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Effect of hydrothermal treated corn flour addition on the quality of corn-field bean gluten-free pasta

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Abstract. Corn semolina supplemented by field bean semolina in ratio of 2/1 (w/w) were used for obtaining protein and fiber enriched gluten-free pasta. The effect of hydrothermal treatment of corn flour on its applicability as gluten-free pasta improver was tested. A central composite design involving water hydration level and the amount of hydrothermal treated corn flour were used. Instrumental analyses of pasta (cooking loss, water absorption capacity, hydration and pasting properties, textural parameters and microstructure) were carried out to assess the impact of experimental factors. Results showed that hydrothermal treatment of corn flour affected in different extent on pasta properties, improving cooking and textural characteristics of pasta. The optimum formulation of corn-field bean contained 7.41 g of treated corn flour and 77.26 mL of water was selected on the base of desirability function approach with value of 0.825 which showed the best pasta properties. Obtained results showed also that addition of treated flour induced significant differences ($p < 0.05$) in all parameters in comparison with control pasta.

1 Introduction

Pasta is a traditional cereal-based food product that is becoming increasingly popular worldwide because of its convenience, palatability, and nutritional quality. High quality cooked pasta from durum wheat semolina has pleasant taste and firm texture, low surface stickiness and does not release an excessive amount of organic matter into the cooking water [1]. This is clearly related to the fact that gluten is the main structure-forming protein and it is considered as a fundamental factor of wheat pasta quality during cooking [2]. However, wheat pasta is not suitable for people with celiac disease because their immune system generates antibodies against gluten, causing damage to the tiny hair-like projections in the small intestine [3]. It is known that the treatment of celiac disease is based on life-long excluding of gluten from the diet [4, 5].

Numerous studies have focused on improving the sensory and nutritional qualities of gluten-free products especially bakery and pasta products. This has been done by using other ingredients to solve the issue of the lack of nutrients in these products and to prevent deficiency diseases such as celiac disease. Moreover, supplementation of cereals based pasta with leguminous is envisaged in order to improve the nutritional value of formula. Field bean constitutes an interesting source of fiber and protein enabling to supplement protein intake from cereals and tubers for the better amino acids balance [6] and it could enhanced nutritional value of the final product [7, 8].

The replacement of gluten presents a major technological challenge leading to the search for alternatives to gluten in the manufacture of gluten-free (GF) pasta products [2]. Currently, there have been extensive researches for the development of GF dough with appropriate viscoelastic properties, involving diverse approaches. As regards pasta, several ingredients (modified starches, gluten-free flours, and additives) have been used as an alternative to gluten in order to create a starchy network that can withstand the physical stress of cooking and impart firmness to the cooked product [9, 10].

One of the usual methods to produce GF pasta is to obtain pre-gelatinized starch through heat and cool stages, thus forming a rigid network based on the retrograded starch [11, 12]. Pre-gelatinization can help to improve functional properties and give body and texture to the product. In the literature, it has also been reported that substances that swell in water could replace gluten in the dough [13]. The pre-gelatinized starch is composed of small gel particles, that when dissolved, yield solutions of high viscosity [14]. Many foods have include pre-gelatinized starch to provide stable texture at room and refrigeration temperatures, among these are instant puddings, gravy mixes, pie fillings and glazes [15].

The various reasons, like the low availability and diversity, the high costs of GF products and the needs of

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the celiac disease population, are considered to find appropriate products on the market. These reasons constitute our fundamental arguments to propose formula for GF laminated pasta.

The aim of this study was to evaluate the effect of hydrothermal treated corn flour addition as an improver in manufacturing of GF laminated pasta based on corn and supplemented with field bean. The evaluation was carried out using central composite design (CCD) and response surface methodology (RSM) to define the levels of water and treated corn flour needed to ensure improvement of various properties of GF pasta products. Moreover, optimum formula composition was selected on the base of desirability function approach (DFA) with best characteristics.

2 Materials and Methods

2.1 Raw materials

As Corn (*Zea mays* L) semolina (particle size below 500 µm) was provided by PZZ Lubella Sp. z o. o. Sp. K. (Lublin, Poland), containing g per 100 g of moisture - 14.5, ash - 0.1, fat 3.1, protein 6.5, fiber 2.2. Field bean semolina (*Vicia faba minor*) (particles smaller than 500 µm, composition in g per 100 g of moisture 10.15, ash - 2.37, fat - 1.29, protein - 31.2, fiber - 11.03) was obtained after grinding the dehulled bean seeds purchased from Alamir Company (Al Behera, Egypt).

