whose levels needed to be optimized and the output were the responses resulting from interactions of independent variables. Thus, in this paper, the effect of flour concentration (FC), sugar concentration (SC) and time of cooking (CT) on sensory characteristics (appearance, taste, texture, flavor and overall acceptability) and textural properties (back extrusion test: firmness, consistency, cohesiveness and work of cohesion) for the development of an acceptable porridge was studied.

Further, rheological behavior of a product affects the flavour and mouth-feel and in turn sensory attributes which are dependent on it (Ojijo and Shimoni, 2004). In starchy pastes, the rheological behavior of porridges depends on structure of the amylose matrix, rigidity, swelling, volume fraction and shape of the granules and particles and the granule–amylose matrix interactions (Morris, 1986). Apart from this, flow properties of food are of great importance in processing, quality control and structural studies (Manohar *et al.*, 1997). Particle size distribution has a marked effect on the rheology of the product. Owing to the importance of rheological characteristics and particle size of porridge, rheological properties in terms of flow curve and oscillatory testing, and particle size distribution of optimized porridge was determined and compared with conventionally consumed control wheat porridge (CWP). The optimized porridge can serve as a convenient and nutritionally rich food for the health conscious rich and under-nourished poor.

MATERIALS AND METHODS

COMPOSITION AND PREPARATION OF BASE MIX AND PORRIDGE

Corn (*Zea mays)* flour, wheat (*Triticum aestivum*) flour, finger millet (*Eleusine coracana*), whole green gram (*Vigna radiata*), unsalted roasted peanuts (*Arachis hypogaea*) powder, dairy whitener and papaya (*Carica papaya)* were procured from the commercial markets in Bhopal, India while soy protein isolates was procured from Sonic Biochem, Indore, India. Finger millet and whole green gram were first cleaned thoroughly and any seeds which were spoiled or with cracked hull were discarded and the remaining seeds were surface sterilized with 0.1% (w/v) potassium permanganate solution and then soaked in distilled water for 4h at room temperature. The excess water was drained, sample further rinsed with distilled water, seeds placed in a single layer on filter paper in sterile petridishes and placed in the Seed Germinator (Indosaw, Ludhiana, India) at the 25°C, 90% R_h for 24 h and 48 h for finger millet and green gram respectively. After sprouting the seeds were dried in an oven overnight at 60°C. They were then cooled in a desiccator, powdered using analytical mill (Cole Parmar, IL, USA) at high speed (20,000 rpm). Papaya was deseeded and the pulp was manually extracted and dried in trays at 60°C for 24 h. The dried mass was then powdered using analytical mill (Cole Parmar, IL, USA) at high speed (20,000 rpm). In order to develop nutritionally rich base flour; corn: 30g, wheat: 20g, malted finger millet: 8 g, sprouted green gram: 10g, soy protein isolate: 7g, dairy whitener: 10g, roasted peanuts powder: 10g and papaya powder: 5 g were weighed and mixed together, sieved through a 600 micron sieve, packed in LDPE packs and stored at 7°C until used for porridge preparation. Before the optimization of parameters for preparation of porridges, functional properties of the multi-nutrient porridge flour and wheat flour roasted) were determined. The least gelation concentration (LGC) was determined using the modified method of Coffman and Garcia (1977) to test the porridge forming ability. The LGC was taken as the concentration when the sample from the inverted test tube did not fall or slip (Emmanuel et al., 2010).

For the preparation of porridge, multi-nutrient base flour was first roasted at 120°C for 2.5 min then mixed with sugar powdered using analytical mill (Cole Parmar, IL, USA) at high speed (20,000 rpm) and sieved through 600 micron sieve. Boiling water was added to the sample with simultaneous mixing to prevent lump formation; this was followed by heating for time specified by experimental design. Porridge was cooled to room temperature before further analysis.

EXPERIMENTAL DESIGN

RSM, by central composite rotatable design (CCRD) for three variables, FC, SC and CT at five levels was used to plan the experiments. Subjective parameters like sensory responses were recorded. To support these subjective responses and to minimize any error generated by individual bias, objective responses like firmness and consistency which are important quality parameters for products like porridge were also determined by back extrusion test. In all20 experiments were conducted, of which 6 experiments were at center point (Table 1). CCRD is a multivariate, multilevel experimental procedure that analyses the interaction between variables and hence it was chosen for the given study. However, CCRD has a limitation that it chooses points out of the design space in form of α value. Therefore while designing the experimental condition careful attention was paid to choose those points which would select α points within our practical range. Hence the maximum and minimum points of our independent variables were selected as ±α points.

