

Optimization of Process Variables for the Development of Flaxseed and Defatted Flaxseed Based Pasta

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Abstract

The present day approach is value addition of convenience foods by incorporating strengthful ingredients, which offer either therapeutic or preventive medicinal health benefits, in addition to provision of their basic nutrition. Flaxseed is one of the nutritional crops as it is rich in omega-3 fatty acids, proteins, dietary fiber and phytochemicals. Central Composite Rotatable Design (CCRD) was used to optimize process parameters for development of flaxseed and defatted flaxseed based pasta products, by response surface methodology with three variables at five levels. The low and high levels of the variables were 70 to 90g for semolina; 10 and 30g for flaxseed or defatted flaxseed; 15 and 20% water (% of amount of semolina and flaxseed) for flaxseed based pasta, and 20 and 30% water (% of amount of semolina and flaxseed) for defatted flaxseed based pasta. Pasta was made by extrusion using a spiral die in pilot plant pasta making machine (D-35, La Parmigiana), followed by convective dehydration to a final moisture content of 7-8% (w.b) to make it shelf stable product. The optimum values for process variable for maximum possible gelatinization, color parameter (L*), overall acceptability, minimum free fatty acid, and color parameter (a*) are semolina 90g, flaxseed 15g and water* 20 for flaxseed based pasta, and semolina 87.79g, flaxseed 15g and water* 30 for defatted flaxseed based pasta.

Keywords: Flaxseed; Defatted flaxseed; Pasta; Gelatinization; Optimization; ALA Content (alpha-linolenic acid)

Introduction

Nowadays, interest has led to produce a wide variety of foods referred to as functional foods and nutraceuticals because these type of foods offer either therapeutic or preventive medicinal health benefits, in addition to provision of their basic nutrition. Flaxseed is the small flat oval seed from flax (*Linum usitatissimum*), which has been gaining popularity as a functional food because of its high content of biologically active compounds, their health benefits, and disease preventive properties [1]. The Latin name of flaxseed is *Linum usitatissimum*, which means "very useful". Flax is a nutrition crop because of the high content of alpha-linolenic acid in the flaxseed oil, its dietary fiber, high quality proteins and lignans as secondary metabolite. Traditionally, industrial applications of flaxseed include as linen textile or drying oil in paints, varnishes, and linoleum [2]. Medicinal applications of flaxseed as antitumoral and anti-inflammatory remedy were also known since antiquity [3,4]. The use of flaxseed in food can increase the content of α -linolenic acid and long chain ω -3 fatty acids in both blood plasma and erythroplastid fat, and reduce the content of cholesterol [5]. Omega-3 fatty acids also have anti-inflammatory, anti-thrombotic, and anti-arrhythmic properties [6]. Additionally, insoluble fibers present in flaxseed affects plasma lipids and lignans such as Secoisolariciresinol Diglucoside (SDG), which exhibit protective effects against hormone-related types of cancer like breast cancer, and against non-hormone related colon cancer [7-11]. Functional properties of flaxseed proteins, including hypotriglyceridemic and hypocholesterolemic effects are reported to be superior to those of commonly known soy proteins [12].

Recent food applications of flaxseed oil include their use in salad dressings, as a partial substitute for milk fat in ice cream desserts [13,14]. The flaxseed fibre has a wide range of applications in various areas such as textile, paper, and biocomposite manufacturing [15]. Flax gums are used as a food ingredient to improve texture, to prevent syneresis in dairy products, and can play the role of the stabiliser in vegetable and fruit juices [16]. Flaxseed proteins have been assessed as techno-

functional ingredients in many food formulations, such as bakery products and pastries, meat emulsions, sauces and ice creams [17-19]. Recently, efforts have been made for utilizing flaxseed or understanding its functional properties, but little work had been referred with reference to systematic development of flaxseed based products.

In past decade, pasta products have given a new dimension in the convenience foods. Though traditionally, wheat based noodles were in practice, in recent years with the technological development, many products of commerce have taken its place. The value addition by incorporation of strengthful ingredients or fortification with nutrients is the present day approach. The present study was conducted for development and optimization of value added flaxseed and defatted flaxseed based pasta products, using response surface methodology.

Materials and Methods

Processing of flaxseed

Flaxseed was purchased from Grain Market, Sector- 26, Chandigarh. Flaxseeds were cleaned, milled in a flour mill, and sieved. Defatted flaxseed was obtained by extracting milled flaxseed with chloroform:methanol (2:1) solvent mixture. Sample and solvent is mixed in 2:1 and stirred for 1h in a shaker. The micelle was removed by vacuum filtration and extraction was repeated twice. After complete extraction,

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the resulting meal was dried in a tray drier at 50°C, till the material is free of solvent.

Chemical analysis

The flaxseed and defatted flaxseed flour was analyzed for moisture, crude protein (N×6.25), fat, ash and crude fiber contents, according to standard method (AOAC) [20]. The carbohydrate content was calculated by difference method. Insoluble and soluble dietary fiber was estimated by enzymatic method of Asp et al. [21]. All proximate analyses were carried out in triplicate and reported in percentages. Color values (L*, a*, b*) of pasta was measured by Hunter Color Lab difference meter (L* means lightness, with 100 for white, 0 for black; a* indicates redness when positive, and greenness when negative, b* indicates yellowness when positive, and blueness when negative), and free fatty acid (FFA, %) was determined, according to the method reported by Hautfenne [22] for fats and oils.

Gelatinization (%)

The gelatinization (%) was measured according to the method reported by Birch and Priestley [23]. The cooked pasta was dried in oven at 58°C, and ground through the sieve (80 mesh). The sample (0.2 g) was prepared in 125 ml Erlenmeyer flasks; 98ml of distilled water and KOH (10 M) 2.0 ml was added and then mixed for 5 minutes, prior to centrifugation at 3000 rpm for 15 min. The supernatant (1.0 ml) was pipetted and added with hydrochloric acid (0.5M) 0.4 ml, followed by 10 ml of distilled water and 0.1 ml of iodine solution. The mixture was homogenized, then measuring the absorbance at 600 nm.