2.2 Chemical composition analysis

The standard procedures of AACC methods [16] were used for analyzing fat, ash and protein content in the pasta samples making. Soxhlet extraction with n-hexane (AACC 30-10) was used for determining the fat content. The amount of ash was determined by incinerating in a muffle furnace at 550°C (AACC 08-01) and the Kjeldahl procedure (AACC 46-10) was used for determining the protein content in three replications. The procedure of AOAC [17] was used for determining fiber content with Scharrer-Kürschner method. Measurements were performed in double.

2.3 Hydrothermal treatment of corn flour

Hydrothermal treatment of corn flour (HTCF) was carried out according to Bourekoua et al. [18]. Corn flour (PZZ Lubella Sp. z o. o. Sp. K., Lublin, Poland) with particles smaller than 200-µm was used for produced treated flour. Flour was mixed with distilled water (21 ± 1°C) at the ratio 1/5 (w/w). The mixture was heated for 6-7 min with continuous stirring until the inner temperature reaches 65°C. Afterwards, the obtained paste was cooled at room temperature for 1 h, and then kept at 4°C for 24 h. Before being used as pasta ingredients, the treated corn flour was maintained at room temperature for 1 h.

2.4 Experimental Design

A CCD with 2 factors was employed to determine the effect of two variables: hydration level (X_1) and hydrothermal treated corn level (X_2) on cooking and textural properties of pasta followed by optimisation of the process using RSM. The CCD included two sections: factorial section was a 2^2 tests; the star section included four tests (2^2), and five replicated center-points were also added, for a total of $2^2+2^2+5=13$ runs (Table 1). For each response, model selection appeared to be quadratic. Responses of each variable were subjected to statistical analysis in order to define the optimal recipe using DFA. The DFA is a multi-criteria optimization method useful to find the best compromise between several responses. $D = d_i1\times d_i2 \times d_i3\ldots\ldots\times d_in)^{1/n}$, were d_i was the desirability indices for each response (if $d_i = 0$ least desirable; if $d_i = 1$ most desirable) and n was the number of response in the measure [1].

2.5 Pasta-making process

Corn-field bean semolina mixture (CFBS) in a ratio of 2/1 (w/w) cereal-leguminous was used in GF recipe, aim to offering a better nutritional balance in amino-acids [6]. Also, supplementation corn formula based with field bean in order to achieve technological approach for processing and given a good machinability of laminated dough. The hydration level was determined by preliminary experiments. The resulting ranges of water addition were 57.49 to 97.03 mL for 100 g of recipe. Treated corn flour was added in amounts ranging from 0 to 14.82 g for 100 g of recipe. Hydration and HTCF levels were expressed based on the CFBS blend. The basic pasta recipe consisted of 66.66 g of corn semolina, 33.33 g of field bean semolina, 2 g of salt and the amount of distilled water defined in the experimental design.

Pasta produced without addition of HTCF (run 1) was considered as control pasta (Table 1), add optimal pasta preparation.

Table 1. Factors, levels and code values used in the Central Composite Design (CCD) for gluten-free CFBS pasta.

Run	Hydration X_1 (mL)		HTCF X_2 (g)	
	Code	Value	Code	Value
1	0	77.26	-1.414	0
2	+1.414	97.03	0	7.41
3	+1	91.23	-1	2.17
4	0	77.26	0	7.41
5	0	77.26	0	7.41
6	+1	91.23	+1	12.64
7	0	77.26	0	7.41
8	0	77.26	+1.414	14.82
9	0	77.26	0	7.41
10	-1.414	57.49	0	7.41
11	-1	63.28	+1	12.64
12	-1	63.28	-1	12.17
13	0	77.26	0	7.41

The pasta-making process involved premixing of dry ingredients and then distilled water was added. When HTCF was added, the corresponding amount of corn semolina and distilled water were replaced. It must be kept in mind that slurries were contained corn flour and distilled water at the ratio of 1/5 (w/w).

In the first step, the mixture was mixed for 15 min at 25°C using a kitchen Aid model kPM5 (St. Joseph., Michigan, USA). The resulting dough was rounded, divided into balls of 50 g and covered with sealed plastic wrap and then subjected to rest at 25°C for 1 h. The dough was molded and passed through reduction rolls of a pasta machine Marcato Ampia type 150 (Campodarsego, Italy) and the roller gap was maintained at 1.5 mm for the last sheeting. Finally, pasta samples were dried in oven with air circulation at 40°C for 4 h, such that it reached final moisture content below 12% and were stored in sealed plastic bags at room temperature.

