Section A-Research Paper
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Optimization of Xanthan gum incorporated buckwheat and chickpea pasta

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Abstract

This research paper focuses on the development of a low glycemic index pasta product using buckwheat and chickpea. A Box Behnken design with varying proportions of buckwheat (65-85%), chickpea (15-35%), and xanthan gum (1.5-3.5%) was employed to characterize and optimize the pasta formulation based on multiple response parameters, including glycemic index, glycemic load, resistant starch, solid gruel loss, and cooking time. By leveraging the best-fit model, the optimization process aimed at maximizing resistant starch while minimizing glycemic index, glycemic load, cooking time, and solid gruel loss using design expert software. The study revealed that the quadratic model provided the most accurate representation for all response variables. The determined optimum process parameters were as follows: (a) buckwheat content, (b) chickpea content, (c) xanthan gum concentration, (d) glycemic index, (e) glycemic load, (f) resistant starch, (g) solid gruel loss, and (h) cooking time. By achieving a low glycemic index and other desirable characteristics, this investigation holds promising prospects for commercialization and promotes the adoption of such products within the food processing sector. This low glycemic index pasta, enriched with buckwheat and chickpea, offers a healthier alternative to traditional pasta and may contribute to improved dietary choices and overall health.

Keywords

Buckwheat, chickpea, low glycemic index, pasta, response surface analysis, xanthan gum

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Introduction

Cereals and pulses have long been utilized to create various value-added products, and among them, pseudocereals have gained popularity in the development of items such as pasta, biscuits, and cakes. Buckwheat, a nutrient-rich pseudocereal, stands out for its low glycemic index and gluten-free nature, making it a preferred ingredient in the creation of diverse food products (Alvarez-Jubete et al., 2009). Additionally, buckwheat boasts a favorable amino acid profile compared to other cereals, contributing to its popularity as a nutritious food option (Janssen et al., 2017). Moreover, buckwheat has been associated with potential health benefits, including cardiovascular support and management of celiac disease and diabetic complications.

The addition of pulses to pasta formulations can further enhance their nutritional profile, especially in terms of protein content and amino acid balance. Chickpea, with its high protein content (17-22%) and slow-digesting carbohydrates, leading to low glycemic responses in humans, serves as a promising pulse option for incorporation into pasta products (Saleh and Tarek, 2016). Chickpea also contains essential minerals like calcium, sodium, magnesium, and potassium, further contributing to its nutritional value.

Combining buckwheat and chickpea in pasta formulations offers a compelling opportunity to develop a low glycemic index pasta product with improved nutritional quality. Pasta preparation involves a series of operations, and both manual and extrusion technologies are commonly used. Among these, extrusion technology, specifically cold extrusion, has gained recognition for its ability to retain nutritional and quality parameters in food products (Nikmaran et al., 2017). The conventional use of durum wheat in pasta making has evolved to include alternative ingredients such as millets, buckwheat, amaranth, quinoa, and soy flour, owing to their neutraceutical value and growing popularity in various food products. However, the addition of suitable additives is crucial in achieving good pasta quality. Xanthan gum, CMC, tragacanth, and other gums have been studied as additives to control moisture content, texture, and porosity in gluten-free pasta products (Mir et al., 2015; Singh et al., 2015; Turabi et al., 2010; Hojjatoleslami& Azizi, 2015; Herranz et al., 2016). These additives play a vital role in enhancing the sensory and textural attributes of gluten-free pasta. Process variables, such as ingredient concentrations (buckwheat, chickpea, and xanthan gum), significantly influence pasta quality attributes like glycemic index, glycemic load, resistant starch, solid gruel loss, and cooking time. Optimization of these parameters is essential for the successful development of cold extruded pasta with low glycemic index. Response surface methodology (RSM) has proven to be a valuable tool for optimizing process parameters in various food formulations. Several studies have applied RSM to develop non-wheat pasta, reduce gluten content in gluten-free bakery products, and investigate the effect of various ingredients and cooking times on food properties (Yadav et al., 2012; Huang, Knight & Goad, 2001; Shirashoji et al., 2006, 2010; Motevalizadeh et al., 2018). However, the application of RSM in the context of cold extrusion technology for low glycemic index pasta products remains an unexplored area of research.

Given the potential benefits of incorporating buckwheat and chickpea into pasta formulations, along with the need for optimization of additives using RSM in cold extrusion technology, this study aims to develop xanthan gum incorporated pasta using buckwheat and chickpea flours through a Box Behnken design approach with response surface methodology (RSM). By optimizing the process parameters, this research seeks to create a low glycemic index pasta product with improved nutritional and functional quality.

MATERIALS AND METHODS

Raw Materials and Sample Preparation:

Buckwheat (common variety) and chickpea (G-1581) grains were procured from Krishi Vigyan Kendra (KVK), Gurez, SKUAST-Kashmir (34.08°N and 74.79°E), and KVK Samba, SKUAST-Jammu (32.72°N and 74.850°E), respectively. The samples were carefully transported to the laboratory in airtight polyethylene bags to prevent external contamination. Upon arrival, the buckwheat and chickpea grains were thoroughly washed and sun-dried for five days in May, with an exposure time of 7-8 hours per day to the sun. Subsequently, foreign particles were removed through sorting. The dried and cleaned grains were milled to a fine flour using a 200 µ sieve, and the obtained flour was stored in airtight containers until further use.

Pasta Preparation:

A series of pasta formulations were prepared using a cold extruder (Pasta and Noodle Maker, Model 16009 Make, Kent) with the following ingredients: buckwheat flour (85%) (common variety), chickpea flour (G-1581) (35%), and xanthan gum (3.5). The water and salt content were kept constant at 40% and 1.5%, respectively, in all treatment combinations. The response surface methodology (RSM) with Box Behnken design (BBD) was employed to optimize and characterize the pasta formulation, and a total of 17 different combinations were prepared.

Formulation of Different Blends for Cold Pasta Extrudates:

To create various pasta types with different buckwheat (65-85%), chickpea (15-35%), and xanthan gum (1.5-3.5%) levels, the ingredients were blended using the cold extruder. Lukewarm water was gradually added during the blending process, with continuous scraping to prevent surface fouling. The ingredients were thoroughly mixed for approximately 10 minutes, and the resulting dough was automatically extruded through a die attached to the extruder to achieve the desired pasta shape. The extrudates were then collected and dried using a tray drier at 40°C until their moisture content reached 5-6%. After cooling at room temperature, the pasta was packaged and stored in Ziplock bags for further analysis.Furthermore, water and salt content were kept constant at 40% and 1.5%, respectively, in all treatment combinations.

Evaluation of Treatment Combinations:

The different treatment combinations were evaluated for various attributes, including glycemic index, glycemic load, resistant starch, solid gruel loss, and cooking time. The optimization criteria were set to minimize glycemic index, minimize glycemic load, maximize resistant starch, minimize solid gruel loss, and minimize cooking time.