The gelatinization (%) of standard starch was prepared as in the same manner of sample to obtain the standard curve of rice and applied to calculate degree of gelatinization of sample.

Experimental design

Experiments were conducted according to Central Composite Rotatable Design (CCRD) [24], with three variables at five levels each, to optimize the process variables for development of flaxseed and defatted flaxseed based pasta products. The CCRD design predicts uniformly at all constant distances from their center points. The independent variables for development of flaxseed pasta were amount of semolina (g), flaxseed flour (g) and water (ml) (% of semolina (g) and flaxseed flour (g)) (Table 1), and for defatted flaxseed pasta were amount of semolina (g), defatted flaxseed flour (g) and water (ml) (% of semolina (g) and defatted flaxseed flour (g)) (Table 2). The water absorption

Variable Levels						
Process variable	Code	Coded Levels				
		-1.68	-1	0	+1	+1.68
Semolina (g)	X ₁	63.18	70	80	90	96.82
Flaxseed (g)	X ₂	3.18	10	20	30	36.82
Water (% of X ₁ +X ₂)	X ₃	13.3	15	17.5	20	21.71

Table 1: Experimental design in coded and uncoded form of process variables for development of flaxseed based pasta.

Variable Levels						
Process variable	Code	Coded Levels				
		-1.68	-1	0	+1	+1.68
Semolina (g)	X ₁	63.18	70	80	90	96.82
Defatted flaxseed (g)	X ₂	3.18	10	20	30	36.82
Water (% of X ₁ +X ₂)	X ₃	16.6	20	25	30	33.41

Table 2: Experimental design in coded and uncoded form of process variables for development of defatted flaxseed based pasta.

Semolina (g)	Flaxseed (g)	Water*	% FFA	% Gelatinization	OAA	Colour (L')	Colour (a')
70	10	15	1.385	48.628	7.265	62.99	3.002
90	10	15	1.316	58.886	8.165	61.778	2.739
70	30	15	3.532	55.732	6.815	73.111	3.666
90	30	15	3.43	69.26	6.995	71.558	3.481
70	10	20	1.392	52.856	7.335	62.05	3.102
90	10	20	1.325	62.17	8.215	62.728	2.813
70	30	20	3.651	63.714	7.025	70.045	3.687
90	30	20	3.577	73.114	7.145	71.29	3.348
63.18	20	17.5	3.127	48.172	6.715	61.439	3.464
96.82	20	17.5	2.86	70.342	7.215	63.897	3.044
80	3.18	17.5	0.83	61.886	8.315	61.365	2.3
80	36.82	17.5	4.49	73.714	7.465	77.389	3.75
80	20	13.29	2.58	49.2	7.215	67.772	3.353
80	20	21.7	2.61	62.056	7.315	66.907	3.367
80	20	17.5	2.87	63.376	7.565	67.47	3.581
80	20	17.5	2.42	59.142	7.415	67.195	3.38
80	20	17.5	2.91	60.064	7.265	67.03	3.3
80	20	17.5	2.48	63.738	7.735	65.313	3.569
80	20	17.5	2.97	59.668	7.135	65.242	3.447
80	20	17.5	2.38	63.94	7.615	67.24	3.566

* Water (ml)=% of Semolina (g)+Flaxseed (g)

Table 3: Central Composite Rotatable Design with experimental values of response variables for development of flaxseed based pasta.

Semolina (g)	Defatted Flaxseed (g)	Water*	% FFA	% Gelatinization	OAA	Colour (L')	Colour (a')
70	10	20	0.306	57.4	7.35	71.88	2.712
90	10	20	0.266	73.72	8.25	70.668	2.449
70	30	20	0.866	63.1	6.9	82.001	3.376
90	30	20	0.84	80.5	7.08	80.448	3.191
70	10	30	0.347	71.96	7.42	70.94	2.812
90	10	30	0.299	84.38	8.3	71.618	2.623
70	30	30	0.89	75.42	7.11	78.935	3.397
90	30	30	0.82	87.86	7.23	80.18	3.058
63.18	20	25	0.778	58.46	6.8	71.329	3.174
96.82	20	25	0.767	84.12	7.3	73.787	2.95
80	3.18	25	0.173	69.14	8.3	69.55	2.21
80	36.82	25	0.995	80.24	7.65	86.279	3.51
80	20	16.59	0.286	69.84	7.3	75.662	3.063
80	20	33.41	0.318	89.66	7.4	74.797	3.077
80	20	25	0.546	83.01	7.65	75.36	3.291
80	20	25	0.521	85.5	7.5	75.085	3.09
80	20	25	0.467	82.66	7.35	74.98	3.01
80	20	25	0.493	82.56	7.82	73.013	3.279
80	20	25	0.461	85.62	7.22	73.132	3.157
80	20	25	0.421	83.46	7.7	75.23	3.276

* Water (ml)=% of Semolina (g)+Defatted Flaxseed (g)

Table 4: Central Composite Rotatable Design with experimental values of response variables for development of defatted flaxseed based pasta.

power of flour mixture varied according to amount of flaxseed and semolina, so amount of water was calculated as percentage of amount of semolina and flaxseed. The dependent variables chosen were %free fatty Acid, %gelatinization, color parameter (L*, a*), and overall acceptability (OAA). Experimental design in uncoded form of process variables, along with results for optimization of process variables for flaxseed and defatted flaxseed pasta are given in table 3 and 4, respectively.

The experiments were conducted randomly to minimize the effects of unexplained variability in the observed responses, because of external factors.

