ISSN
2217-5369
(print version ceased in 2023)
2217-5660 (online)

www.foodandfeed.fins.uns.ac.rs
FOOD AND FEED RESEARCH
Journal of the Institute of Food Technology – FINS
University of Novi Sad

FINS

UDK 664.69:633.17]:66.022.392

DOI: 10.5973/ffr0-47055

Original research paper

DEVELOPMENT AND SENSORY PROPERTIES OF EXTRUDED SORGHUM-BASED GLUTEN-FREE PASTA

Blessing Gwekwe[1], Loveness K. Nyanga[1], Tonderayi M. Matsungo[1], Cathrine Chidewe[2], Stanley Mukanganyama[2], Elijah Nyakudya[3], Florence Mtambanengwe[3], Paul Mapfumo[3], Prosper Chopera[*1]

[1]University of Zimbabwe, Faculty of Science, Department of Nutrition Dietetics and Food Sciences, Harare, 630 Churchill Avenue, Mt Pleasant, Zimbabwe
[2]University of Zimbabwe, Faculty of Science, Department of Biotechnology and Biochemistry, Harare, 630 Churchill Avenue, Mt Pleasant, Zimbabwe
[3]University of Zimbabwe, Faculty of Agriculture Environment and Food Systems, Harare, 630 Churchill Avenue, Mt Pleasant, Zimbabwe

Abstract: Pasta is one of the most consumed staples worldwide. New formulations incorporating novel nutritious ingredients are now common in its production. The purpose of this study was to formulate, optimise and evaluate the sensory properties of sorghum-based extruded gluten-free pasta. Sorghum flour, pearl millet flour, high-iron bean flour (Biofortified NUA 45 beans) and Hermes potato flour were evaluated for proximate and micronutrient composition, formulated to produce pasta through the extrusion process. Three sorghum-based pastas, namely sorghum high bean pasta (SHBP), sorghum bean pasta (SBP) and sorghum high potato pasta (SHPP) were produced and evaluated for sensorial properties (visual, palpatory and gustatory qualities). The Box-Benhken Design (BBD) in conjunction with Response Surface Methodology (RSM) was used to select the best formulation by evaluating cooking quality parameters and sensory parameters. The protein content in the four flours ranged from 10.52% to 22.00%. NUA 45 bean flour had significantly ($p<0.05$) higher protein content than the other flours. Potato flour had significantly higher carbohydrate content (73.82%) than other flours. SHPP had a significantly ($p<0.001$) higher optimum cooking time (7 minutes) than SHBP (5 minutes) and SBP (6.2 minutes). SHPP had significantly ($p<0.001$) higher water absorption (WA) capacity (238%) than pasta SHBP (190%) and SBP (210%). A significant ($p<0.001$) difference in the swelling index (SI) of the three pasta samples was observed, with pasta SHBP having a significantly lower SI (1.02%) than pasta SBP (1.15%) and pasta SHPP (1.24%). The cooking loss (CL) for pasta SHPP (11%) was significantly higher ($P<0.001$) than for pastas SHBP and SBP, with pasta SHBP having the lowest CL. There was no significant ($p>0.05$) difference in the cross-sectional area, surface appearance and surface property of the three cooked pastas. A significant ($p<0.05$) difference in shape between SHBP and SBP samples was noted. The gluten-free pasta was developed and produced successfully. Sorghum high bean pasta treatment (SHBP) was found to be superior in terms of sensory, nutritional and physical properties as compared to the other pasta samples, making it good for commercialisation.

Key words: *gluten-free pasta*, *sorghum, extrusion, organoleptic properties, cooking properties*

Corresponding author: Phone: ++263773222710
E-mail address: pchopera@gmail.com

INTRODUCTION

Recently pasta formulations, including non-wheat ingredients like sweet potato flour and tapioca starch, have been reported and their dough is made into different shapes and sizes, then dried and stored (Anyobodeh, Spio-Kwofie&Anaman, 2016). It is reported that about 14.3 million tonnes of pasta are produced annually worldwide. Pasta is traditionally made from wheat flour. Sorghum flour with similar attributes as wheat flour and some peculiar desirable sensory and nutritional properties can also be used for pasta production as a substitute for wheat. It is common practice to use pasta as a carrier of health-promoting compounds since its nutritional properties can be improved by adding several types of proteins, fibres and plant phytochemicals (Palavecino, Curti, Bustos, Penci&Ribotta, 2020).