Process optimization for xanthan gum incorporated extrudates

Experimental design

Box Behnken Design (BBD) was used to examine the effects of three independent variables viz. buckwheat (A), chickpea (B) and xanthan gum (C) on dependent variables viz. glycemic index (GI), glycemic load(GL), resistant starch (RS), solid gruel loss (SGL) and cooking time (CT). The buckwheat levels ranged from 65-85 % with central point as 75. Similarly, chickpea concentration ranged from 15-35% and xanthan gum ranged from1.5 -3.5 %with central points as 25 and 2.5, respectively.

Statistical Software Design Expert 12.0 (Stat Ease Inc., Minneapolis, MN, USA) was used to develop second order polynomial models for dependent variables to fit the experimental data for each response.

$$y_i = b_o + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x^2 \; \sum_{i=1}^{3} \sum_{i=1}^{3} \sum_{i=1}^{3} b_{ij} x_i x_j \qquad (5)$$

Where, x_i (i = 1, 2, 3) are independent variables (buckwheat, chickpea and xanthan gum) and b_o, b_i, b_{ii} and b_{ij} are coefficient for intercept, linear, quadratic and interactive effects, respectively. Data was analysed by multiple regression analysis and statistical significance of the terms was examined by analysis of variance (ANOVA) for each response.

Optimization of the process for preparation of xanthan gum incorporated extrudates was done by numerical optimization using response surface of desirability function. For numerical optimization, the optimum condition criteria was used to minimize (a) glycemic index, (b) glycemic load, (c) solid gruel loss, (d) cooking time and maximize (e) resistant starch

Determination of product response

Glycemic index

The invitro-glycemic index (GI) of the sample was determined by following the procedures of Goniet al.1997. All of the samples except for white bread were cooked at 80°C for 30 min in tap water(5 ml) in capped tubes until complete gelatinization of the sample occurred. Then, 10 ml of HCl–KCl buffer (pH 1.5) was added and homogenized for 2 min. Then, add 0.2 ml of a solution containing 1 g of pepsin in 10 ml HCl–KCl buffer (pH 1.5) to the sample and incubated in a shaking water bath at 40°C for 60 min followed by the addition of 15 ml of trismaleate buffer (pH 6.9) for adjusting the volume of the sample to 25 ml. Around 5 ml of trismaleate buffer containing 2.6 IU of α-amylase (Sigma Aldrich) from porcine pancreas was added to the sample to obtain maltodextrins; the flask was then placed in a shaking water bath at 37°C. Aliquots of 0.1 ml were taken from each flask at 0, 30, 60, 90, 120, 150, and 180 min into the test tube and boiled in water for 5 min for inactivating the α-amylase. Then, 1 ml of 0.4 M sodium-acetate buffer (pH 4.75) and 60 ml of amyloglucosidase were added and incubated at 60°C for 45 min for hydrolysing maltodextrins to glucose. The glucose concentration was measured by a glucose oxidase-peroxidase kit. The rate of starch digestion was expressed as the percentage of total starch hydrolysed at different times (0, 30, 60, 90, 120, 150, and 180 min). The kinetics of starch hydrolysis, the area under the hydrolysis curve (AUC), hydrolysis index (HI), and GI were calculated by Equations (7)– (10), respectively;

$$C = C_0(1 - e^{-kt}) \qquad (7)$$

$$AUC = C_\infty(t_f - t_0) - \left(\frac{C_\infty}{k}\right)(1 - e^{-k(t_f - t_0)}) \qquad (8)$$

$$HI = \left(\frac{AUC_{sample}}{AUC_{white\ bread}}\right) \times 100 \qquad (9)$$

$$GI = 39.71 + (-0.549HI) \qquad (10)$$

where C is the percentage of starch hydrolyzed at time t, C_∞ is the percentage of starch hydrolyzed after 180 min, k is the kinetic constant (min^{-1}), t is the time (min), t_f is the final time (180 min), t_0 is the initial time (0 min), and HI is the hydrolysis index which is defined as the percentage of AUC of the treated sample divided by the corresponding area of white bread and is expressed as the percentage.

Glycemic load

The glycemic load (GL) of the sample was determined using the following equation (11)

$$Glycemic\ load\ (GL) = \frac{Available\ carbohydrate \times Glycemic\ index}{100} \quad (11)$$

where, available carbohydrate was determined by subtracting dietary fiber from total carbohydrates.

Resistant Starch

Resistant starch (RS) was determined following the protocol of Goniet al. (1997). Briefly, protein and digestible starch were removed after treating with pepsin (Merck 7190, Darmstadt, Germany; 40 , 1 h, pH 1.5), and α-amylase (Sigma A-3176, Madrid, Spain; 37 ^{0}C, 16h, pH 6.9), respectively. After centrifugation, residues were dispersed with 2 M KOH to dissolve RS, incubated with amyloglucosidase and glucose was quantified spectrophotometrically using the GOPODreagent (676543, Roche Diagnostics, Barcelona, Spain).

RS was calculated as

$$Resistant\ starch = mg\ glucose\ \times 0.9 \quad (12)$$

Cooking time

Cooking time was determined by American Association of Cereal Chemists (AACC) approved method 16-50 (2000) and characterized by the disappearance of the opaque centre while cooking the pasta extrudates in excess water. About, 5 g pasta sample was cooked in a beaker containing 75 ml of distilled water. Pasta extrudates were pressed between two plates after every 30 seconds. The optimum cooking time of pasta extrudates was recorded when the white bubble reaction of cooked pasta disappeared.

Gruel solid loss (%)

Gruel solid loss of cooked pasta extrudates was determined by measuring the amount of solid substance lost to the cooking water. (AACC, 2000) Approximately 10 g sample of pasta extrudates was placed into 300 ml boiling distilled water in a 500 ml beaker. Cooking water was collected in an aluminium dish and placed in an oven at 105^{0}C and evaporated to dryness. The residue was weighed and reported as a percentage of starting material. Cooking loss was calculated as

$$\text{Solid Gruel loss (\%)} = \frac{Driedresidueincookingwater}{weight\ ofpasta\ before\ cooking} x\,100 \quad (13)$$

Results and Discussions

Experimental datasheet

The experimental data obtained at various combinations of buckwheat, chickpea and xanthan gum using BBD design of RSM is presented in Table 1.

Table:1 shows the experimental data obtained at various combinations of buckwheat, chickpea and xanthan gum using BBD design of RSM.

Std	Run	Buckwheat (A)	Chickpea (B)	Xanthan gum (C)	Glycemic Index (G.I)	Glycemic Load (GL)	Resistant Starch (RS)	Solid Gruel Loss (SGL)	Cooking Time (CT)
		%	%	%			%	%	mts
1	17	65	15	2.5	33.85	8.98	5.25	5.06	2.87
2	3	85	15	2.5	30.76	5.76	7.93	4.88	3.02
3	1	65	35	2.5	33.31	8.11	5.37	3.05	4.42
4	13	85	35	2.5	29.74	4.74	8.94	4.66	3.45
5	8	65	25	1.5	32.98	7.98	5.73	4.03	4.13
6	5	85	25	1.5	29.47	4.47	8.68	4.58	3.54
7	9	65	25	3.5	32.71	7.44	5.85	3.25	4.14
8	10	85	25	3.5	29.56	4.1	9.09	4.17	3.98
9	7	75	15	1.5	32.19	7.33	6.84	4.37	3.21
10	15	75	35	1.5	31.06	6.06	6.67	3.67	4.62
11	16	75	15	3.5	31.84	6.67	7.14	4.65	3.63
12	2	75	35	3.5	31.38	5.99	7.44	2.92	4.53
13	11	75	25	2.5	31.76	6.67	7.42	4.75	4.38
14	14	75	25	2.5	31.75	6.75	7.32	4.28	4.29
15	6	75	25	2.5	31.79	6.63	7.32	4.36	4.22
16	4	75	25	2.5	31.75	6.71	7.85	4.4	4.02
17	12	75	25	2.5	31.74	6.9	7.32	4.86	4.07

Effect of independent variables on the responses

Effect of buckwheat on the responses.