Preparation of pasta

Flaxseed flour, semolina and water were weighed according to the experimental design (Table 3). Salt (3%) and lemon juice (8%) was mixed with pre-weighed amount of water to enhance the flavour of pasta. Dough was prepared by mixing all the ingredients, and rested for half an hour. Then, it was extruded using a spiral die in pilot plant pasta making machine (D-35, La Parmigiana). Extruded samples were then dried in a tray drier at 60°C to a final moisture content of 7-8 % (w.b). Dried samples were packed in paper-foil-polythene laminate pouch and stored for analysis at room temperature. Similar procedure was repeated using defatted flaxseed flour for preparation of defatted flaxseed pasta (Table 4).

Sensory evaluation

A known amount of extruded samples (25 g) was taken and added to boiling salted water pan, while continuing the heating for 10-12 min. After every minute, a piece of pasta was held between two glass plates and was compressed. Optimum cooking of pasta was established, when no white core was observed after compressing. Organoleptic quality of cooked flaxseed and defatted flaxseed pasta was determined with the help of a 10-member consumer panel, using a 9-point Hedonic scale. The organoleptic attributes included appearance, flavour, odor, taste and overall acceptability. The average scores of all 10 panelists were computed for different characteristics.

Statistical analysis and optimization

The second-order polynomial equation was fitted to the experimental data of each dependent variable

$$Y_{ku} = \beta_0 + \sum_{i=1}^n \beta_{ki} x_{iu} + \sum_{i=1}^n \beta_{kii} x_{iu}^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^n \beta_{kij} x_{iu} x_{ju} + e_u \quad (1)$$

Where Y_{ku} =response variable (Y_{1u} =% free fatty acid, Y_{2u} =% gelatinization, Y_{3u} =overall acceptability of cooked pasta, Y_{4u} =color parameter (L'), Y_{5u} =color parameter (a')), x_{iu} represents the coded independent variables (x_{1u} =semolina (g), x_{2u} =flaxseed (g) or defatted

flaxseed (g), x_{3u} =water (ml) (% of x_{1u} and x_{2u}). Coefficient β_{ko} is the value of fitted response at the center point design, i.e. point (0,0,0), and β_{ki} , β_{kii} and β_{kij} are the linear, quadratic and interaction regression coefficients, respectively.

Optimization of the process variable for development of flaxseed and defatted flaxseed based pasta was aimed at finding the levels of independent variables, viz. semolina, flaxseed or defatted flaxseed and water which would result in minimum free fatty acid and color parameter (a') and maximum degree of gelatinization, overall acceptability and color parameter (L') of pasta. Response Surface Methodology (RSM) was applied to the experimental data using Design Expert statistical software (version 6.0.1, Stat-Ease, Inc., Minneapolis, MN), to evaluate the effect of various process parameters on measured responses at 5% level of significance. Analysis of variance (ANOVA) was conducted to fit the model represented by Eq. (1) to examine the statistical significance of the model terms. The adequacy of the models was determined using model analysis, lack-of-fit tests, and R^2 (coefficient of determination). The value of β coefficient was used to compare the relative contribution of each independent variable in the prediction of the dependent variable. Higher the positive value of β of a parameter, higher would be the effect of that parameter, and vice-versa. The response surface plots were generated for interaction of any two independent variables, while holding the value of third-and fourth-variable as constant (at the central value). The same software (version 6.0.1, Stat-Ease, Inc., Minneapolis, MN) was used for the generation of response surface plots, superimposition of contour plots, and optimization of process variables.

Constituents	Flaxseed Flour	Defatted Flaxseed Flour
Moisture (w.b)	8.78±0.02	7.83±0.1
Fat	41.78±0.1	0.94±0.06
Protein	22.59±0.12	38.16±0.15
Crude fiber	9.687±0.2	15.14±0.21
Ash	3.48±0.2	5.86±0.2
Carbohydrates	13.683±0.4	31.97±0.3
Soluble dietary Fiber	14.43±0.2	21.34±0.2
Insoluble dietary fiber	30.62±0.2	41.67±0.2

Table 5: Proximate composition of flaxseed flour and defatted flaxseed flour.

Source	df	Flaxseed flour based pasta				Defatted flaxseed based pasta			
		β	SS	F Value	p-value	β	SS	F Value	p-value
Model	9		16.605	27.459	<0.0001		1.198	82.311	<0.0001
Constant	1	2.681	-	-	-	0.484			
Semolina	1	-0.056	0.042	0.631	0.4454	-0.015	0.003	1.857	0.2029
Flaxseed	1	1.093	16.316	242.819	<0.0001	0.262	0.939	580.443	<0.0001
Water	1	0.024	0.008	0.120	0.7357	0.010	0.001	0.787	0.3959
Semolina ²	1	0.050	0.036	0.532	0.4826	0.106	0.163	100.903	<0.0001
Flaxseed ²	1	-0.068	0.067	0.995	0.3421	0.040	0.023	14.091	0.0038
Water ²	1	-0.091	0.120	1.780	0.2118	-0.060	0.052	32.014	0.0002
Semolina x Flaxseed	1	-0.005	0.000	0.003	0.9576	-0.001	0.000	0.005	0.9453
Semolina x Water	1	0.004	0.000	0.002	0.9682	-0.006	0.000	0.209	0.6573
Flaxseed x Water	1	0.031	0.008	0.116	0.7402	-0.009	0.001	0.379	0.552
Residual	10		0.672				0.016		
Lack of Fit	5		0.302	0.715	0.6862		0.006	0.605	0.7027
Pure Error	5		0.370				0.010		
R ²		0.96111				0.98668			
Adjusted R ²		0.92611				0.97469			

Table 6: ANOVA showing the variables as a linear, quadratic, and interaction terms on % free fatty acid and coefficients for the prediction models.