2.6 Cooking properties

The optimal cooking time (OCT) of GF pasta products was determined in triplicate according to the method described by Chillo et al. [19]: 10 g of pasta was cooked in 300 mL of boiling distilled water. The OCT corresponded to the disappearance of the white core inside pasta after being compressed between two Plexiglas plates.

Cooking losses (CL) were determined by entirely evaporating the combined cooking and rinsing water in an Erlenmeyer glass beaker in an air oven (SLW 53 STD POL-EKO-APARATURA, Wodzisław Śląski, Poland) at 105°C. The residue was weighed and reported as percentage of dry sample weight before cooking [20]. Water absorption capacity (WAC) was measured as the weight increase of pasta after cooking, and was expressed as percent weight gain with respect to the weight of uncooked pasta [1].

2.7 Hydration properties

The hydration properties of optimum pasta and control sample were determined at ambient temperature designating the water absorption index (WAI) and water solubility index (WSI). Ground pasta samples (0.7 g) were mixed in centrifugal tubes with 7 mL of distilled water. After 5 min of rest the samples were hydrated for 10 min and mixed every minute for uniform reconstitution, followed by centrifugation (15000 rpm, 10 min, 21°C) in a T24 Centrifuge (VEB MLW, Leipzig, Germany). The supernatant was dried to constant weight at 105°C. Tests were carried out in four replications. Calculations of WAI and WSI were made using the equations (1) and (2), respectively, according to Wójtowicz and Mościcki [20].

$$\mathrm{WAI}\ (\mathrm{g/g}) = \frac{\text{Wet sediment weight}}{\text{Dry sample weight}} \tag{1}$$

$$\mathrm{WSI}\ (\%) = \frac{\text{Dry supernatant weight}}{\text{Dry sample weight}} \times 100 \tag{2}$$

2.8. Pasting properties

Pasting properties of ground dry optimum and control pasta were performed according to Bouasla et al. [21] using a Brabender Micro-Visco-AmyloGraph (Brabender OHG, Duisburg, Germany) operated under constant conditions of measuring range (speed: 250 rpm; sensitivity: 235 cmg). The following time-temperature profile was used: heating from 30 up to 93°C, holding at 93°C for 5 min, cooling from 93 to 50°C, and holding at 50°C for 1 min. A heating/cooling rate of 7.5°C·min^{-1} was applied. The following indices were considered: Pasting temperature (PT) (°C), Initial viscosity (IV) (mPas), Peak viscosity (PV) (mPas), Final viscosity (FV) (mPas), Setback (Set) (mPas), and Breakdown (BD) (mPas). Measurements were performed in duplicate.

2.9 Texture measurements

Selected texture properties of GF pasta were evaluated. Texture measurements of pasta were performed on Zwick Roell BDO-FB0.5 TH (Zwick GmbH& Co., Ulm, Germany) equipped with Warner-Bratzler's knife (3 mm thick and 60 mm long, double face truncated at angle 45 °) for cutting tests of cooked optimal products and control pasta, and with OTMS Ottawa cell for firmness, stickiness and cohesiveness test of cooked pasta samples.

The hardness (H) of single cooked strand of optimal pasta samples and control pasta were measured in five replications as cutting force (N) as described by Wójtowicz and Mościcki [20]. Measurements were carried out using the 0.5 kN working head with a speed of 8.33 mm·s^{-1}. The values and curves of cutting forces were recorded and analyzed with *testXpert*® 10.11 software.

For firmness (F) (N), stickiness (S) (mJ) and cohesiveness (CH) (mJ) of cooked pasta products, 50 g of cooked and drained pasta was placed in the testing OTMS chamber, and double-compressed with a head speed 3.3 mm·s^{-1}. The software *testXpert*® 10.11 was used to record data during the tests as means of triple measurements [22].

2.10 Microstructure of dry pasta

Scanning electron microscope (SEM) pictures of optimal dry pasta as well as control pasta were taken for microstructure analysis. The surface and the cross-sections of dry samples were observed [23]. Samples of dry pasta products were cut into 5 mm pieces for surface samples and specimens of 2-3 mm in length for cross-sections were applied on carbon discs using a silver tape and sprayed with gold in a vacuum sublimator k-550X (Emitec, RC, England). The microstructure of samples was observed by a VEGA LMU microscope (Tescan, USA) at the accelerating voltage of 30 kV. Pictures were taken with magnifications × 200, × 600 for surface and × 200, × 600, × 1500 for cross-sections.

2.11 Statistical analysis

Multiple regression analysis was performed to fit second order model to dependent variables by using JMP software version 7 (SAS, USA). The models were used to determine responses surfaces in Statistica software version 10 (StatSoft. Inc., USA).