Glycemic Index

As depicted from the table1, buckwheat had a negative effect on the glycemic index of the sample. At constant chickpea (15%) and xanthan gum (2.5%) glycemic index reduced from **33.85 to 30.76** with buckwheat variation from 65-85 %. Glycemic index showed reducing trend from **33.31 to 29.74**with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. It also showed negative effect with buckwheat variation of 65-85% from **32.98 to 29.47** at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The values of G.I were found to be reduced from **32.71 to 29.56** with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

Glycemic Load

As depicted from the table 1, buckwheat had a negative effect on the glycemic load of the sample. At constant chickpea (15%) and xanthan gum (2.5%) glycemic index reduced from **8.98 to 5.76** with buckwheat variation from 65-85 %. Glycemic load showed reducing trend from **8.11 to 4.74** with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. It also showed negative effect with buckwheat variation of 65-85% from **7.98 to 4.47** at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The values of G.L were found to be reduced from **7.44 to 4.1** with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

Resistant Starch

As depicted from the table 1 , buckwheat had a positive effect on the resistant starch of the sample. At constant chickpea (15%) and xanthan gum (2.5%), resistant starch increased from**5.25 to 7.93 %** with buckwheat variation from 65-85 %. It showed positive trend from **5.37 to 8.94**% with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. The values of resistant starch increased with buckwheat variation of 65-85% from**5.73 to 8.68 %**at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The positive trend of increased resistant starch with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively was found be from **5.85 to 9.09 %.**

Gruel solid loss

Table 1 showed that buckwheat had a positive effect on the gruel solid loss of the sample. However, at constant chickpea (15%) and xanthan gum (2.5%), gruel solid loss decreased from**5.06 to 4.88 %**with buckwheat variation from 65-85 %. It increased from **3.05 to 4.66 %**with buckwheat variation from 65-85 % at constant concentrations of chickpea (35%) and (2.5%) respectively. Gruel solid loss with buckwheat variation of 65-85 % at constant concentrations of chickpea (25%) and xanthan gum (1.5%) was found to be increased to small extent from **4.03 to 4.58 %.**However, , the values of gruel solid loss was found to increased further with buckwheat variation of 65-85% from**3.25 to 4.17 %**at constant concentrations of chickpea (25%) and xanthan gum (3.5%) respectively.

Cooking Time

As depicted from the table 1 , buckwheat had a positive effect on the cooking time of the sample. At constant chickpea (15%) and xanthan gum (2.5%), cooking time increased from **2.87 to 3.02 minutes**with buckwheat variation from 65-85 %. However with buckwheat variation from65-85 % at constant concentrations of chickpea (35%) and (2.5%) cooking time showeddecreasing trend to small extent from **4.42 to 3.45 minutes** respectively. It also showed negative effect with buckwheat variation of 65-85% from **4.13 to 3.54minutes** at constant concentrations of chickpea (25%) and xanthan gum (1.5%) respectively. The values of cooking time were found to be decreased from **4.14 to 3.98 minutes**with buckwheat variation of 65-85 % at constant concentration of chickpea (25%) and xanthan gum (3.5%) respectively.

Effect of chickpea onthe responses

Glycemic Index

As depicted from the table1 , chickpea had a negative effect on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) glycemic index reduced from **33.85 to 33.31** with chickpea variation from 15-35 %. Glycemic index showed reducing trend from **30.76 to 29.74** with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. It gets reduced from **32.19 to 31.06**with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from **31.84 to 31.38** at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

Glycemic Load

Table 1 clearly shows the negative effect of chickpea on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) glycemic load reduced from **8.98 to 8.11** with chickpea variation from 15-35 %. Glycemic load showed reducing trend from **5.76 to 4.74** with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. It gets reduced from **7.33 to 6.06** with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed negative effect with chickpea variation of 15-35% from **6.67 to 5.99** at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

Resistant Starch

As depicted from the table 1, chickpea had positive effect on the resistant starchof the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) resistant starch increased from**5.25 to5.37**% with chickpea variation from 15-35 %. Resistant starch showed increasing trend from **7.93 to 8.94 %** with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. However, it gets reduced from **6.84 to 6.67 %** withchickpea variation of **15-35 %** at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Further, it showed positive effect with chickpea variation of **15-35%** from **7.14 to 7.44** at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

Solid Gruel Loss

Chickpea showed negative effect on the solid gruel loss of the sample as per table 1.

At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) solid gruel loss decreased from **5.06 to 3.05 %** with chickpea variation from 15-35 %. It further showed negativetrend from **5.88 to 4.66 %** with chickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively and then reduced from **4.37 to 3.67 %** with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Solid gruel loss showedagain negative effect with chickpea variation of 15-35% from **4.65 to 2.92 %**at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

Cooking time

Table: 1 depicts that chickpea had positive effect on the cooking time of the sample. At constant concentrations of buckwheat (65%) and xanthan gum (2.5%) cooking time increased from**2.87 to 4.42 minutes** with chickpea variation from 15-35 %. It showed increasing trend from **3.02 to 3.45 minutes** withchickpea variation from 15-35 % at constant concentrations of buckwheat (85%) and xanthan gum (2.5%) respectively. Again, it increasedfrom **3.21 to 4.62 minutes**with chickpea variation of 15-35 % at constant buckwheat (75%) and xanthan gum (1.5%) concentration levels. Solid gruel loss further showed positive effect with chickpea variation of 15-35% from **3.63 to 4.53 minutes** at constant concentrations of buckwheat (75%) and xanthan gum (3.5%) respectively.

Effect of xanthan gum on the responses

Glycemic index

As depicted from the table 1 , xanthan gum had a negative effect on the glycemic index of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic index slightly decreased from**32.98 to 32.71** with xanthan gum variation from 1.5-3.5 %.

However, it increased slightlyfrom **29.47 to 29.56** with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (85%) andchickpea (25%) respectively. It gets reduced from **32.19 to 31.84**with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in glycemic index with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (75%) and chickpea (35%) from **31.06 to 31.38** respectively.

Glycemic Load

As depicted from the table 1, xanthan gum had a negative effect on the glycemic load of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) glycemic load slightly decreased from**7.98 to 7.44** with xanthan gum variation from 1.5-3.5 %. It decreased slightly from **4.47 to 4.10** with xanthan gum variation from**1.5-3.5 %** at constant concentrations of buckwheat (85%) and chickpea (25%) respectively and further reduced from **7.33 to 6.67** with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in glycemic load with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (75%) and chickpea (35%) from **6.06 to 5.99** respectively.