Table 1- Experimental design for preparation of porridge

Code for the values	Independent variables and values		
	Flour concentration (X_1) (FC: %)	Sugar concentration (X_2) (SC: %)	Cooking time (X_3) (CT: min)
-1.68	10	50	1
-1	12	55	1.8
0	15	63	3
1	18	70	4.2
1.68	20	75	5
No of experiments	**Coded values of independent variables**		

8	± 1	± 1	± 1
2	± 1.68	0	0
2	0	± 1.68	0
2	0	0	± 1.68
6	0	0	0
Total : 20			

Code 0: center points, ± 1: factorial points, ± 1.68: alpha points

STATISTICAL ANALYSIS

The first order or second order polynomial expressions for a selected experimental region (FC: 10-20%, SC: 50-75% and CT: 1-5 min) was used to estimate the (best fitting response model) actual response surfaces as functional relationship between the responses and factors was to be determined (Montgomery, 2009).The appearance attribute of sensory response was found to best fit through 2FI model (equation 1) whereas for all other responses quadratic response surface model equation (equation 2) was most appropriate.

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{i=1}^{j-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j + \varepsilon \qquad (1)$$

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{i=1}^{j-1} \sum_{j=2}^{k} \beta_{ij} X_i X_j + \varepsilon \qquad (2)$$

where, y = predicted response, β_0 = intercept, $\beta_{i=}$ linear coefficient, β_{ii}= quadratic coefficient, and β_{ij}= interactive coefficient , Xi and Xj are the independent variables and $\varepsilon$is noise or error.

The statistical adequacy of the model was determined by F-ratio, coefficient of determination (R^2) and lack of fit test (LOF).3D surface contour plots were generated to study the relationship between the response and experimental levels of each factor and to deduce the optimum conditions. All the analysis, model fitting and plots were generated using statistical package, design expert® software (Version 8.0.5.2, 2010, Minneapolis MN, USA).

MEASUREMENT OF RESPONSES

SENSORY ANALYSIS

Sensory evaluation was done on freshly made porridges using affective testing of the quantitative type. Thirty panelists (15 men and 15 women aged between 22-35 y) from staff and students of Central Institute of Agricultural Engineering, Bhopal, India who were non-smokers and did not consume alcohol evaluated the sensory attributes of porridge. The number of panelists was below what is usually required and restricted to 30 due to constraints of manpower and budget. However, since the sensory evaluation was one of the parameters for optimization and was supported by objective evaluations of texture the error if any would be reduced. Panelists were informed the definition of quality attributes selected for sensory evaluation, explaining the score sheet and method of scoring. Porridge was served in bowls in a random order and monadic form. The porridge samples were prepared under the same conditions twice and each panelist evaluated the same sample on two different days. The average score of each panelist was used for analyses. Each panelist was seated in an individual sensory booth with fluorescent lighting and free from distractions and evaluated each of the samples thrice. Panelists had sips of water between each sample to cleanse their palate. The attributes evaluated were appearance (which included color and visible lumps or no lumps in sample), taste, texture (defined in terms of overall mouth feel, stickiness, hardness of samples), flavor (which included combination of aroma and taste and aftertaste) and overall acceptability. The attributes selected were similar to Aboubacar *et al.* (1999) in their study on sensory evaluation of Sorghum porridge. The acceptance test was used to identify the or liking of sensory attributes using the nine point hedonic scale (1=dislike extremely, 2 =dislike very much, 3 =dislike moderately, 4=dislike slightly, 5= neither like nor dislike, 6= like slightly, 7= like moderately, 8= like very much and 9= like extremely). A column for each sample in the hedonic instrument was coded to correspond with the sample code. Average of thirty (corresponding to each panelist) scores for each parameter was reported and used for analysis.

BACK EXTRUSION TEST

Back extrusion cell, consisting of a container of 50 mm diameter with 35 mm disc positioned centrally over the sample container, was used to measure the textural properties of porridge using TA-XT plus Texture Analyser of Stable Micro Systems, UK equipped with a 50 kg-f load cell and operated through software program Texture Expert (Texture Technologies Corp., New York, USA). During the test, the disc penetrated to a depth of 30% (of sample height) at 1 mm/s test speed and returned to its original position. Data was recorded at a rate of 200 points per second. Texture quality parameters viz. firmness, consistency, cohesiveness and work of cohesion (WOC) were estimated using the procedure defined by Angioloni and Collar (2009). All measurements were taken in triplicates.