One way analysis of variance (ANOVA) was applied to compare the effect of water (X_1) and treated corn flour (X_2) on the dependent variables (Y). A coefficient of determination (R^2) was computed and the adequacy of models was tested by lack-of-fit. The model proposed for each response was:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1X_1 + b_{22}X_2X_2 + b_{12}X_1X_2 \quad (3)$$

where: b_0 is the value of the fitted response at the center point of design, that is point (0,0); b_1 and b_2 are the linear regression terms; $b_{11,}$ $b_{22}$are the quadratic regression terms; and b_{12} is the cross-product regression term (interaction coefficients).

Optimization was performed with JMP software version 7 to find the best formula of GF corn-field bean pasta with DFA method. For comparison of measured parameters (cooking, textural parameters, hydration index and pasting properties) between optimized recipe and control pasta results were analyzed with ANOVA test at $p \leq 0.05$ level of significance followed by the Fisher's LSD using Statistica 10 software.

3 Results and discussion

3.1 Chemical composition

The results of chemical composition of pasta samples presented in Table 2 showed that the supplementation of corn semolina with field bean semolina increased significantly ($p < 0.05$) the amount of protein and fiber level. The enrichment of formula studied based on corn semolina with legume causes an increase of 220% of protein content and 231% of fiber level. This crop could be used as good ingredients for enrichment recipe because of its great nutritional value benefit in the human diet.

In addition, celiac consumers have low intake of dietary fiber [21], so proposed formula could be beneficial as highly valuable with increased fiber content. Field bean provide an important amount of protein with good amino acids balance and supplementation of cereals with legumes could enhanced nutritional value of the final product [7, 8, 24].

Table 2. Proximate composition of gluten free pasta samples (g per 100 g^{-1} db).

Component	Corn pasta	Corn-field bean pasta
Protein	6.55 ± 0.11^b	14.47 ± 0.06^a
Fat	3.15 ± 0.06^a	0.82 ± 0.02^b
Ash	0.16 ± 0.03^b	2.44 ± 0.09^a
Fiber	2.21 ± 0.01^b	5.12 ± 0.12^a

$^{a-b}$ Means with the same superscript within row are not significantly different ($p > 0.05$).

3.2 Improving effect of hydrothermal treated corn flour on laminated GF pasta quality

3.2.1 Model fitting

The analysis of variance induced by the hydration level and the amount of treated corn flour on the quality parameters of corn-field bean semolina pasta is shown in the Table 3. The statistical analysis indicated that the fitting models were adequate because they gave satisfactory values of the R^2 and the lack-of-fit test was not significant for all responses indicating a significance and adequacy of the models.

Table 3. Regression coefficients for the predictive models for cooking loss, water absorption capacity, firmness and stickiness.

Model term	CL (%)	WAC (%)	F (N)	S (mJ)
X_1	+0.523	+0.979	-0.016*	+0.023*
X_2	+0.580	+0.012*	+0.396	-0.037*
X_1X_1	+0.025*	-0.135	+0.000*	+0.556
X_2X_2	+0.014*	-0.000*	+0.301	+0.001*
X_1X_2	+0.341	-0.001*	+0.984	-0.870
Lack of fit	ND	ND	ND	ND
F	3.66^{NS}	17.54^{NS}	12.88^{NS}	8.37^{NS}
R^2	0.72	0.93	0.90	0.86

CL: cooking loss, WAC: water absorption capacity, F: firmness, S: stickiness, X_1: water, X_2: HTCF, X_1X_1, X_2X_2: quadratic coefficients, X_1X_2: interaction between coefficients, *F*: variance Ficher- Snedecor, R^2: coefficient of determination, NS: not significant ($p > 0.05$),* significant at $p \leq 0.05$.

3.2.2 GF pasta quality characteristics

The effect of different levels of water and treated corn flour on cooking loss (CL) and water absorption capacity (WAC) of pasta is shown respectively on the Fig. 1 and Fig. 2. The CL of pasta samples varied from 11.00 to 16.06% (Fig. 1). CL decreased with increasing addition of HTCF up to an incorporation level of 8%, which increased with the maximum incorporation as its quadratic effect was positive ($p < 0.05$, Table 3). In addition, CL decreased with increasing level of water and the data in Table 3 showed the presence of positive quadratic effect of water on the value of CL. Heat-treatment of corn flour seems to led to the creation of less soluble components, responsible for the low CL.

In addition, starch is often considered as the main structural network in GF pasta due to its functional properties [25]. The formation of a strong network of retrograded starch around the gelatinized starch triggers less leaching of starchy components from the surface of GF pasta, therefore, less cooking loss [26].