Resistant starch

The values of resistant starch from the table 1 explained the effect of xanthan gum on the resistant starch. Xanthan gum had a positive effect on the resistant starch of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) resistant starch slightly increased from**5.73 to 5.85 %**with xanthan gum variation from **1.5-3.5 %.**However, it also increased from **8.68 to 9.09 %**with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. Again it increased from 6.84 to 7.14 % with xanthan gum variation of **1.5-3.5 %** at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it showed slightly increase in resistant starch with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (75%) and chickpea (35%) from **6.67 to 7.44 %** respectively.

Solid gruel loss

As depicted from the table1, xanthan gum had a negative effect on the solid gruel loss of the sample. At constant concentrations of buckwheat (65%) and chickpea (25%) solid gruel loss slightly decreased from4.03 to 3.25 % with xanthan gum variation from 1.5-3.5 %. It again decreased slightly from **4.58 to 4.17 %** with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. However, it increasedfrom **4.37 to 4.65 %** with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels and reduced afterwards from **3.67 to 2.92 %**with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (75%) and chickpea (35%) respectively.

Cooking time

Xanthan gum showed a slight positive effect on the cooking time of the sample as shown in Table: 1. At constant concentrations of buckwheat (65%) and chickpea (25%) cooking time increased from 4.13 **to 4.14 mts.** with xanthan gum variation from 1.5-3.5 %. However, it increased slightly from **3.54 to 3.98 mts.** with xanthan gum variation from **1.5-3.5 %** at constant concentrations of buckwheat (85%) and chickpea (25%) respectively. It increased from **3.21 to 3.63 mts**with xanthan gum variation of 1.5-3.5 % at constant buckwheat (75%) and chickpea (15%) concentration levels. However, it increased with xanthan gum variation from **1.5-3.5%** at constant concentrations of buckwheat (75%) and chickpea (35%) from respectively.

Model fitness and analysis of variance.

Table 2 : Glycemic Index

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	24.84	9	2.76	4386.46	**< 0.0001**	**Significant**
A-Buckwheat	22.18	1	22.18	35242.81	< 0.0001	
B-Chickpea	1.24	1	1.24	1970.98	< 0.0001	
C-xanthan gum	0.0055	1	0.0055	8.76	0.0211	
AB	0.0576	1	0.0576	91.53	< 0.0001	
AC	0.0324	1	0.0324	51.49	0.0002	
BC	0.1122	1	0.1122	178.34	< 0.0001	
A^2	0.0828	1	0.0828	131.61	< 0.0001	
B^2	0.3720	1	0.3720	591.20	< 0.0001	
C^2	0.8068	1	0.8068	1282.16	< 0.0001	
Residual	0.0044	7	0.0006			
Lack of Fit	0.0029	3	0.0010	**2.64**	**0.1862**	Not significant
Pure Error	0.0015	4	0.0004			
Cor Total	24.85	16				

Table 3: Glycemic Load

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	26.73	9	2.97	369.78	**< 0.0001**	**significant**
A-Buckwheat	22.58	1	22.58	2810.86	< 0.0001	
B-Chickpea	1.84	1	1.84	229.46	< 0.0001	
C-xanthan gum	0.3362	1	0.3362	41.85	0.0003	

AB	0.0056	1	0.0056	0.7002	0.4303	
AC	0.0072	1	0.0072	0.8994	0.3745	
BC	0.0870	1	0.0870	10.83	0.0133	
A²	0.1286	1	0.1286	16.01	0.0052	
B²	0.4875	1	0.4875	60.68	0.0001	
C²	1.32	1	1.32	164.23	< 0.0001	
Residual	0.0562	7	0.0080			
Lack of Fit	0.0130	3	0.0043	**0.3990**	**0.7619**	**not significant**
Pure Error	0.0433	4	0.0108			
Cor Total	26.79	16				

Table 4 : Resistant Starch

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	21.07	9	2.34	43.88	< 0.0001	**Significant**
A-Buckwheat	19.34	1	19.34	362.62	< 0.0001	
B-Chickpea	0.1985	1	0.1985	3.72	0.0951	
C-xanthan gum	0.32	1	0.32	6	0.0442	
AB	0.198	1	0.198	3.71	0.0954	
AC	0.021	1	0.021	0.3941	0.5501	
BC	0.0552	1	0.0552	1.04	0.3428	
A²	0.0703	1	0.0703	1.32	0.2886	
B²	0.831	1	0.831	15.58	0.0056	
C²	0.0018	1	0.0018	0.034	0.859	
Residual	0.3734	7	0.0533			
Lack of Fit	0.1619	3	0.054	**1.02**	**0.472**	**not significant**
Pure Error	0.2115	4	0.0529			
Cor Total	21.44	16				

Table : 5 Solid Gruel loss

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Model	6.42	9	0.7134	14.88	0.0009 Significant
A-Buckwheat	1.05	1	1.05	21.93	0.0023

B-Chickpea	2.71	1	2.71	56.62	0.0001	
C-xanthan gum	0.3444	1	0.3444	7.18	0.0315	
AB	0.8010	1	0.8010	16.71	0.0046	
AC	0.0342	1	0.0342	0.7139	0.4261	
BC	0.2652	1	0.2652	5.53	0.0509	
A^2	0.0002	1	0.0002	0.0034	0.9549	
B^2	0.0521	1	0.0521	1.09	0.3318	
C^2	1.12	1	1.12	23.41	0.0019	
Residual	0.3356	7	0.0479			
Lack of Fit	0.0700	3	0.0233	**0.3514**	**0.7917**	**not significant**
Pure Error	0.2656	4	0.0664			

Table : 6
Solid Gruel loss

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4.44	9	0.4931	32.52	< 0.0001	**significant**
A-Buckwheat	0.3081	1	0.3081	20.32	0.0028	
B-Chickpea	2.3	1	2.3	151.71	< 0.0001	
C-xanthan gum	0.076	1	0.076	5.02	0.0601	
AB	0.3136	1	0.3136	20.68	0.0026	
AC	0.0462	1	0.0462	3.05	0.1243	
BC	0.065	1	0.065	4.29	0.0771	
A^2	0.6838	1	0.6838	45.1	0.0003	
B^2	0.5247	1	0.5247	34.6	0.0006	
C^2	0.1005	1	0.1005	6.63	0.0368	
Residual	0.1061	7	0.0152			
Lack of Fit	0.016	3	0.0053	**0.2371**	**0.8666**	**not significant**
Pure Error	0.0901	4	0.0225			
Cor Total	4.54	16				

Cor Total 6.76 16

The glycemic index (GI) is defined as the increment area under blood glucose response curve after intake of standard amount of carbohydrates from a test food relative to a control food (glucose or white bread) (Ludwig and Eckel,2002). The significant terms in the quadratic model for glycemic index were**A, B, AB, BC, A^2 , B^2 , and C^2**. All these possessed high **F** values and **$p < 0.0001$**. The lack of fit for the case was insignificant with low F value **(2.64)** and high p value **(0.1862).**R^2 ,adj$R^2$and PredR^2values for the glycemic response model were **0.9997, 0.9992 and 0.9956** respectively. All these adequately confirm good fitness of the quadratic model. The model expression to represent the glycemic index variation of the sample with buckwheat, chickpea and xanthan gum is as follows:

$$Y_1 = +31.76-1.66A -0.39B - 0.02C - 0.12\,AB + 0.09\,AC + 0.16\,BC - 0.14\,A^2 + 0.29\,B^2 -0.43\,C^2 \quad (14)$$