OPTIMIZATION AND VALIDATION OF PROCESS

The goal for optimization was to select the combinations with maximum score of sensory responses whereas the back extrusion responses were given a target value equivalent to texture value of CWP i.e. Firmness-0.9061N, Consistency-24.7 N-s, Cohesiveness-0.89N and WOC-1.54N-s. The combination with greatest desirability was chosen and validated for efficacy.

ANALYSIS OF OP

The roasted flour and sugar was mixed in the proportions as optimized by RSM with boiling water (500 ml) and stirred till a smooth slurry was obtained followed by heating for the time specified in the design. The OP was cooled to room temperature before further analysis. For CWP, 10% roasted wheat flour and 70% sugar (with respect to FC) was mixed with hot water and heated for 2 min 20 seconds and was treated as control. The packed bulk density test for multi-nutrient flour and wheat flour was determined by tap test method and was expressed as the ratio of the mass of the samples to their volumes and reported in g/ml. Average values of five replicates was recorded (Adebowale et al., 2005).Water absorption index (WAI) of the flour samples was determined by method outlined by Anderson et al. (1969). WSI was expressed as a percentage of solid in the sample extract (Mandge *et al*., 2011).The moisture content, crude protein, fat and ash contents of the samples were estimated by AOAC methods (1995).

RHEOLOGY OF PORRIDGE

Rheological tests were carried out on OP and CWP using a rheometer (Anton Paar, Germany: Physica MCR 51), equipped with a stainless steel concentric cylinder system (Cup diameter: 18.079 mm, bob diameter: 16.657 mm and bob length: 24.99 mm) having a built-in peltier temperature control (Accuracy ± 0.1 °C), was used for measurement of shear stress exerted by the porridge achieved by rotation of coaxial cylindrical attachment. Following parameters were recorded:

FLOW CURVE

The flow curves of porridge samples were measured at 25°C. The samples were allowed to rest for 2 min after loading, before measurement. Experiment involved increasing the shear rate linearly from 20 $s^{-1}$to 1000 s^{-1}over a span of 120 s; a total of 48 data sets consisting of shear rate, shear stress and apparent viscosity were recorded. The choice of shear rate range was based on preliminary experiments where it was observed that apparent viscosity values were not consistent at shear rates less than 20 s^{-1} or more than 1000 s^{-1}. It was hypothesized that shear stress data at higher shear rates would be useful in design of bulk conveying system for the porridge.

FREQUENCY SWEEP TEST

Before determining viscoelasticity moduli i.e. storage modulus G' – elastic components, loss modulus G" – viscous component, G* – complex modulus; linear viscoelastic region was determined by amplitude sweep test at constant frequency of 1 Hz and varying the shear stress from 0.1 to 10000 Pa at 10 points per decade. Since the points after 200 Pa were constant the test was repeated for shear stress from 0.1 to 200Pa. The viscoelastic region for both optimized and control porridge was found at 1% strain or 5Pa stress. Hence, 1% strain was used for frequency sweep test.

In frequency sweep test, viscoelasticity moduli were determined in linear viscoelastic region at four angular frequencies i.e. 16.2, 31.7, 47.3 and 62.8 Hz. Both optimized and control porridge samples were maintained at 25°C for this test.

PARTICLE SIZE OF PORRIDGE

Particle size analysis for average particle sizes (d3,2 – Surface-weighted mean diameter – Sauter Mean Diameter and d4,3 – Volume-weighted mean diameter – De Brouckere Mean Diameter) were determined using a particle size analyzer (Mastersizer, Malvern Inc., Worcestershire, United Kingdom). Mean diameters d3,2 and d4,3 were defined by:

d3,2 = Σ ni di3/Σni di2 and
d4,3 = Σ ni di4/Σni di3,
where ni is the number of droplets of diameter di.

The refractive index ratio of 1.47 was used to calculate particle size distributions. 10–14% obscuration was obtained by diluting samples with water. The absorption value was set up at 0.001. All measurements were carried out at 25ºC. All analyses were performed in triplicate.

RESULTS AND DISCUSSION

The present research work was carried to make porridge from multi-nutrient base flour mix containing various proportions of corn, wheat, malted finger millet, sprouted green gram, soy protein isolate, dairy whitener, roasted peanuts and papaya powder with the hypothesis that this porridge, due to its ingredients is nutritionally rich and therefore is better than conventional wheat porridge which has only one ingredient. The porridge forming ability of multi-nutrient mix was analyzed by LGC and was 4%, similar to wheat flour, confirming that our base mix had porridge forming ability. LGC is attributed to the relative ratios of different constituent’s proteins, carbohydrates and lipids in flour samples (Sathe *et al.,* 1982).Once that was established,the flour and sugar concentration and cooking time were optimized as given below.