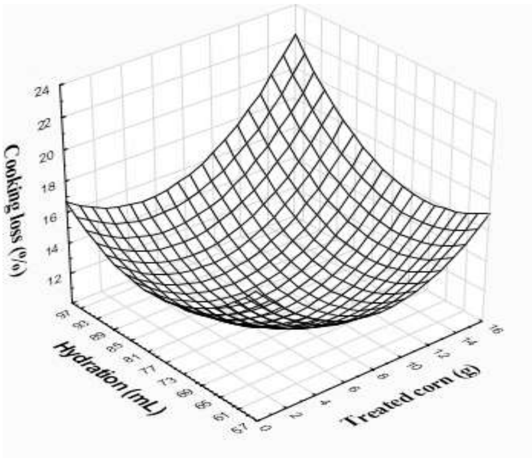

Fig. 1. Response surface of CL of gluten-free CFBS pasta depend on hydration level and HTCF amount.

The water absorption capacity (WAC) of pasta from all 13 runs ranged from 160.10 to 237.00% (Fig. 2). WAC increased with increasing addition of HTCF up to an incorporation level of 14% as its positive linear effect and decreased with maximum incorporation as its negative quadratic effect ($p < 0.05$, Table 3). Moreover, the chart (Fig. 2) showed a negative interaction effect between two variables (water and HTCF) ($p < 0.05$, Table 3).

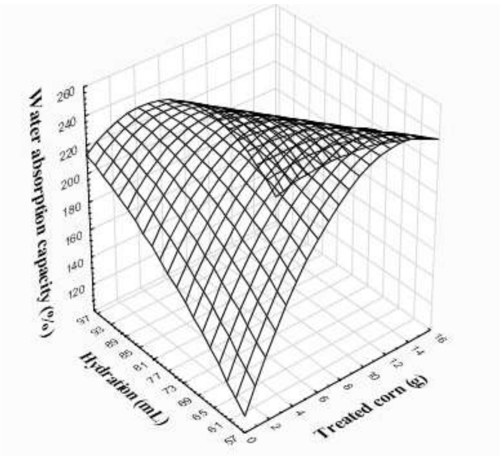

Fig. 2. Response surface of WAC of gluten-free CFBS pasta depend on hydration level and HTCF amount.

WAC is an important measured index, which depends on the amount of damaged starch and the weakness of its granules [21]. This behavior suggests that conditions of hydrothermal treatment of corn flour seemed led to the formation of more hydrophilic structure causing higher water absorption. Moreover, low WAC indicates poor quality of cooked pasta due to the chewy texture [27]. Many authors confirmed the dependence of GF pasta cooking properties with water amount and indicated also its dependence on the type of raw material [3].

Regarding texture, response surface for all 13 runs showed that the firmness ranged from 352.90 to 516.00 N (Fig. 3).

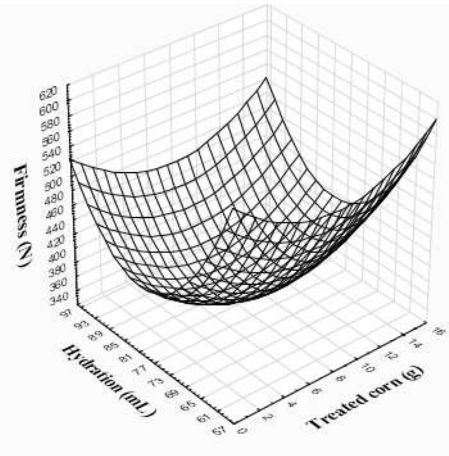

Fig. 3. Response surface of F of gluten-free CFBS pasta depend on hydration level and HTCF amount.

The graph showed that the firmness of samples decreased slightly with the addition of HTCF up to an incorporation level of 6%, which increased with the maximum incorporation. The chart (Fig. 3) showed that the firmness decreased with increasing level of water in the recipe up to 82 mL as its linear effect was negative which increased with the maximum hydration as its quadratic effect was positive ($p < 0.05$, Table 3). Response surface obtained for the stickiness measurement showed that this parameter ranged from 22.14 to 47.5 mJ (Fig. 4). Stickiness was much higher if higher amount of water was used during pasta preparation as its linear effect was positive ($p < 0.05$, Table 3). Moreover, increasing amount of treated corn flour affected higher pasta stickiness. the chart (Fig. 4) showed that the stickiness decreased with increasing level of up HTCF up to an incorporation level of 8% as its linear effect was negative which increased with the maximum addition as its quadratic effect was positive ($p < 0.05$, Table 3).