The best fit quadratic model for glycemic load response variable affirms A, B, AB, A^2 and B^2 as the significant terms with high F values and **$p < 0.0001$. With F= (0.39)** and high p value **(0.7619).** R^2,adjR^2 and Pred R^2 values for the glycemicload response model were **0.9979, 0.9952 and 0.9897** respectively. All these adequately confirm good fitness of the quadratic model. The model expression to represent the glycemic load variation of the sample with buckwheat, chickpea and xanthan gum is as follows:

$$Y_2 = +6.73-1.68\,A -0.48\,B - 0.20\,C - 0.03\,AB + 0.04AC + 0.14\,BC - 0.17\,A^2 + 0.34\,B^2 -0.55\,C^2 \quad (15)$$

Similarly, significant terms for the quadratic model of resistant starch are A, C and B^2 with high **F values and $p < 0.0001$**. The response model refers to insignificant lack of fit**(F =1.02 and p = 0.4720).** R^2,adj R^2 and pred R^2 were **0.9826, 0.9602 and 0.8638** respectively. Adequate precision value **(22.08) >4** is desirable for the model. All these confirm good fitness of the quadratic model expressed as:

$$Y_3 = +7.45 + 1.55\,A +0.15\,B + 0.20\,C + 0.22\,AB + 0.07\,AC + 0.11\,BC - 0.12\,A^2 - 0.44\,B^2 +0.02\,C^2 \quad (16)$$

The best fit quadratic model for solid gruel loss response variable affirms A, B, C, AB and C^2 as the significant terms with high **F values and $p < 0.0001$.** With **F= (0.35) and high p value(0.7917).** R^2 ,adj$R^2$and Pred R^2 values for the solid gruel loss response model were **0.9503,0.8865 and 0.7728**respectively. All these adequately confirm good fitness of the quadratic model. The model expression to represent the solid gruel loss variation of the sample with buckwheat, chickpea and xanthan gum is as follows:

$$Y_4 = +4.53+0.36A-0.58B - 0.20C + 0.44\,AB +0.09\,AC-0.25\,BC - 0.006A^2 - 0.11\,B^2 -0.51\,C^2 \quad (17)$$

The significant terms in the quadratic model for cooking time response variable were A, B, AB, A^2 , B^2 , and C^2 . All these possessed high **F values and $p < 0.0001$.** The lack of fit for the case was insignificant with low **F value (0.23) and high p value (0.86).**R^2 ,adjR^2 and Pred R^2 values for cooking time model were **0.9766, 0.9466 and 0.9126** respectively. All these adequately confirm good fitness of the quadratic model. The model expression to represent the cooking time variation of the sample with buckwheat, chickpea and xanthan gum is as follows:

$$Y_5 = +4.20-0.19\,A -0.53B +0.09\,C - 0.28\,AB + 0.10\,AC - 0.12BC - 0.40\,A^2 - 0.35\,B^2 + 0.15\,C^2 \quad (18)$$

All response variables were found to be significantly influenced with the variation of concentration in buckwheat, chickpea and xanthan gum, their square terms and interaction terms **($p<0.0001$).**

Table:7 summarizes the analysis of variance (ANOVA) data for different responses indicating the statistical validity. Among various alternate models, the quadratic model was the best fit model for all the responses.

Table 7 ANOVA for the fit of data to Response Surface Models

Responses	R^2	Adjusted R^2	Predicted R^2	Adequate Precision	C.V. (%)	p-value	Lack of Fit
Glycemic index	0.9998	0.9996	0.9980	228.82	0.079	0.05	N.S
Glycemic load	0.9979	0.9952	0.9897	70.77	1.37	0.05	N.S
Resistant starch	0.9826	0.9602	0.8638	22.08	3.21	0.05	N.S
Solid gruel loss	0.9503	0.8865	0.7728	13.24	5.17	0.05	N.S
Cooking time	0.9766	0.9466	0.9126	18.46	3.15	0.05	N.S

Response surface analysis

Figure **a-k** depict the response surface plot of glycemic index, glycemic load, resistant starch, solid gruel loss and cooking time respectively for the sample. The negative coefficient of the linear terms of buckwheat (A), chickpea (B) and xanthan gum (C) suggest the decrease in glycemic index with increase in these variables. The decrease in GI of extrudates with increase in the levels of buckwheat flour is attributed to lower the GI value of buckwheat **(34.70)** (Rozanska et al., 2020). Further, an increase in the levels of chickpea reduces GI which is due to higher protein levels present in chickpea flour. Proteins cause interference in the starch absorption by obstructing the enzyme binding sites thereby changing its digestibility characteristics. (Jamiah et al., 2009). Goni et al., (2003) have also reported the similar results for chickpea flour incorporated pasta. The pasta proteins with low GI could help to broaden up the range of low GI foods available to the consumer. The decrease in GI with increase in the levels of xanthan gum is attributed to increase in resistant starch (RS) (Naseer et al., 2021).

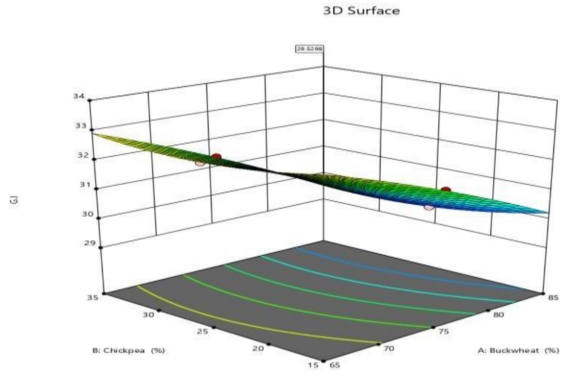
The glycemic load is the amount of available carbohydrates that elicits a certain value of GI. Glycemic load of the developed pasta ranged from **4.1 to 8.98** (Table 1) The fitted regression equation (14) shows the decrease in glycemic load (GL) with increase in the levels of buckwheat (A), chickpea (B) and xanthan gum (C) as is evident from their negative coefficients. Since, glycemic index and glycemic load are positively correlated and foods with low GI values can also elicit low GL within a precise portion size (Parsad et al., 2019). Therefore, the similar behaviour of glycemic index and glycemic load was justified.