MODEL ANALYSIS

Table 2 shows the experimental conditions generated by CCRD along with their experimental response values, estimated regression coefficients of the fitted model along with their model F- ratio, R^2 and lack of fit (LOF) values. To examine goodness of fit independent variables and their dependent parameters were fitted to models and examined. Analysis of variance (ANOVA) using F-value tests were usedto calculate the significance of each type of model. Based on the results of F-value the highest order model with significant terms which showed the relationship between parameters was chosen. The quadratic models fitted well for all the responses studied except in sensory response in terms of “appearance” where it fitted well in a 2FI model. However the model for “appearance” was considered significant because of the subjective nature of the response (Yadav et al., 2008). The R^2 values for taste, texture, flavor, appearance, OAA, firmness, cohesiveness, consistency, WOC, shear stress and apparent viscosity were found to be greater than 0.80 and a non-significant LOF indicated the adequacy of the fitted models. Thus, all the responses fitted adequately to the proposed model and hence represented the real relationship among the parameters.

Table 2 - Estimated coefficients of the fitted regression models

Coefficient	Sensory Evaluation					Back extrusion			
	Appearance	Taste	Texture	Flavor	OAA	Firmness	Consistency	Cohesiveness	WOC
Intercept									
β_0	7.88	7.51	7.40	7.83	7.27	2.94	67.01	2.33	5.84
Linear									
β_1	-0.13*	0.11	-0.12*	-0.065*	-0.033	0.89*	22.73*	0.90*	2.30*
β_2	-0.16*	0.21*	0.067	0.071*	0.040	0.14	-2.96	-0.13	-0.077
β_3	0.051	0.029	-0.16*	-0.11*	-0.12*	0.86*	12.26*	0.45*	1.14*
Quadratic									
β_1^2	-	-0.28*	-0.26*	-0.17*	-0.29*	-0.34*	-3.26	-0.064	-0.11
β_2^2	-	0.23*	0.21*	0.00762	0.24*	-0.56*	-12.23*	-0.41*	-0.91*
β_3^2	-	0.25*	0.073	0.098*	0.30*	-0.54*	-15.88*	-0.54*	-1.52*
Interactive									
β_{12}	0.42*	0.12	0.25*	0.13*	0.059	-0.15	-9.03	-0.37	-0.73
β_{13}	-0.26	-0.27	-0.29	-0.19	-0.48	0.80*	13.88*	0.44*	1.10*
β_{23}	-0.11	-0.10	0.14	-0.091*	-0.13	-0.28*	-3.67	-0.098	-0.28
R^2	0.76	0.86	0.84	0.95	0.90	-3.67	0.83	0.83	0.81
F-value	10.95*	14.05*	12.40*	27.59*	20.55*	32.08*	11.68*	11.39*	9.79*
LOF	NS	NS	NS	NS	NS	NS	NS	NS	NS

Significant terms at $p \leq 0.05$, NS: not significant, App: appearance, Tex: texture, OAA: overall acceptability, WOC: work of cohesion

Table 3 - Criteria used for optimization with predicted and actual values

Constraints	Goal	Lower limit	Upper limit	Predicted values	Actual values
Appearance	Maximize	7.11	8.80	8.32	8.55
Taste	Maximize	6.25	8.50	8.48	8.60
Texture	Maximize	6.25	8.03	7.90	8.00
Flavor	Maximize	7.20	8.30	8.30	8.00
OAA	Maximize	6.25	8.50	8.30	8.60
Firmness (N)	Target	0.15	4.62	1.01	1.048 ± 0.2*
Consistency (Nsec)	Target	4.86	110.80	26.54	26.07 ± 0.7*
Cohesiveness (N)	Target	0.17	4.041	0.99	1.023 ± 0.05*
Work of Cohesion (Nsec)	Target	0.20	10.63	2.63	2.60 ± 0.23*