Source	df	Flaxseed flour based pasta				Defatted flaxseed based pasta			
		β	SS	F Value	p-value	β	SS	F Value	p-value
Model	9		257.152	25.907	<0.0001		437.209	142.621	<0.0001
Constant	1	30.831				41.907			
Semolina	1	2.943	118.289	107.254	<0.0001	3.725	189.4648	556.243	<0.0001
Flaxseed	1	2.188	65.402	59.301	<0.0001	1.394	26.556	77.965	<0.0001
Water	1	1.522	31.632	28.682	0.0003	2.864	112.039	328.933	<0.0001
Semolina ²	1	-0.448	2.892	2.623	0.1364	-2.257	73.414	215.534	<0.0001
Flaxseed ²	1	1.062	16.260	14.743	0.0033	-1.656	39.520	116.026	<0.0001
Water ²	1	-1.090	17.107	15.511	0.0028	-0.762	8.357	24.535	0.0006
Semolina x Flaxseed	1	0.247	0.489	0.443	0.5205	0.069	0.038	0.111	0.7459
Semolina x Water	1	-0.280	0.625	0.567	0.4689	-0.554	2.453	7.202	0.0229
Flaxseed x Water	1	0.308	0.758	0.687	0.4265	-0.346	0.959	2.816	0.1243
Residual	10		11.029				3.406		
Lack of Fit	5		4.700	0.743	0.624		0.957	0.391	0.8371
Pure Error	5		6.329				2.449		
R ²		0.95888				0.99227			
Adjusted R ²		0.92186				0.98531			

Table 7: ANOVA showing the variables as a linear, quadratic, and interaction terms on gelatinization and coefficients for the prediction models.

Source	df	Flaxseed flour based pasta				Defatted flaxseed based pasta			
		β	SS	F Value	p-value	β	SS	F Value	p-value
Model	9		3.294	10.455	0.0005		3.0632	4.2421	0.0170
Constant	1	7.455				7.775			
Semolina	1	0.214	0.62471	17.8445	0.0018	0.323	1.4246	17.7559	0.0018
Flaxseed	1	-0.324	1.437	41.038	<0.0001	-0.093	0.1175	1.0646	0.040
Water	1	0.047	0.031	0.879	0.3706	0.103	0.1441	1.7957	0.2099
Semolina ²	1	-0.173	0.431	12.306	0.0057	-0.234	0.7880	9.8212	0.0106
Flaxseed ²	1	0.154	0.342	9.780	0.0107	0.164	0.3872	4.8257	0.0427
Water ²	1	-0.067	0.064	1.839	0.2049	0.067	0.0641	0.7987	0.3925
Semolina x Flaxseed	1	-0.185	0.274	7.821	0.0189	0.001	0.0000	0.0002	0.9903
Semolina x Water	1	-0.010	0.001	0.023	0.8829	-0.004	0.0001	0.0014	0.9709
Flaxseed x Water	1	0.030	0.007	0.206	0.6599	0.011	0.0010	0.0126	0.9128
Residual	10		0.350				0.8023		
Lack of Fit	5		0.094	0.366	0.8526		0.3525	0.7835	0.6023
Pure Error	5		0.256				0.4499		
R ²		0.95393				0.96267			
Adjusted R ²		0.92747				0.93706			

Table 8: ANOVA showing the variables as a linear, quadratic, and interaction terms on overall acceptability and coefficients for the prediction models.

Results and Discussion

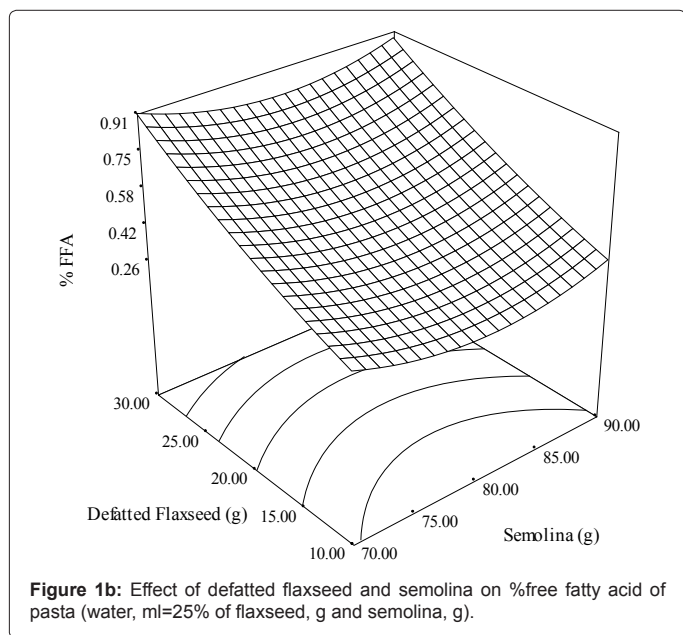
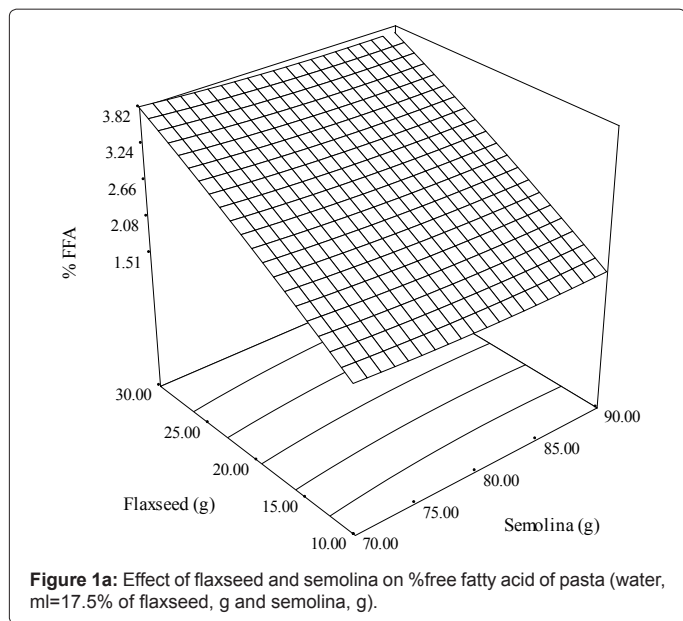
Proximate composition

The fat content of flaxseed flour is found to be above 40%, and after solvent extraction, the fat content reduced to less than 1% (Table 5). The protein, crude fiber and ash content of defatted flaxseed are higher than that of flaxseed flour, which is due to removal of fat. The results of chemical components in flaxseed flour are within the amounts reported by Mueller, Mazza, Bozan and Temelli et al. [4,25,26]. The moisture content of flaxseed flour is found to higher than reported by Bozan and Temelli [26], which may be due to climatic changes.