Globally, sorghum is one of the most important but least utilized staple crops. Its ability to grow in arid conditions and resistance to diseases qualifies it as an important crop for global food security (Girard &Awika, 2018). Sorghum is a leading cereal ranked fifth in production among cereals, following maize, wheat, rice, and barley, with 57.6 million tons of annual production globally in 2017 (Xiong, Zhang, Warner & Fang, 2019). Sorghum grain is a rich source of nutrients and health-beneficial phenolic compounds. The phenolic profile of sorghum is exceptionally unique and more abundant (Xiong et al., 2019) and diverse than other common cereal grains. Moreover, the phenolic compounds, 3-deo-xyanthocyanidins, and condensed tannins can be isolated and used as promising natural multifunctional additives in broad food applications. More in-depth exploration of functional foods in pasta has been explored and reported by Sycheva, Skorbina, Trubina, Omarov and Sarbatova (2019).

Sorghum contains proteins that are unable to form the composite viscoelastic doughs required for bread-making and pasta production. The protein digestibility and lack of protein functionality limit the application of sorghum in food. It is, therefore, essential to identify processes to improve the digestibility and functionality of sorghum protein to enable its uptake in food applications, especially in the gluten - free food product range (McCann, Krause &Sanguansri, 2014).

Cereal-based gluten-free (GF) products are not only exclusively consumed by individuals suffering from medically diagnosed celiac disease but by a growing number of consumers who spontaneously reduce and/or avoid gluten from their eating habits (Cervini, Gruppi, Bassani, Spigno&Giuberti, 2021). The disorders related to gluten namely, celiac disease, wheat allergy, and non-celiac gluten sensitivity are becoming an epidemiological phenomenon with a global prevalence of about 5% (Jalgaonkar, Jha, Nain &Iquebal, 2017). The sorghum-based product range varies from 100% sorghum to blends with wheat flour in different proportions. Gluten-free food items are rapidly capturing the market, and sorghum is one of the main alternatives for wheat flour (Thilakarathna, Madhusankha&Navaratne, 2022*)*. Nearly 59% of the gluten-free market is occupied by North America (Thilakarathna et al. 2022), and the concept is becoming popular in Europe and Australia. The global gluten-free food market in 2006 was $700 million, and it was estimated to increase by 700% when it came to 2020 (de Oliveira, de Oliveira, de Alencar, Queiroz & de Alencar Figueiredo, 2022). The current gluten-free market is dominated by bakery items and related products such as bread, cakes, biscuits, noodles, cereal bars, and pastries, as many researches on improving the sensory attributes of sorghum-based products are ongoing (Cayres, Ramirez Ascheri, Couto, Almeida &Melo, 2020). In a 100 g amount, raw sorghum provides 329 calories of energy, 72% carbo-hydrates, 4% fat and 11% protein (Adeyeye, 2016). Among cereals without gluten, sorghum represents a staple food for more than half a billion people in at least thirty countries (Padalino, Conte & Del Nobile, 2016).

The extrusion process has been reported for numerous applications, including infant food, pasta, instant noodles, texturized vegetable protein, ready-to-eat cereals, snack products, pet food, precooked flour, meat products, etc. (Raleng, Singh, Singh &Attkan, 2016). The process simply involves the transformation of a plasticized biopolymer-based formulation into a uniformly processed viscoelastic mass that is conditioned for forming or shaping products through a die. The process of extrusion can be divided into two categories. First, non-cooking forming extrusion, where the pressure produced by the screw squeezes the material through a die. Second, cooking extrusion which, as the name implies, involves the raw ingredients being cooked by the combined action of heat, mechanical shearing and pressure in the presence of moisture (Fabbri et al., 2007). The processing conditions are critical for ensuring the appropriate texture and cooking behaviour of pasta products (Minarovičová et al., 2018)