* Mean ± standard deviation

Table 4 - Frequency sweep test results for control and optimized porridge

Parameters	Angular Frequencies (Hz)			
	16.2	31.7	47.3	62.8
	Storage modulus (Pa)*			
Optimized porridge	72.14 ± 23.78	134.38 ± 33.15	211.17 ± 48.09	321.67 ± 64.57
Control porridge	90.82 ± 25.27	145.67 ± 21.75	213.34 ± 29.09	285.17 ± 54.20
Loss modulus (Pa)*				
Optimized porridge	122.19 ± 24.68	129.71 ± 26.43	163.83 ± 31.01	180.33 ± 30.05
Control porridge	144.50 ± 32.93	151.50 ± 31.78	186.33 ± 36.65	200.33 ± 35.82
Complex viscosity (Pa s)*				
Optimized porridge	8.83 ± 1.81	5.83± 1.10	5.79 ± 0.83	6.05 ± 074
Control Porridge	10.56 ± 2.53	6.63 ± 1.17	6.02 ± 0.81	5.58 ± 0.78

* - mean ± standard deviation

RESPONSES TO RSM

SENSORY RESPONSES

Sensory analysis in terms of appearance, taste, texture, flavor and overall acceptability directly affected the quality of a food product (Khan *et al.*, 2012), hence the same were chosen as responses for the optimization of process parameters for preparation of the porridge. All the sensory responses fitted adequately to the second order models.

FC had a significant ($p \leq 0.05$) negative effect on all the sensory attributes except 'taste', with which it had an insignificant relation. Except for a significant ($p \leq 0.05$) decrease in 'appearance',increase in SC was marked by an increase in all the other aspects of sensory evaluation.SC had a direct effect on the porridge taste which showed that a sweeter porridge was more acceptable. Variations CT resulted in giving a mixed set of response. The 'appearance' and 'taste' registered insignificant increase with CT, while all the other attributes decreased significantly ($p \leq 0.05$). The interactions of FC and SC had significant ($p \leq 0.05$) effect on 'appearance', 'texture' and 'flavour'. The 'appearance' score was highest at minimum values of FC and SC (Fig.1a), the same trend was observed in the individual effects as well. The interaction of FC and SC was synergistic on the 'texture '. Maximum 'texture' scores were registered at low and as well as high FC x SC levels (Fig.1b). The 'flavour' scores were best for the porridge prepared at the centre point values of FC and SC (Fig. 1c).

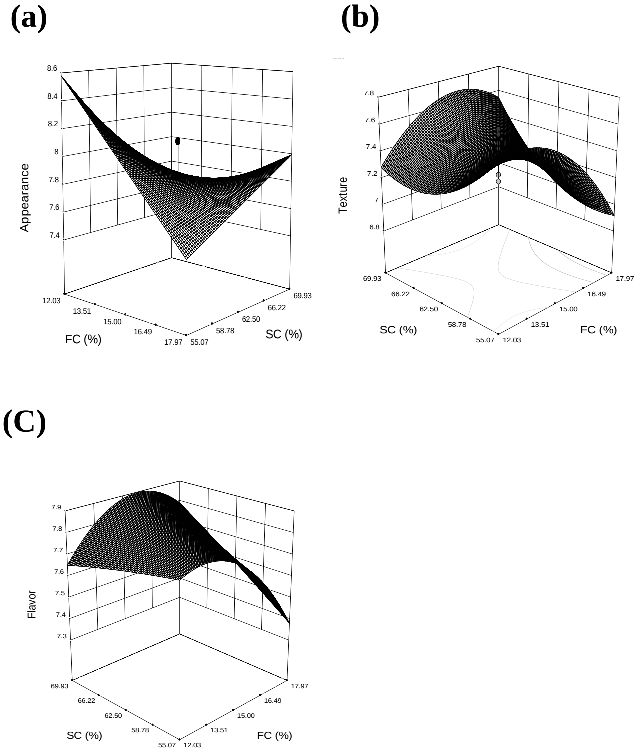

Figure 1: Response surface plots for sensory attributes

BACK EXTRUSION RESPONSES

The fluid flow properties of porridge namely, 'firmness', 'consistency', 'cohesiveness' and WOC were determined by the back extrusion process. All these properties were found to have a significant ($p \leq 0.05$) positive relation with FC and CT. The effect of SC on all back extrusion parameters was negative and not significant ($p>0.5$) except firmness where the effect non-significant. Regression analysis showed that all the properties determined by back extrusion were affected most by FC, followed by CT and then by SC. Also these properties were affected significantly by the interactive effect of FC and CT. The effect of FC and SC was not significant for any of the back extrusion responses. These findings are in agreement with reports of Gujral and Sodhi (2002) while handling wheat porridge. 'Firmness' was the only attribute that was significantly ($p \leq 0.5$) affected by the interaction of SC and CT. At a combination of maximum FC and CT values, firmness, consistency, cohesiveness and WOC were found to be maximum (Fig. 2a-d).