Diagnostic checking of fitted models and response surfaces

The results of second-order response surface model (eq. 1) in the form of ANOVA are given in table 5-9 for development of flaxseed and defatted flaxseed based pasta. The results indicated that the fitted quadratic models accounted for more than 95% of the variation in the experimental data ($R^2 > 0.90$), which were significant at 5% level of significance ($p < 0.05$).

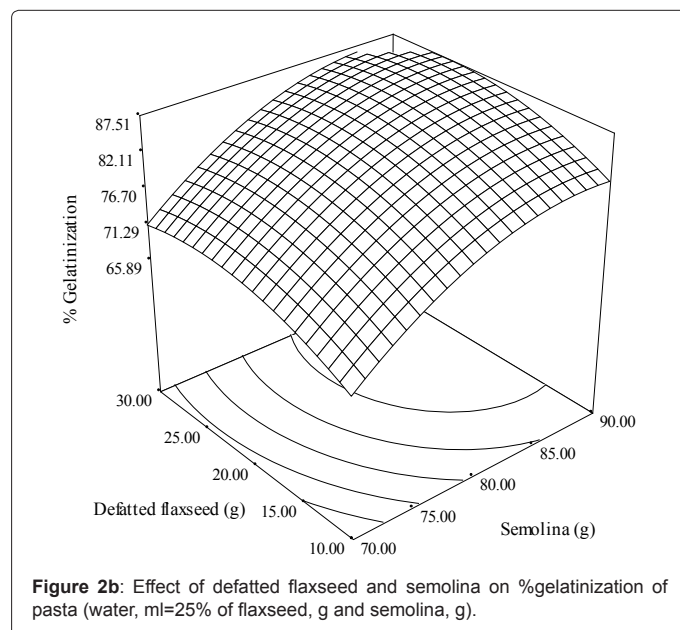
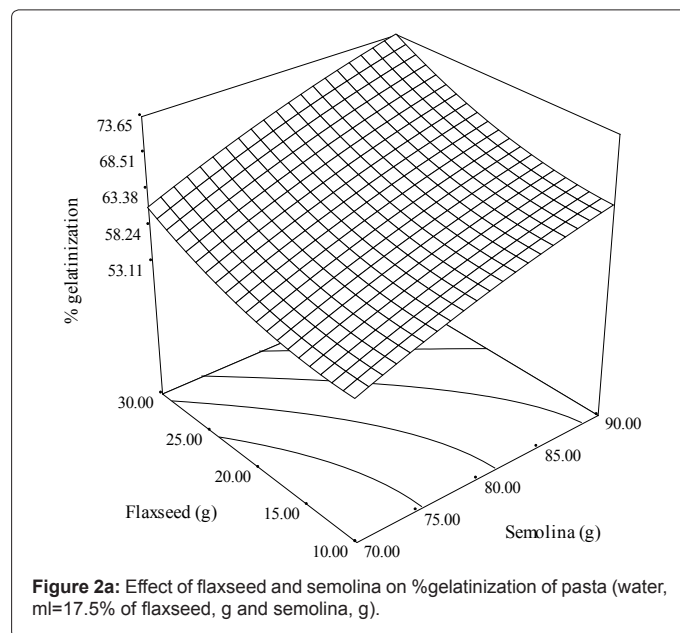
Free fatty acid (%) varied from 0.83-4.49 in flaxseed flour based pasta and 0.173-0.995 in defatted flax pasta (Table 3 and 4). The higher FFA of flaxseed based pasta is due to presence of unsaturated lipids in flaxseed. Flaxseed products are stable, despite their high ALA (alpha-linolenic acid) content. Storing milled flaxseed at ambient temperatures for more than 4 months did not cause noticeable changes in quality. The endogenous antioxidants in the milled flaxseed may account for this stability [27,28]. Chen et al. [28] observed that flaxseed products can tolerate heat to a certain extent. Heating at 178°C for 1.5 hours did not change the ALA content in the whole flaxseed. ALA decreased from 55.1 to 51.3% in ground flaxseed under the same conditions, and the ALA content dropped to 51.7% in lipid extracts under the same conditions. The magnitude of p values revealed that the linear and quadratic terms of flaxseed concentration had significant effect ($p < 0.05$) on FFA (Table 6). Semolina contains less than 4% lipids, out of which more than 50% are saturated; as a result, the effect of semolina content on FFA is insignificant. The model F-value was 27.459 and 82.311 for flaxseed and defatted flaxseed based pasta, which implies that both models are significant. FFA (%) increased with amount of flaxseed in both the



flaxseed and defatted flaxseed pasta, as shown in figure 1a and b.