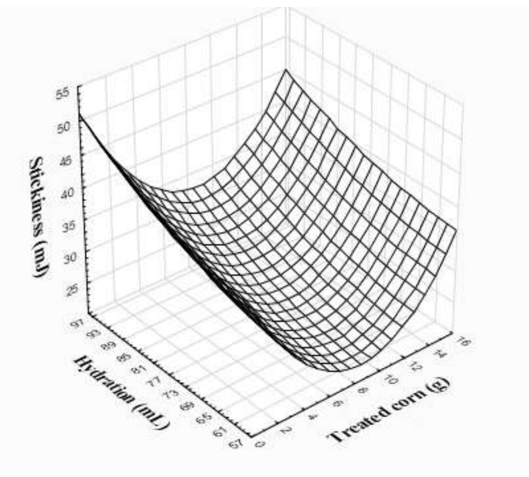

Fig. 4. Response surface of S of gluten-free CFBS pasta depend on hydration level and HTCF amount.

Generally, the addition of treated corn may improve the textural quality of GF pasta particularly in term of stickiness, because the partial gelatinization of starch increases the dough consistency. Heat treatment of corn flour seem to favor the formation of a strengthened starchy network, involving the majority of starch macromolecules (as exhibited by its low cooking loss) with a positive effect on the texture of cooked pasta in terms of its high firmness and low stickiness. These modifications of starch organization are responsible for decreasing stickiness and increasing hardness of pasta. In addition, Raina et al. [28] reported that the textural quality of both uncooked and cooked rice pasta improved significantly when treated rice flour was used. Moreover, the intensity of flour pre-gelatinization plays a very important role in imparting a desirable pasta texture [2]. Also, a similar behavior was found by Hormdok et al. [29] when used rice from different treatment (annealing and treatment at low moisture and high temperature) in order to improve of rice noodles quality. These particular hydrothermal treatment suppress granule swelling, retard gelatinization, and increase starch paste stability [29, 30], thus improving cooking behavior and texture properties of rice noodles [2].

3.3 Characteristics of optimum GF pasta

3.3.1 Cooking and textural quality

The selection of improver content and water level were obtained by applying the DFA to obtain optimum recipe with low CL and stickiness, higher WAC and firmness (Table 4).

Table 4. Criteria used to obtain the desirability functions, predicted responses.

Parameter	Objective	Predicted response	Experimental response
CL (%)	minimum	11.05^a	11.03^a
WAC (%)	maximum	236.47^a	236.42^a
F (N)	maximum	353^a	353.03^a
S (mJ)	minimum	16.10^a	26.12^a

CL: cooking loss, WAC: water absorption capacity,
F: firmness, S: stickiness,
^{a}Experimental responses with the same superscript than predictive response indicate there are not significant differences ($p > 0.05$).

The optimal amounts of 100 g of CFBS were 7.41 g of treated corn and 77.26 mL of water with a desirability value of 0.825. These levels of improver and water resulted in GF pasta with good quality characteristics compared to the pasta without improver. The cooking behavior, textural properties (cutting force, firmness, stickiness and cohesiveness) of optimum and control GF pasta are shown in the Table 5.

The optimum pasta had significantly lower CL (11.03%) than control pasta (16.12%). As regard WAC, optimum recipe showed higher values (236.46%) than control pasta (160.17%). In addition, optimum sample presented the higher and better values of hardness of cooked pasta (1.43 N), firmness (353.03 N) and cohesiveness (24.13 mJ) with lower stickiness (26.12 mJ) than the control pasta (0.51 N, 324.07 N, 15.59 mJ, 47.74 mJ, respectively).

Table 5. Characteristics of optimal and control gluten-free CFBS.

Parameters	Optimum pasta	Control pasta
Cooking quality		
CL (%)	11.03 ± 0.03^a	16.12 ± 0.12^b
WAC (%)	236.46 ± 0.16^a	160.17 ± 0.19^b
Textural parameters		
H (N)	1.43 ± 0.03^a	0.51 ± 0.03^b
F (N)	353.03 ± 0.07^a	324.07 ± 1.63^b
S (mJ)	26.12 ± 0.05^a	47.74 ± 0.22^b
Ch (mJ)	24.13 ± 0.07^a	15.59 ± 0.08^b
Pasting properties		
PT (°C)	76.73 ± 0.20^a	73.33 ± 0.49^b
IV (mPas)	17.33 ± 0.57^a	13.58 ± 0.52^b
PV (mPas)	175.33 ± 3.51^a	261.33 ± 3.21^b
FV (mPas)	305 ± 6.80^a	461 ± 2.64^b
BD (mPas)	19.66 ± 2.51^a	234.33 ± 3.05^b
Set (mPas)	149.66 ± 2.51^a	34.33 ± 2.08^b
Hydration properties		
WAI ($g \cdot g^{-1}$)	2.66 ± 0.07^a	1.15 ± 0.11^b
WSI (%)	9.2 ± 0.04^a	13.13 ± 0.04^b

$^{a-b}$ Means with the same superscript within row are not significantly different ($p > 0.05$).