OPTIMIZATION AND VALIDATION OF PROCESS

The criteria used for optimization along with predicted value of responses have been presented in Table 3. The error between predicted values and actual value for optimized condition was computed and was found to be less than 5%, indicating success of optimization. The optimized conditions for porridge making from base flour mix were FC: 17.9%, SC: 69.93% and CT: 1.8 min. OP was prepared and compared with CWP.

Analysis of multi-nutrient flour mix and OP

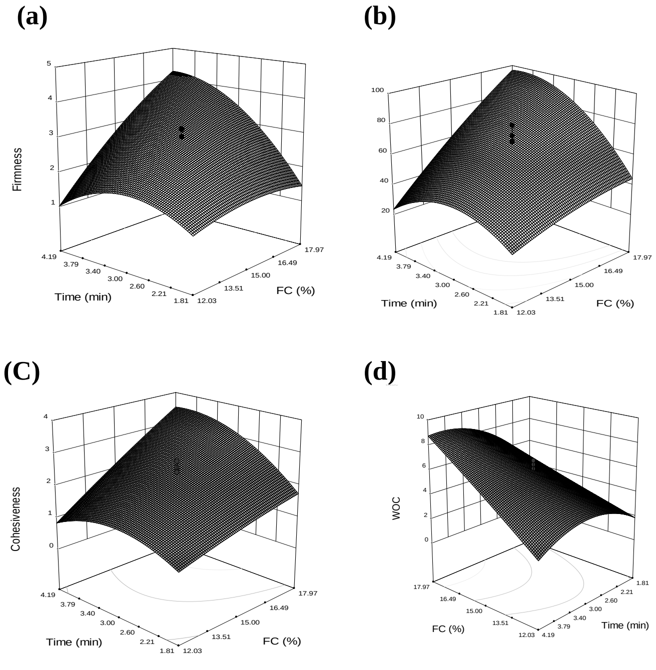

Figure 2: Response surface plots for back extrusion.

FUNCTIONAL QUALITY OF BASE MIX

Bulk density was calculated for roasted base mix flour and wheat flour. The bulk density of wheat flour (750 kg/m^3) was higher than multi-nutrient flour mix (730 kg/m^3) though not significantly different. Water absorption index (WAI) can be used as a gelatinization index indicating ability of flour to absorb water (Mandge *et al.*, 2011) making it a useful criterion for porridge formation.

WAI was found to be higher for multi-nutrient flour mix (2.5 g/unit g sample) as compared to control wheat flour (2.3 g/unit g sample) which may be due to high protein content (Dev and Quensil, 1988) of the base mix.

A high water solubility index (WSI) of multi-nutrient flour mix (20.80%) indicates high soluble solids and greater ability to solubilise in cooking water as compared to wheat flour (8.31%).

NUTRITIONAL ANALYSIS AND PARTICLE SIZE OF PORRIDGE

The nutritional parameters of OP were studied and compared with CWP. On statistical analysis, significant difference ($p \leq 0.05$) was found in all parameters studied. The moisture content (%) of OP was 72.6 ± 0.14 and lower than CWP (82.2 ± 0.49), due to the high FC. The percent fat (1.8 ± 0.05), protein (3.7 ± 0.16) and ash (0.4 ± 0.01) content of OP was also found to be higher than CWP (fat- 0.5% ± 0.0; protein- 1.3% ± 0.01; ash - 0.2% ± 0.0) on fresh matter basis. The base mix used for making porridge contained high protein (dairy whitener, soy protein isolate), fat (corn flour and roasted peanuts) and mineral (sprouted green gram and finger millet flours) rich ingredients improving nutritional quality of OP.In porridges nutrients interact and form a stable emulsion enhancing mouth-feel of the food improving sensory properties (Alpaslan and Hayta, 2002, Nazni and Pradeepa, 2010).

Particle size analysis revealed that both D3, 2 and D4, 3 of CWP (201.99 ± 2.41 µm and 67.31 ± 2.60 µm) was significantly higher ($p \leq 0.5$) than the OP (168.03 ± 1.33 µm and 35.06 ± 1.62 µm). It can be inferred that sprouting of green gram and malting of finger millet caused some structural break-down resulting in production of smaller particles in the base mix thus reducing the mean particle size of the OP. This inference is in agreement with findings of Qi et al. (1994) and Kawai et al. (1997).