Gelatinization is of utmost importance in food modifications, such as those that take place in cooking, baking, drying and extruded foods. The honeycomb-like structure of cooked pasta is mainly due to the coagulated protein embedded in the gelatinized starch. Determination of pasta cooking quality was more dependent on a continuous protein network than the physicochemical properties of the gelatinized starch. In the absence of coagulated protein, “starch pasta” strands fractured into small pieces and did not swell [29]. The gelatinization (%) varied from 48.172- 73.714 in flaxseed flour based pasta and 57.4-89.66 in defatted flax pasta (Table 3 and 4). Lower gelatinization in flaxseed based pasta may be attributed to high lipid content as lipid binds to starch granules and stabilizes the granular structure. Lauro et al. [30] and Elaiison et al. [31] observed decreased gelatinization of starch with increasing amounts of lipids. Gelatinization increased with amount of

semolina, defatted flaxseed and water. The magnitude of p values from table 7 revealed that all linear and quadratic terms of process variables had significant effect ($p < 0.05$) on gelatinization of both flaxseed and defatted flaxseed based pasta. Semolina content had most significant effect on gelatinization, followed by water content and flaxseed content (Table 7). Further, interaction terms had no significant effect ($p > 0.05$) on gelatinization. The model F-value was 257.907 and 142.621 for flaxseed and defatted flaxseed based pasta, which implies that both models are significant. The relative magnitude of β values indicated the maximum positive effect of amount of semolina ($\beta = 2.943$ and 3.725), followed by amount of water ($\beta = 2.188$ and 2.864) and amount of flaxseed ($\beta = 1.522$ and 1.394), on gelatinization for flaxseed and defatted flaxseed based pasta (Table 7). The quadratic and interaction terms of all the process parameters had least effect on gelatinization, as compared to the



linear terms of process variables. The effect of process parameters on gelatinization is shown in figure 2a and b.

Effect of various process parameters on Overall Acceptability (OAA) is indicated in figure 3a and b. The overall acceptability of cooked pasta varied from 6.8 to 8.4, with the change in process parameters (Table 3 and 4). Semolina content had most significant effect on overall acceptability of flaxseed based and defatted flaxseed based cooked pasta. OAA did not increase with amount of flaxseed, which may be due to brown color of flaxseed and fishy odour of omega-3 fatty acids, which increased with amount of flaxseed (Figure 3a and b) and negative β value was observed (Table 8). OAA decreased with amount of semolina and increase in amount of flaxseed flour. The results are in agreement with the studies of Ogunronbi et al. [32] on flax based bread, and Khouryieh and Aramouni [33] on flax based cookies. Water

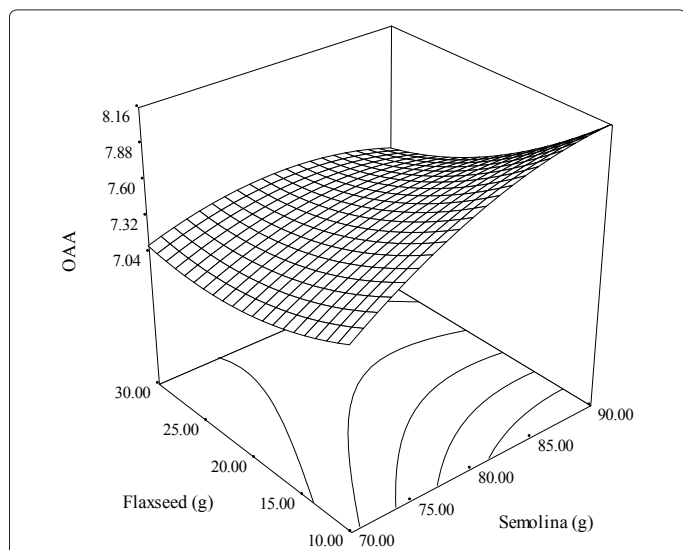


Figure 3a: Effect of flaxseed and semolina on overall acceptability of cooked pasta (water, ml=17.5% of flaxseed, g and semolina, g).

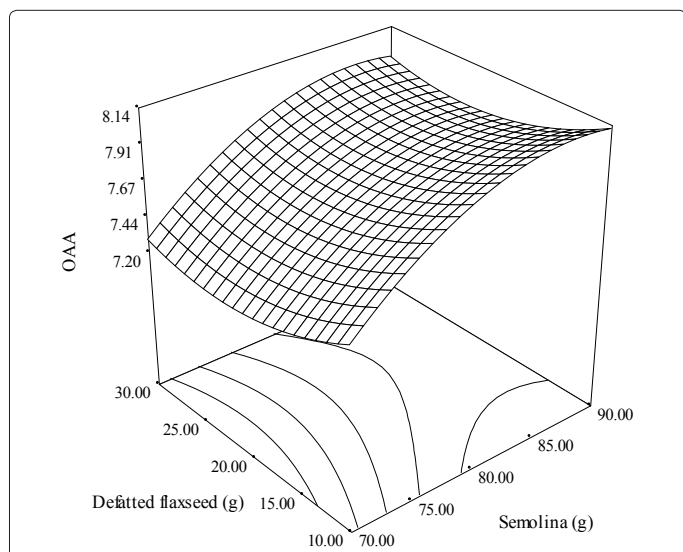


Figure 3b: Effect of defatted flaxseed and semolina on overall acceptability of cooked pasta (water, ml=25% of flaxseed, g and semolina, g).

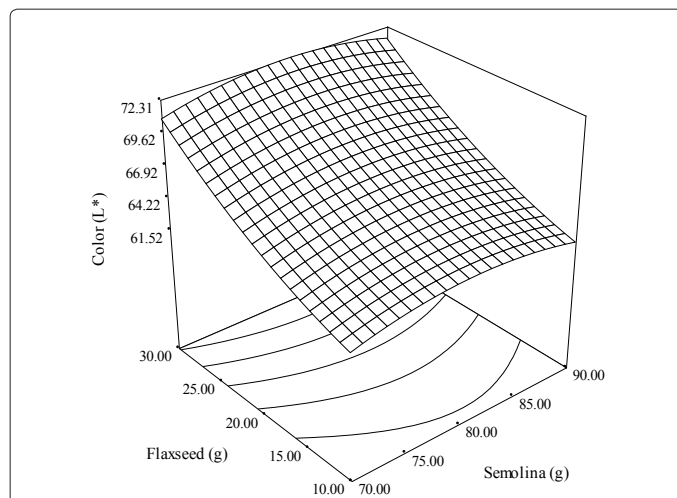


Figure 4a: Effect of flaxseed and semolina on color parameter (L*) of pasta (water, ml=17.5% of flaxseed, g and semolina, g).