Resistant starch (RS) is defined as the starch and products of starch degradation that are not absorbed in the small intestines of healthy individuals (Bjork, 1992). RS is an important parameter which contributes to glycemic response (GR) offered by carbohydrates-rich food. Hence a lot of research is going on with an intention to enhance the RS content of processed foods because of the positive health benefits (Akerberg*et al.*, 1998). Table 1 shows that RS ranged from **5.25 to 9.04 .**

The fitted regression equation (16) shows significant ($p \leq 0.05$) effect of buckwheat (A) and chickpea (B) could be seen indicating the increase in resistant starch (RS) with increase in these variables. The increase in RS with increase in the levels of buckwheat (A) could be due to the higher content of RS in buckwheat flour (3.80%). Furthermore, the addition of chickpea flour increases RS content possibly due to the interaction between starch and protein, thus making them resistant to digestion (Jamilah et al., 2009). Specifically, the proteins have been shown to affect the rate of starch hydrolysis in cereals (Ezeogn et al., 2008). It is believed that proteins strongly protect starch granules by surrounding their surface and impeding free access to amylolytic enzymes (Rooney and Pflugfelder, 1986). Similarly, Jenkins et al. (1983) suggested a decrease in GR after consumption of wheat flour, owing to the presence of gluten. Gluten surrounds the starch granules which could slow down the starch hydrolysis in small intestines.

The fitted regression equation (17) indicates significant **($p \leq 0.05$)** effect of buckwheat (A) and chickpea (B) could be seen indicating the decrease in solid gruel loss (GSL) with increase in these variables. The increase in gruel solid loss with increase in the levels of buckwheat (A) could be due to the higher content of RS in buckwheat (3.80%). The decrease in gruel solid loss with increase in chickpea (B) may be due to decrease in cooking time and proper swelling of solids without disintegration and fragmentation.