Hydrothermal treatment of corn flour which has partially gelatinized starch improved the quality of the corn-field bean pasta, in terms of cooking loss and water absorption. The treated corn flour may have act as a binder, re-polymerizing into a network around the starch granules because of the different gelatinization temperatures, thereby increasing their tolerance to cooking stress, as suggested by Pagani [31] and Marti et al. [2]. Moreover, the best cooking and textural properties in optimum formula might be related to the pasting properties derived from pre-gelatinized corn flour. Hydrothermal treatment of corn flour might stimulate the variation in the physical and chemical properties of starch. These modifications of starch organization are responsible for stronger structure than control pasta resulting reduced stickiness and cooking loss and improved pasta texture.

3.3.2 Hydration properties

The results of hydration properties of pasta sample are presented in Table 5 and showed significances differences in WAI and WSI between optimum and control pasta ($p < 0.05$). The significant increase of WAI in optimum sample as compared to control results probably from greater possibility of exposed hydrophilic groups to create bonds with water molecules while gel formation. Moreover, the reduction in WSI was observed compare to the control sample without HTCF.

Hydrothermal treatment applied in our work probably leads to re-organization of the starch granules, what entails other specific interactions between the starch molecules [32] such as formation of more ordered double helical amylopectin side-chain clusters and amylose–lipid complexes located within the granules. The similar phenomenon of decrease of solubility index was reported in other studies [33, 34].

3.3.3 Pasting properties

The pasting properties of both optimum and control recipe were investigated by the measurements of viscoamylograph test. The results of pasting parameters presented in Table 5 showed some significances differences in pasting properties of optimized formula (PT, IV, PV, FV, BD and Set) in comparison with the control pasta without HTCF ($p < 0.05$). These differences can be due to the modification and changes of rigidity of starch granules after treatment. The Brabender viscograms showed increasing the IV of HTCF (17.33 mPas) as confirmation of partial gelatinization of starch under hydrothermal treatment comparing to control pasta (13.58 mPas). The high IV for HTCF was attributed to the modification in the molecular organization of the starch during treatment, which resulted in loss of granule integrity and breaking the order of crystallinity of the starch [32, 33]. Hydrothermal treatment of corn flour exhibited a significant lowering of PV in optimum recipe (175.33 mPas) comparing to control pasta (261.33 mPas). The decrease in PV might be relating with the limited swelling capacity and had an effect on increasing PT (76.73°C) in comparison with control formula with HTCF (73.33°C). This corresponds with the increased temperature needed to gelatinize undamaged starch granules, as found by Hormdok and Noomhorm [29]. Observations of the increase in pasting temperature, decrease in PV, FV and BD, might be elucidated by alterations of pasting properties in treated flour possibly due to production of the bonds between the chains in the amorphous regions of starch granules as well as modification of crystallinity during a hydrothermal treatment, as reported previously by other authors [34, 35]. Moreover, reduction in BD after heat treatment indicates higher stability of starch subjected to continuous heating, as reported by Adebowale et al. [36].

3.3.4 Microstructure of dry pasta

Surface of traditional laminated GF pasta is presented on the Fig. 5. Structure of pasta fabricated from CFBS recipe without improver (Fig. 5A) was compact with small amount of empty spaces but lack of continuity due to the absence of gluten and starch granules were not well agglomerated and separate starch granules were visible on pasta surface, especially at high magnification (Fig. 5B).

Some structures of proteins matrix can be observed around starch granules which affects low amount of components leaching from the surface during cooking. More compacted and uniform structure was observed on the surface of pasta laminated from optimum recipe with addition of treated corn flour (Fig. 5C). Agglomerates of starch and proteins are surrounded by pre-gelatinized starch which forms continuous phase responsible for better results of CL and lower amount of starchy components passing into cooking water. Pre-gelatinized corn flour forms aggregates linked all pasta components what is clearly visible at high magnification (Fig. 5D).