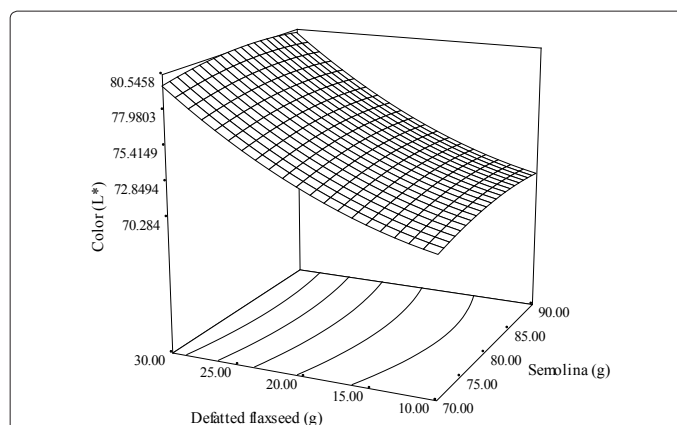


Figure 4b: Effect of defatted flaxseed and semolina on color parameter (L*) of pasta (water, ml=25% of flaxseed, g and semolina, g).

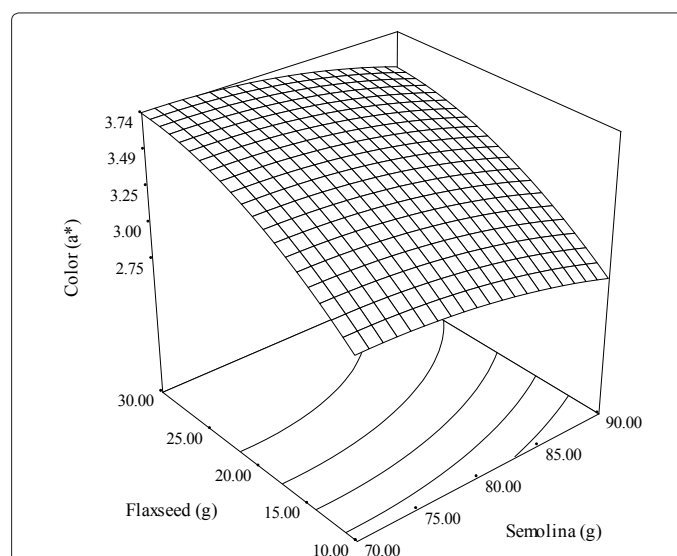


Figure 4c: Effect of flaxseed and semolina on color parameter (a*) of pasta (water, ml=17.5% of flaxseed, g and semolina, g).

content had non significant effect on OAA of both flaxseed and defatted flaxseed based pasta. All other process variables have significant effect ($p < 0.05$) at linear and quadratic levels on OAA. The model F-value was 10.455 and 4.241 for flaxseed and defatted flaxseed based pasta, which implies that both models are significant (Table 8).

The color of the pasta plays a major role in consumers' perception and acceptability of the product. The color parameter values, (L' and a'), for flaxseed and defatted flaxseed based pasta are presented in table 3 and 4, respectively. The values of color parameter (b') in pasta were found to be low, so were not included in optimization studies. The values of color parameters (L') of defatted flaxseed pasta were higher than that of flaxseed based pasta, is possibly due to removal of oil. The linear and interaction terms of flaxseed or defatted flaxseed had a significant effect on color of pasta (Table 9a and 9b). All other process parameters except quadratic term of semolina had a non significant effect on color of pasta. The model F-value and non significant lack of fit presented in table 9a and 9b for flaxseed and defatted flaxseed based pasta, implies that both models are significant. The observed results are in agreement with the studies of Khouryieh and Aramouni [33], on flax

based cookies. The effect of process variables on color parameters (L' and a') is shown in figure 4a-4d.

Optimization of process variables for the development of flaxseed and defatted flaxseed based pasta

Graphical multi-response optimization technique was adopted to determine the optimum conditions for the osmo-convective dehydration of ginger cubes. The contour plots for all responses were superimposed, and regions that best satisfy all the constraints were selected as optimum conditions. The main criterion for constraints optimization was minimum possible %FFA, and color parameter (a') and maximum possible %gelatinization, color parameter (L') and OAA. These constraints resulted in "feasible zone" of the optimum solutions (shaded area in the superimposed contour plots).

To optimize the process variables for the development of flaxseed and defatted flaxseed based pasta by numerical optimization technique, equal importance of '3' was given to all three process parameters (viz. semolina, flaxseed or defatted flaxseed and water content) and 5 responses (viz. %FFA, %gelatinization, OAA, L' and a'). For the preparation of a functional food having properties of flaxseed, while optimizing the flaxseed content was selected in range of 15-30% because it is beneficial from the nutritional and therapeutic point of view. The optimum values of process variable for semolina, flaxseed and water content are represented in table 10a and 10b. The optimum processing conditions were experimentally verified and proven to be adequately reproducible with $\pm 0.1\%$ deviation.