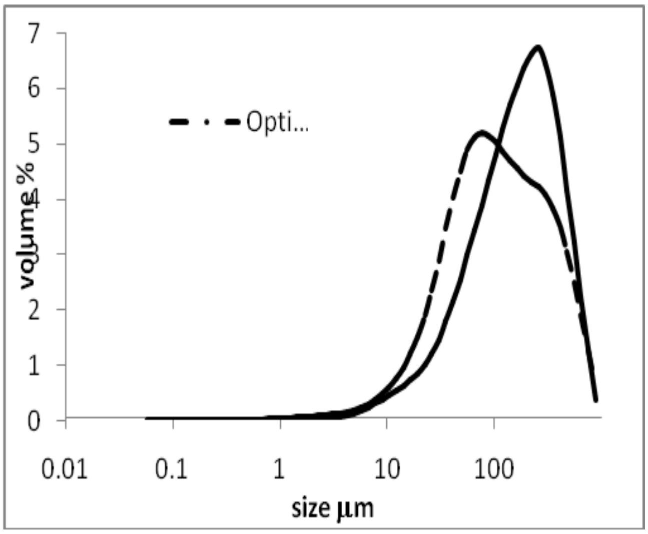

Figure 3: Particle size distribution of control wheat porridge (CWP) and optimized porridge (OP).

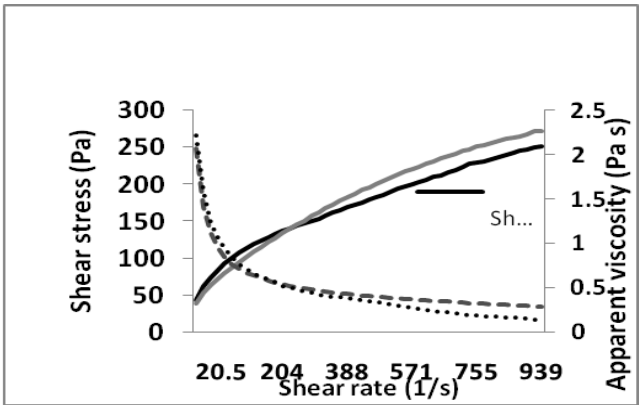

Figure 4: Flow curve control wheat porridge (CWP) and optimized porridge (OP).

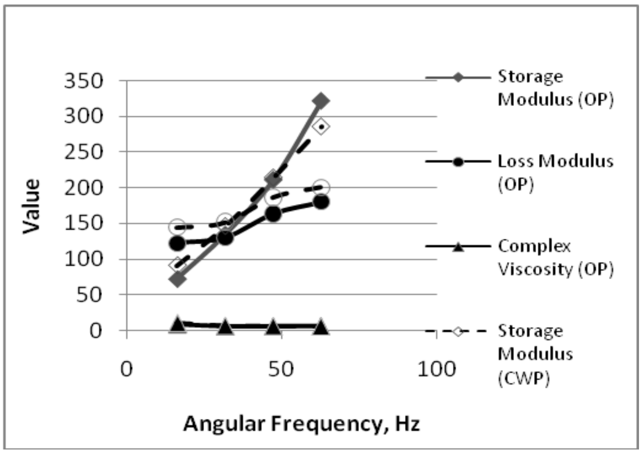

Figure 5: Complex viscosity, storage modulus and loss modulus parameters of control wheat porridge (CWP) and optimized porridge (OP).

RHEOLOGICAL MEASUREMENTS OF PORRIDGE FLOW CURVE

From the flow curve (Figure 4), it was observed that as the shear rate increased the apparent viscosity decreased indicating the shear-thinning or pseudo plastic behavior of the porridge samples with presence of yield stress. Singh and Heldman (2009) have reasoned that when foods like porridge are subjected to a shear, the randomly distributed particles orient themselves in the direction of flow; similarly, coiled particulates deform and elongate in the direction of flow and agglomerated particles break up into smaller particles resulting in increased "fluidity". The shear stress and apparent viscosity values of CWP were more than that of OP at shear rates lower than 286 $s^{-1}$and 204 s^{-1}, respectively. However, at higher shear rates OP showed more viscosity than CWP (Figure 4). This implies that if a facility is producing both types of porridges, the shear rates during pumping of product should be ideally between 204 to 286 s^{-1} so that the pumping machine is not required to be changed when the handled product is changed. For a constant volume fraction, decreased particle size resulted in an increase in the number of particles (Figure 3) increasing particle-particle interactions, viscosity and stress acting upon the particles. As per Engelen et al. (2005) increased particle size makes the product gritty which in turn is inversely proportional to viscosity and therefore affects the mouth-feel of the product. Thus, the higher particle size of CWP is related to its lower viscosity. Also, the higher protein and fat content of OP could have increased the frictional resistance offered by the sample in a flow field resulting in increased mean apparent viscosity. High protein with high molecular weights adds effect thereby exhibiting well pronounced non-Newtonian character (Bhattacharya *et al.,* 1999).