The technology for making noodles and pasta from sorghum makes the product cheaper and healthier, as sorghum products are known for high B vitamin and dietary fibre content (Jood, Khetarpaul& Goyal, 2012). Snacks which are nutritionally rich and of a high commercial value are among some of the new extruded sorghum products. The extrusion properties of sorghum are excellent and equal to maize and rice (Adiamo, Fawale&Olawoye, 2018). Response Surface Methodology (RSM) uses quantitative data from appropriate experimental designs to determine and simultaneously solve multivariate equations that can be graphically represented as response surfaces (Anitha, Esther Magdalene Sharon, Marx Nirmal&Mathanghi, 2023). Therefore, this study was designed to develop novel gluten-free extruded pasta using sorghum flour as a substitute for wheat and to evaluate its organoleptic properties.

MATERIALS AND METHODS

Sorghum and pearl millet were bought from farmers in Buhera, Manicaland, Zimbabwe (19° 20' 0" South, 31 26' 0” East). The two grains were cleaned and sorted to remove all foreign materials. The grains were naturally fermented for 48 hours under room temperature and pressure in the presence of sodium benzoate to avoid fungal growth. The grains were then dried in a food drier model SM12, Qingdao, China for 8 hours at 45 ºC. Flours from the fermented grains were produced after decortication and milling by a stone miller from Ruzha Brands, Harare, Zimbabwe. NUA 45 bean flour was produced by milling the dry beans into flour. Fresh potatoes were bought from a supermarket Bon Mache, Belgravia shops in Harare. The potatoes were cleaned by running tap water and were peeled and grated into small pieces. The grated potato pieces were soaked in 0.5% citric acid solution for two minutes to prevent oxidation and sun-dried and then milled into potato flour following the protocol by Ndungutse, Ngoda, Vasanthakaalam, Shakala and Faraj (2019) with slight modifications. All flours were sieved through a 300 µm sieve to obtain homogenous flour properties.

Proximate analysis of sorghum, pearl millet, bean and potato flours

A proximate analysis of white sorghum flour, pearl millet flour, bean flour and potato flour was performed according to standard methods of Winger, Khouryieh, Aramouni and Herald (2014). Protein determination was done using the Kjeldahl method (Winger et al., 2014). Fat determination was done using the Soxhlet method (Winger et al., 2014). Ash determination was done using the muffle furnace method (Winger et al., 2014). Moisture determination was done using the oven method (Winger et al., 2014). The carbohydrate content was calculated using the difference method. Minerals were extracted from the ashed samples. About 2.0 g of the sample was acid-digested with a diacid mixture (HNO3:HClO4, 5:1, v/v) in a digestion chamber. The digested samples were dissolved in double-distilled water and filtered (Whatman No. 42). The filtrate was made to 50 mL with double-distilled water and was used for the determination of total calcium and phosphorus. Calcium was determined by a titration method. Phosphorus was determined spectrophotometrically by using the molybdo-vanadate method.

Experimental design

A Box-Behnken Design (BBD) (Table 1) was used for studying the ingredient behaviour in a very precise way over a relatively small region (Palavecino et al., 2017) with the maximum factor levels (ingredients) being established in preliminary experiments to guarantee easy dough handling. The ingredient (C) hydrocolloid (guar gum) content limits were established by *Codex Alimentarius* regulation (Mortensen et al., 2017). The variables in the experiment were hydrocolloid content, bean flour content and potato flour content. The constants in the experiments were sorghum/pearl millet flour – 300 g each, 6 whole eggs, 270 ml of water and 20 ml of olive oil. The Box-Benhken Design (BBD) under Response Surface Methodology (RSM) with 17 runs was used to select the best formulation by considering cooking quality parameters and organoleptic parameters. A conclusion was reached after analysing the results from the 17 runs that were performed. Three pasta samples namely, sorghum high bean pasta (SHBP), sorghum bean pasta (SBP) and sorghum high potato pasta (SHPP) were developed and produced in triplicates. The samples collected from the three treatments were analysed for physicochemical, sensorial and nutritional properties.