The fitted regression equation (18) shows significant ($p \leq 0.05$) positive effect of buckwheat on cooking time whereas, chickpea and xanthan gum indicates negative linear effect indicating the decrease in cooking time with increase in these variables.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B: Chickpea (%)
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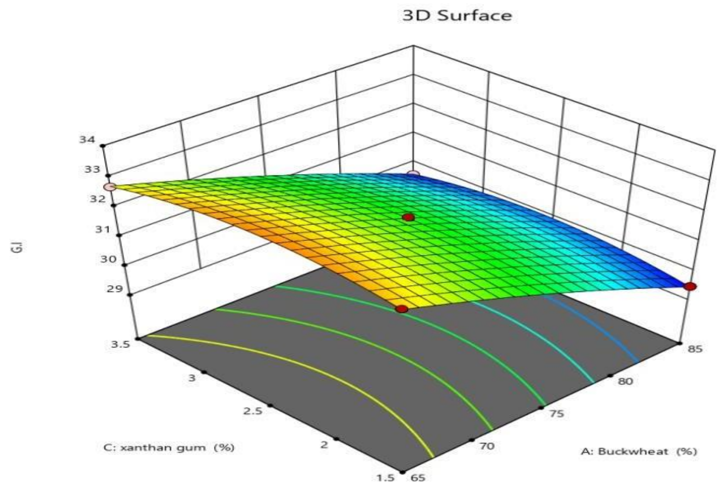
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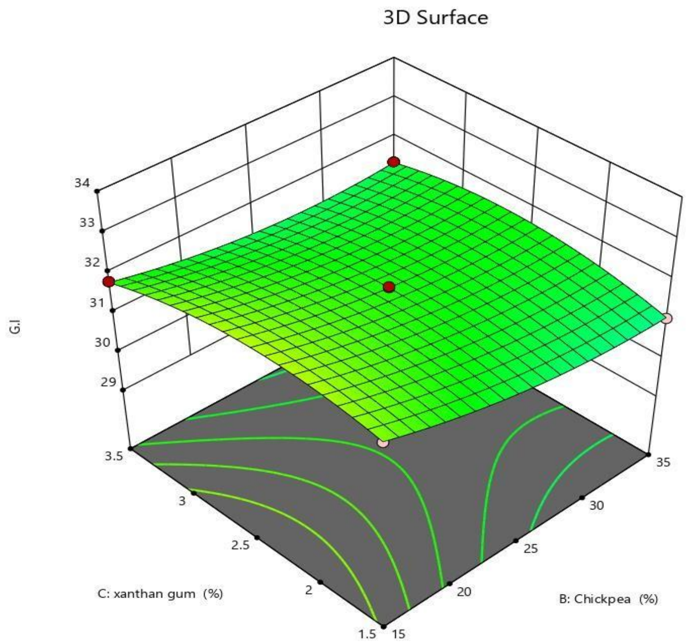
A: Buckwheat (%)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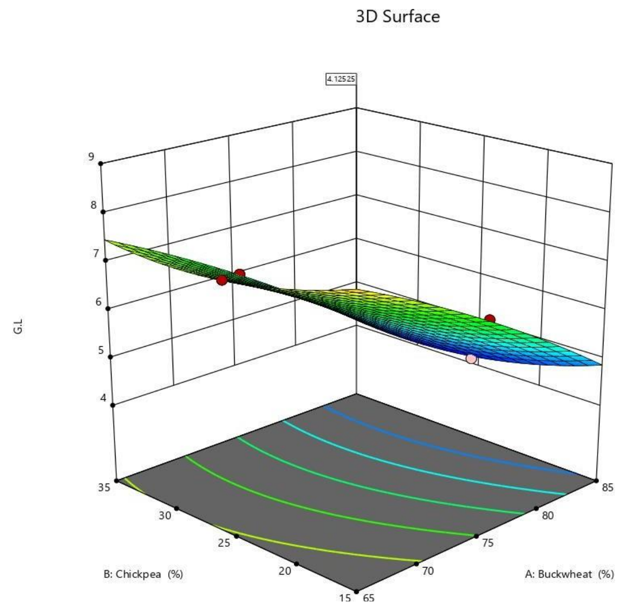
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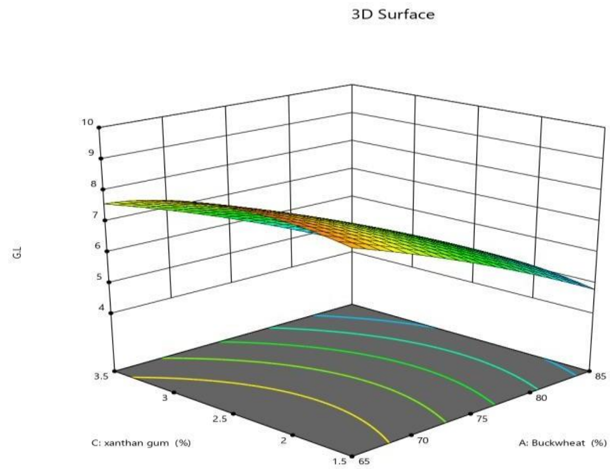
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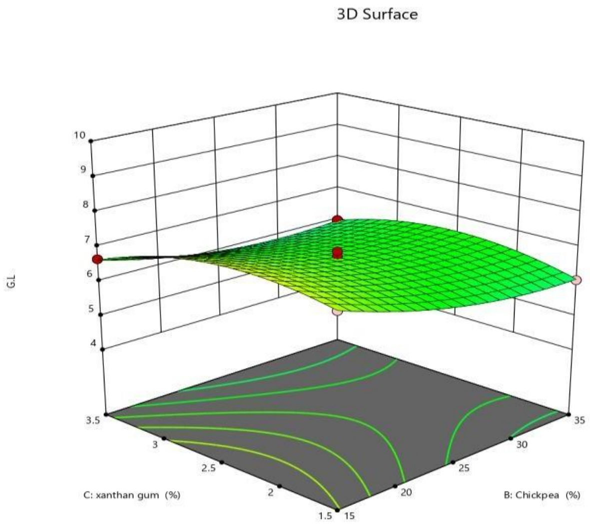
A: Buckwheat (%)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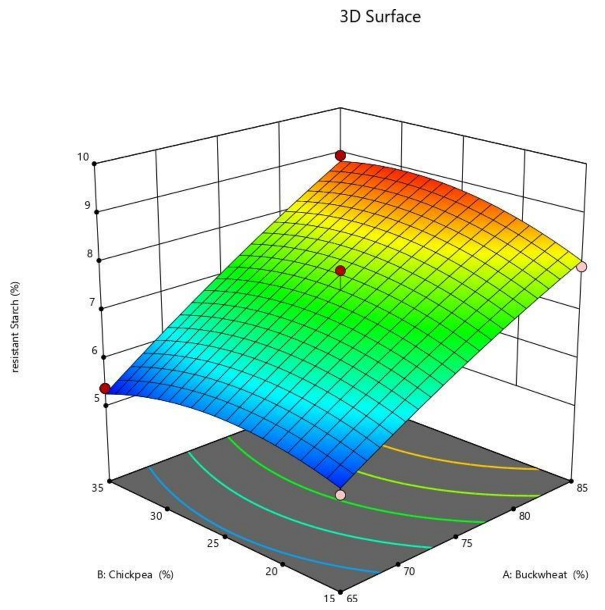
B: Chickpea (%)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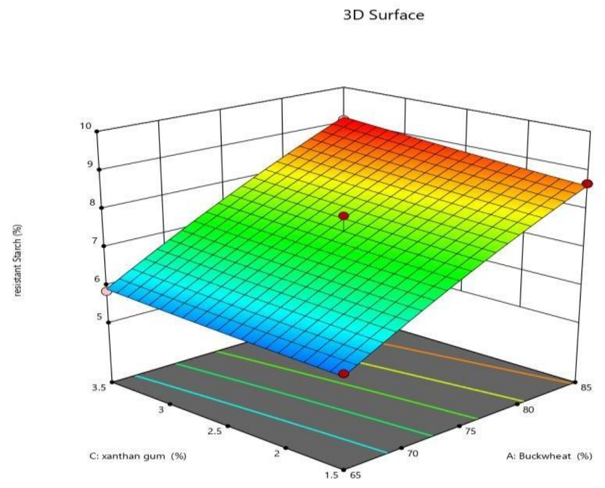
A: Buckwheat (%)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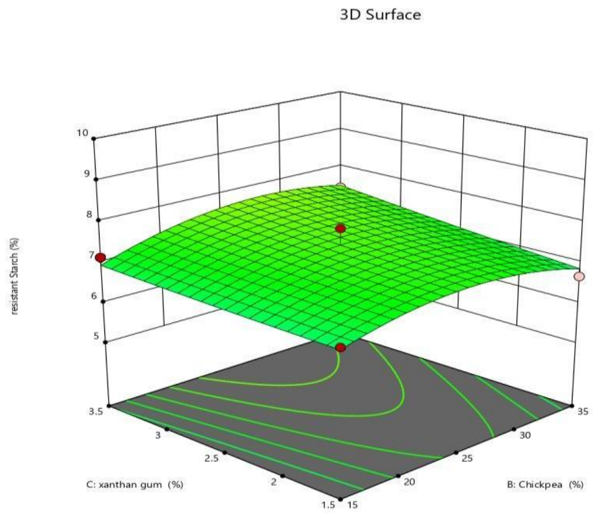
A: Buckwheat (%)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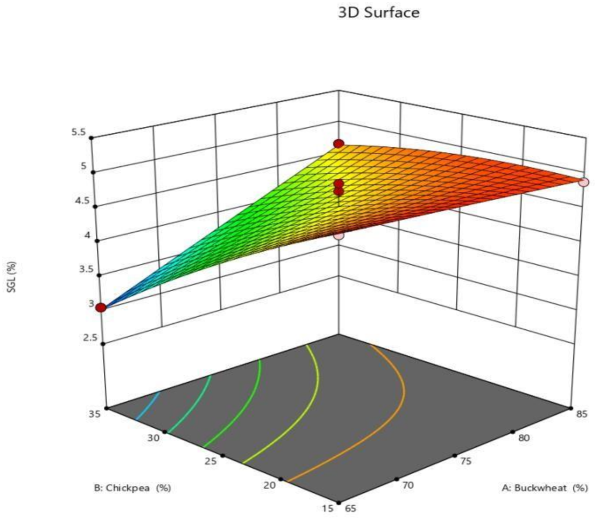
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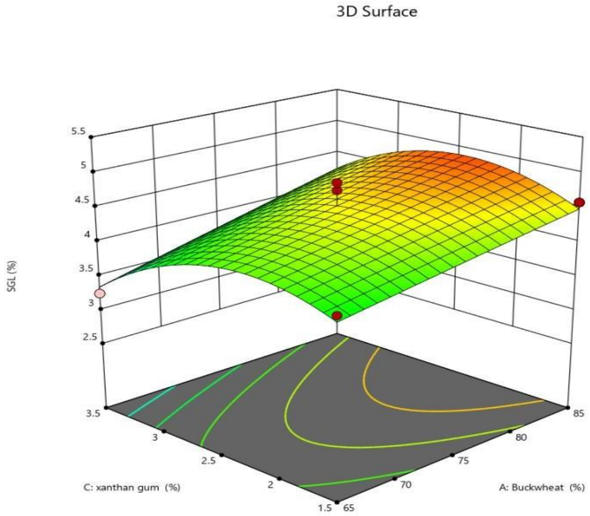
A: Buckwheat (%)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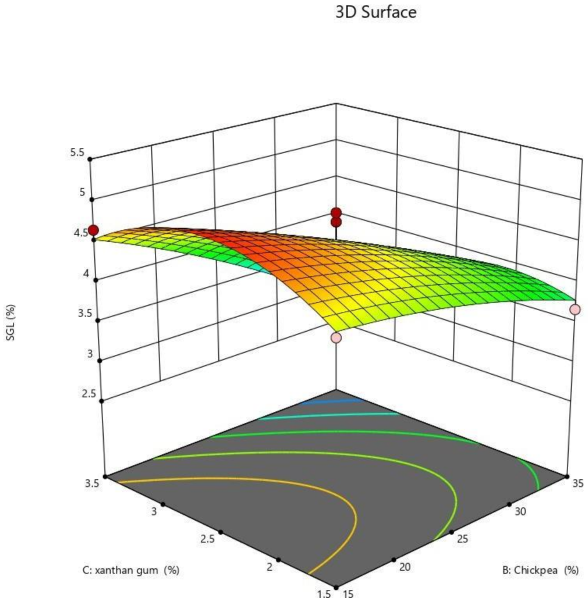
A: Buckwheat (%)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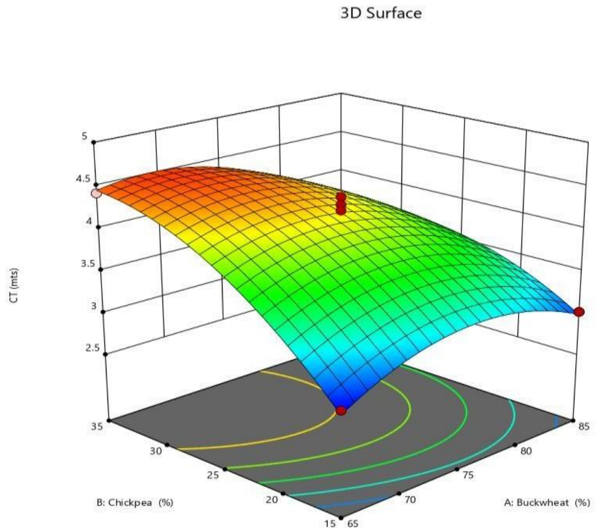
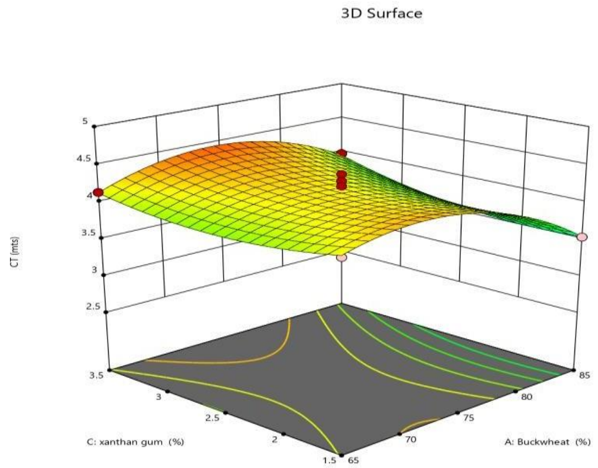
B: Chickpea (%)