FREQUENCY SWEEP TEST

In oscillatory mode of testing rheological properties, frequency sweeps aid in comparing different food products or the effect of various ingredients and processing treatments on viscoelasticity of food products (Steffe, 1996).In our study, frequency sweep test was conducted which measured storage modulus (G'), loss modulus (G") and complex viscosity (η*) of both optimized and control porridge (Table 4). This test helped in predicting the viscoelastic behaviour of the sample. The frequency sweep is used commonly for oscillatory testing because it shows the relationship between viscous and elastic behaviour of the material and the rate of application of strain and stress (Andronoiu *et al.,* 2010). In this test the parameters were measured at four different frequencies and the results obtained have been presented in Figure 5.

Statistical analysis of the obtained data showed that angular frequency significantly affected the storage modulus value ($p<0.05$) for both the porridge samples (CWP and OP) whereas, the loss modulus and complex viscosity values were not affected by angular frequency. The storage modulus was found to be lower than loss modulus at lower frequency but as the frequency increased the value of storage modulus increased. It is evident that both the porridge samples behaved like dilute solutions (Newtonian fluid) at lower frequency but as the frequency increased, the samples showed more gel like behavior as also reported by Citerne *et al.* (2001)for peanut butter. This behavior is similar to the behavior of concentrated solutions as explained by Steffe (1996). Andronoiu *et al.* (2010) explained that at slow frequency flow units within a sample had sufficient time for movement and rearrangement, thus the sample was more fluid-like. The crossover frequency for G' and G" was slightly higher in case of CWP compared to that of OP (Figure 5). This could probably be due to higher protein content of OP, undergoing gelation when heated, resulting in a rigid or stiff product (Clark and Lee-tuffenel, 1986; Ahmed et al., 2006) causing increased elastic modulus.

The values of storage and loss moduli were in the range reported by Steffe (1996) for concentrated solutions. G' value is a measure of elastic behaviour of a sample, while G" value represent the viscous behaviour of a sample (Mezger, 2002; Tabilo-Munizagaand Canovas, 2005). The G' value being higher than G" values at majority of applied frequencies indicate that the OP sample had more of an elastic behaviour. Citerne *et al*. (2001) reported that there was an existence of yield stress causing a plateau in G' at lower frequency. However in this study though the yield stress was observed (Fig.4) a corresponding plateau in G' was not seen (Figure 5).

G', G" and η* of OP were compared with CWP using paired t-test and it showed that these attributes for both the samples were not significantly different ($p>0.18$) at any given frequency. The results implied that the OP would be acceptable to the consumers on account of mouth-feel that is normally governed by the rheological properties.

CONCLUSIONS

Response surface methodology showed that flour concentration; sugar concentration and cooking time significantly affected the organoleptic quality, textural and rheological properties of porridge. Among the three process parameters, FC and CT had the most significant effect on evaluated porridge quality parameters. The interactions of FC and SC had significant effect on ‘appearance’, ‘texture’ and ‘flavour’ estimated by semi-trained sensory evaluation panel. A polynomial model of second order could predict organoleptic quality, textural and rheological responses based on process parameters.

The OP prepared from the multi-nutrient base mix was compared with the traditional wheat flour porridge, a control, in terms of nutritional, particle size and rheological properties. The OP was superior to the control porridge in terms of protein and fat content. The particle size of the OP was smaller than that of control porridge indicating an improved capacity of the nutrients to be absorbed by the body. From rheological studies it was observed that mean apparent viscosity and yield stress was lower for OP due to significant difference in the particle size and particle size distribution of the two samples. This makes the porridge easier to consume. On account of other rheological properties, viz. storage modulus (G'), loss modulus (G") and complex viscosity (η*), both the porridges were found similar suggesting they are likely to have comparable mouth-feel. Intensive evaluations especially sensory in nature will be carried out by a panel of more than 100 members when the porridge will be ready for commercialized development.

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