Conclusion

Response surface methodology was successfully used in optimizing process parameters for the development of flaxseed and defatted flaxseed based pasta. Graphical technique was applied to locate optimum operating conditions, which were experimentally verified and found to be adequately reproducible. Optimum solutions using numerical optimization obtained were: semolina 90 g, flaxseed 15 g and water 20 (% of amount of semolina and flaxseed) for development of flaxseed based pasta, and semolina 87.79 g, flaxseed 15 g and water 30 (% of amount of semolina and flaxseed) for development of defatted flaxseed based pasta, to get maximum possible gelatinization, color parameter (L'), overall acceptability, minimum free fatty acid and color

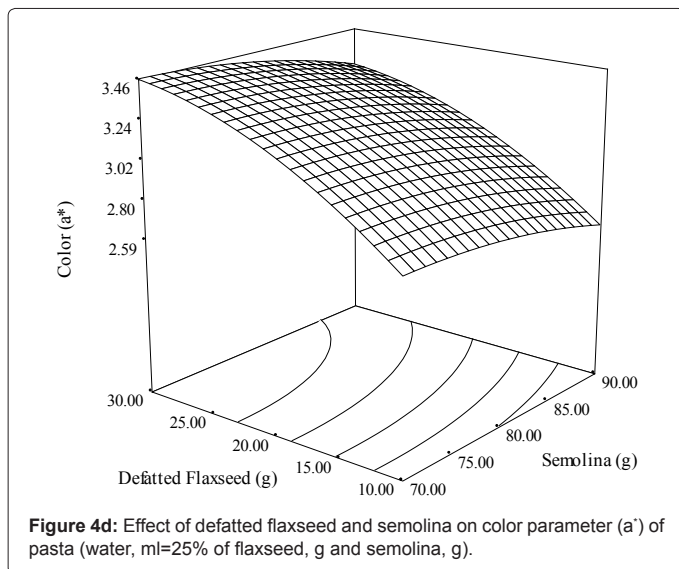


Figure 4d: Effect of defatted flaxseed and semolina on color parameter (a') of pasta (water, ml=25% of flaxseed, g and semolina, g).

Source	df	Flaxseed flour based pasta				Defatted flaxseed based pasta			
		β	SS	F Value	p-value	β	SS	F Value	p-value
Model	9		348.465	44.953	<0.0001		346.244	38.568	<0.0001
Constant	1	66.5659				74.4488			
Semolina	1	0.241	0.79347	0.92123	0.3598	0.241	0.79347	0.79546	0.3934
Flaxseed	1	4.643	294.391	341.795	<0.0001	4.730	305.504	306.272	<0.0001
Water	1	-0.350	1.67216	1.94142	0.1937	-0.350	1.672	1.676	0.2245
Semolina ²	1	-1.280	23.626	27.430	0.0004	-0.558	4.488	4.500	0.0599
Flaxseed ²	1	1.092	17.172	19.938	0.0012	1.336	25.712	25.777	0.0005
Water ²	1	0.371	1.986	2.306	0.1598	0.386	2.152	2.158	0.1726
Semolina x Flaxseed	1	0.028	0.006	0.007	0.9331	0.028	0.006	0.006	0.9378
Semolina x Water	1	0.586	2.747	3.190	0.1044	0.586	2.747	2.754	0.128
Flaxseed x Water	1	-0.418	1.398	1.623	0.2315	-0.418	1.398	1.401	0.2639
Residual	10		8.613				9.975		
Lack of Fit	5		3.409	0.655	0.6731		4.054	0.685	0.6561
Pure Error	5		5.204				5.921		
R ²		0.97588				0.972			
Adjusted R ²		0.95417				0.9468			

Table 9a: ANOVA showing the variables as a linear, quadratic, and interaction terms on color (L') and coefficients for the prediction models.

Source	df	Flaxseed flour based pasta				Defatted flaxseed based pasta			
		β	SS	F Value	p-value	β	SS	F Value	p-value
Model	9		2.432	22.778	<0.0001		1.964	19.322	<0.0001
Constant	1	3.473				3.185			
Semolina	1	-0.131	0.233	19.606	0.0013	-0.099	0.1339	11.867	0.0063
Flaxseed	1	0.364	1.805	152.11	<0.0001	0.338	1.5577	137.961	<0.0001
Water	1	0.006	0.001	0.045	0.836	0.014	0.0025	0.22326	0.6467
Semolina ²	1	-0.071	0.072	6.097	0.0331	-0.050	0.036	3.217	0.1031
Flaxseed ²	1	-0.152	0.332	27.994	0.0004	-0.122	0.213	18.879	0.0015
Water ²	1	-0.033	0.016	1.353	0.2718	-0.047	0.032	2.864	0.1214
Semolina x Flaxseed	1	0.003	0.000	0.008	0.9294	-0.009	0.001	0.057	0.8155
Semolina x Water	1	-0.023	0.004	0.341	0.572	-0.010	0.001	0.071	0.7955
Flaxseed x Water	1	-0.036	0.010	0.862	0.3751	-0.048	0.019	1.649	0.228
Residual	10		0.119				0.113		
Lack of Fit	5		0.050	0.725	0.6336		0.044	0.642	0.6809
Pure Error	5		0.069				0.069		
R ²		0.95349				0.96562			
Adjusted R ²		0.9363				0.93668			

Table 9b: ANOVA showing the variables as a linear, quadratic, and interaction terms on color (a') and coefficients for the prediction models.

Parameters	Criteria	Responses			Desirability	Optimum conditions		
		Predicted value	Observed value			Semolina (g)	Flaxseed (g)	Water*
%FFA	Minimum	1.83	1.95	0.652	90	15	20	
%Gelatinization	Maximum	64.75	65.91					
OAA	Maximum	7.74	7.6					
Color (L')	Maximum	64.28	65.72					
Color (a')	Minimum	3.02	3.07					

* Water (ml)=% of Semolina (g)+Flaxseed (g)

Table 10a: Optimum solution for various process variables for development of flaxseed based pasta.

Parameters	Criteria	Responses			Desirability	Optimum conditions		
		Predicted value	Observed value			Semolina (g)	Flaxseed (g)	Water*
%FFA	Minimum	0.37	0.38	0.789	87.79	15	30	
%Gelatinization	Maximum	88.29	87.82					
OAA	Maximum	8.13	8.07					
Color (L')	Maximum	72.96	73.09					
Color (a')	Minimum	2.86	2.78					

* Water (ml)=% of Semolina (g)+Defatted Flaxseed (g)

Table 10b: Optimum solution for various process variables for development of defatted flaxseed based pasta.

parameter (a'). Thus, flaxseed and defatted flaxseed based pasta was developed, having functional properties of flaxseed.

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