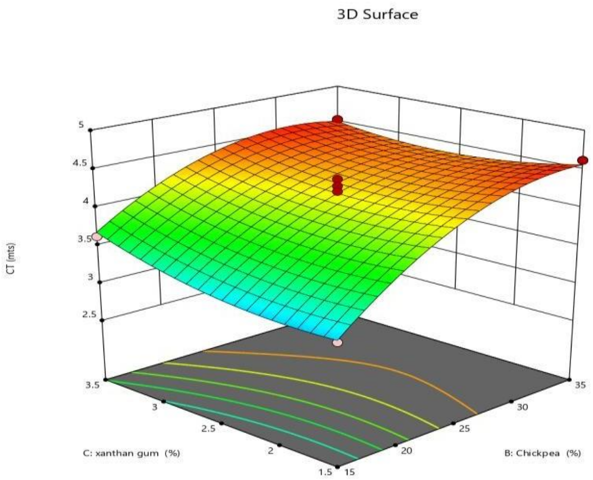


Figure (a-o, that is given above)Effect of independent variables on dependent variables (glycemic index,glycemic load, resistant starch, solid gruel loss and cooking time)

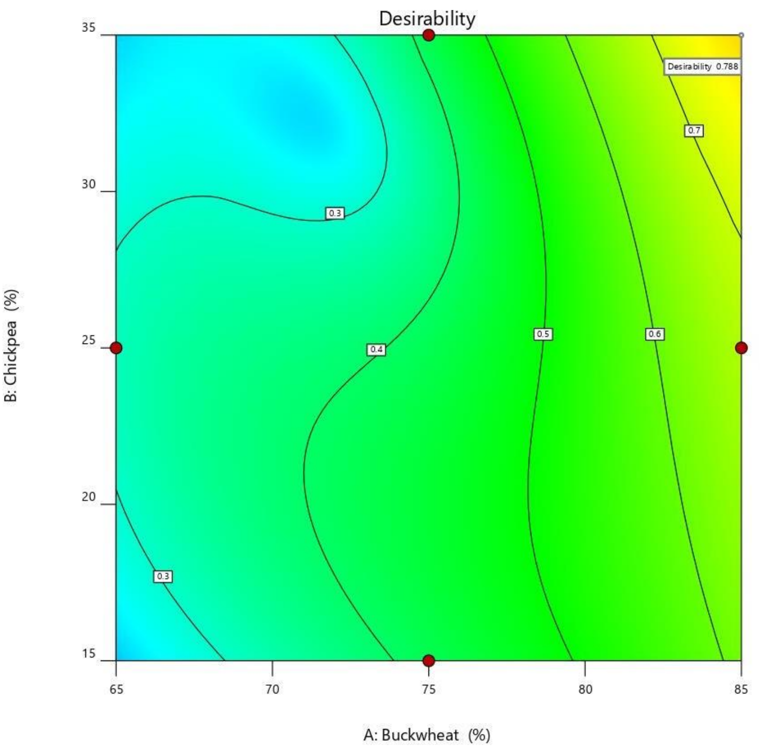
RSM Optimization and validation of process parameters

Optimization of process variables was carried out using Numerical Optimization tool of Design Expert 12.0 software. The optimization was based on simultaneous minimization of glycemic index, glycemic load, solid gruel loss, cooking time and maximization of resistant starch of the sample. The results indicate that the models developed for all the product responses were significant ($p<0.05$) with high coefficient of determination **(R^2=0.9503-0.9998).** The coefficient of determination computed were highly desirable for all the selected parameters which ensures the reasonable fit of empirical models with actual data. The predicted and adjusted R^2 values for all the product responses were found to be in sound range as observed in all the models, suggesting the adequacy of model discrimination in all the parameters. Models for all the parameters showed non-significant lack of fit thereby depicting that the second order polynomial models correlated well with the measured data.

Optimization and model validation

RSM Optimization and validation of process parameters

The optimization of process variables were carried out using numerical optimization tool of Design Expert 12.0 and was used to develop second order polynomial models for dependent variables to fit the experimental data for each response. The optimization was done on the basis of maximization of resistant starch and minimization of glycemic index, glycemic load, solid gruel loss and cooking time of the sample. The desirability value obtained was 0.78. The optimum conditions obtained for the development of low GI extrudates were- buckwheat flour (84.99%), chickpea flour (35%) and xanthan gum (3.50%).The predicted response values and the actual values obtained were almost in range with a variation of less than 4%.



Conclusion

In this study, low glycemic indexed pasta was developed using buckwheat and chickpea flours with addition of xanthan gum. Response Surface Methodology (RSM) was employed to optimize the pasta formulation. The results indicated that buckwheat positively influenced resistant starch content, gruel solid loss, and cooking time, while chickpea had a negative effect on glycemic index. The optimized formulation with 85% buckwheat flour, 35% chickpea flour, and 3.5% xanthan gum exhibited a lower glycemic index and higher resistant starch content, making it a potentially healthier option for individuals with diabetes or those seeking better dietary choices. However, sensory evaluation was not fully explored, and further research is recommended to assess consumer preferences. Overall, this study demonstrates the potential of utilizing buckwheat and chickpea flours in gluten-free pasta production to improve its nutritional profile, offering healthier options for a growing population with dietary restrictions and health-conscious consumers. The combination of these ingredients with xanthan gum as a binder shows promise for developing innovative and nutritious pasta formulations with broader applications in the food industry.

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