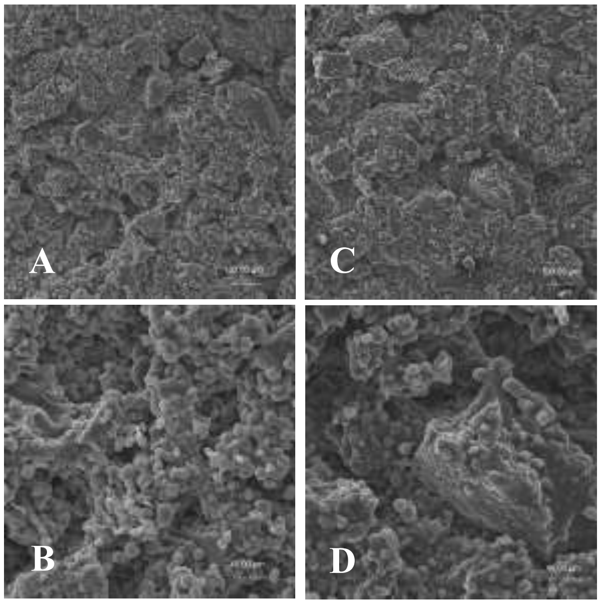

Fig. 5. SEM surface of laminated pasta from control and optimized recipe with different magnifications; control pasta: A x 200, B x 600, optimum pasta: C x 200, D x 600.

Analyzing cross-sectional microstructure of pasta presented on the Fig. 6, it could be concluded similar observations.

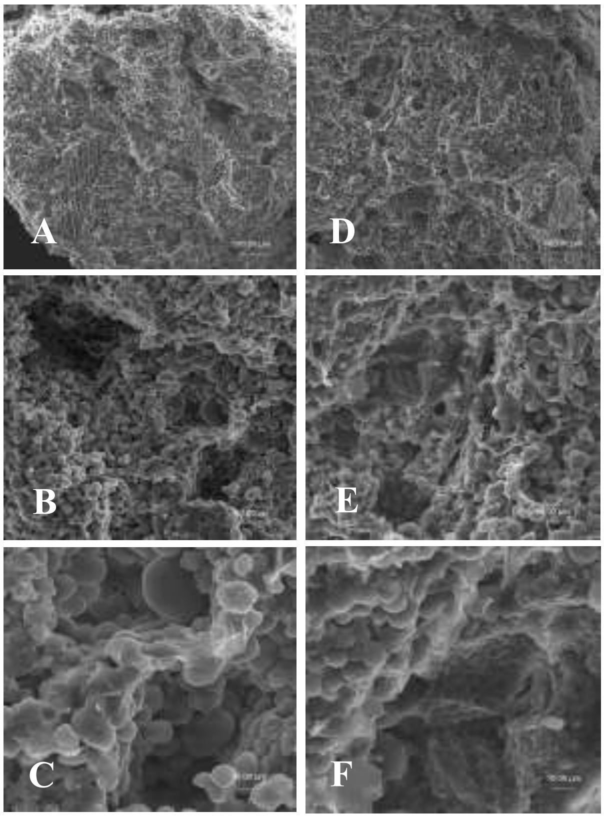

Fig. 6. Cross-section with various magnifications of control CFBS pasta (A x 200, B x 600, C x 1500) and optimum pasta with the addition of HTCF (D x 200, E x 600, F x 1500) observed with SEM.

Fig. 6 B shows the loose and discontinuous internal structure of CFBS pasta with small amount of swollen starch granules with visible higher dimensions and only few places are linked by protein fibrous fraction comes from field bean flour (Fig. 6C).

More compact and homogenous structure can be observed if pre-gelatinized corn flour was used as pasta improver (Fig. 6D). Comparing the size and amount of visible starch granules pasta with addition of treated corn flour shows lower amount of free starch and more uniform distribution of pasta components inside the pasta tread. Starch granules are surrounded by continuous phase of gelatinized starch and packed tightly next to each other, which limits leaching of unbounded components during cooking and guarantee better firmness of improved pasta (Fig. 6E and 6F).

4 Conclusion

A recipe based on corn-field bean semolina was used with hydrothermal treated corn flour added as pasta improver. Enrichment of formula with field bean semolina provide an important amount of dietary fiber and protein with good amino acids balance and could improved nutritional value of the final product. An experimental design, used to optimize the level of water addition and the amount of improver, revealed the impact of those factors on the quality characteristics of GF pasta and allowed determining the optimal levels for improving the cooking quality and textural parameters. The optimal GF corn-field bean pasta was produced by incorporating 7.41 g of treated corn flour and 77.26 mL of water (based on 100 g of semolina blends). According to the results of cooking and texture parameters, pasting and hydrations properties and microstructure observations, it can be concluded that optimized corn-field bean pasta was obtained using hydrothermal treated corn as pasta improver, leading to produce GF laminated pasta for celiac consumers.

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