Pasta preparation

The pasta treatments were prepared using a domestic extruder pasta machine (Mini macaroni spaghetti-making machine model 80, Qingdao, China). Firstly, dry ingredients (300 g) of each flour, an adequate volume of water for each treatment (about 270 mL, based on dough consistency, since in pasta making water component is always around 30%, and 30% of 900 (3 flours) is equal to 270mL) were mixed for 3 min in the representative bowls. The obtained dough was forced to pass through the extruder cavity fixed with a spaghetti die of 2 mm diameter. The extrusion step was performed three times to improve the quality and homogeneity, according to (Suhendro et al., 2000). The operational temperature was 50 °C, the extrusion pressure was 28 bars and the screw rotational speed was 200 (rpm). Lastly, the extruded pasta was dried at 45 °C and 75% relative humidity in a 12-tray drier (Chinese model SM12, Qingdao, China). The drying process lasted 90 min to reach 13 m/m % moisture content, which is required by Codex Alimentarius Hungaricus (Biró, Fodor, Szedljak, Pásztor-Huszár & Gere (2019). All the pasta samples were made in triplicate. The three best formulations based on the Response Surface Methodology taking into account their protein content and surface appearance were selected. These were run 7 labelled SHBP, run 14 labelled SBP and run 11 labelled SHPP respectively. The composition of the three treatments is shown in Table **2.** The content of other ingredients – sorghum/pearl millet flour, whole egg, water and olive oil content was kept constant in all formulations. The incorporation of legume flour (bean flour) was aimed at improving the protein content of the pasta. The incorporation of potato flour was to enhance the flavour of the pasta. The use of non-gluten cereals (sorghum and pearl millet) was to make sure a gluten-free product was achieved.

Cooking properties

The optimal cooking time (OCT) was determined by the disappearance of the opaque line in the centre of the pasta based on the AACC 66-50.01 methods (AACC, 2009). The OCT was determined by compressing a pasta sample between 2 glass slides and observing the line disappearance by taking samples at intervals of 1 minute. The gluten-free pasta cooking properties were determined according to methods proposed by (Tudorică, Kuri & Brennan, 2002). Water absorption (WA) of the pasta was determined as the weight difference between the cooked pasta in OCT and raw pasta expressed as percentage of raw pasta.

$$\boldsymbol{WA}\,\% = \frac{\boldsymbol{a-b}}{\boldsymbol{b}} \times \boldsymbol{100}$$

a is the weight of the cooked pasta in grams.
b is the weight of the dry pasta in grams (Biró et al., 2019)

Table 1
The Box-Behnken Design for the three pasta treatments with 17 runs

Variable	Factor	Low	Middle	High
Bean flour (g)	A	0	10	20
Potato flour (g)	B	0	10	20
Hydrocolloid (g)	C	5	10	20

Table 2
The composition of the pasta formulations

Formulation	Guar gum (g)	Bean flour (g)	Potato flour (g)
SHBP	20.0	20.0	10.0
SBP	12.5	20.0	0.0
SHPP	20.0	10.0	20.0

The different compositional levels of the pasta formulations were chosen on the basis of the best ranking results from the preliminary RSM trials, after sensory evaluation

The swelling index (SI) was determined as the difference in weight between the cooked pasta in OCT and the dried cooked pasta at 105 °C. The swelling index of cooked pasta (grams of water per gram of dry pasta) was calculated in accordance with the procedure established by (Yang, 2020).

$$SI = \frac{Weight\ of\ cooked\ pasta - Weight\ of\ pasta\ after\ drying}{Weight\ of\ pasta\ after\ drying}$$

Cooking loss (CL) was determined by evaporation of the cooking water contained in a pre-weighed beaker, to constant weight at 105 °C. The residue was expressed as g of solids/100 g of raw pasta. The reported values were the average of at least triplicates for each sample. Cooking loss (CL) is related to leaching of solids during cooking and is widely used as an indicator of the overall cooking performance (Jalgaonkar et al., 2017).

$$CL\% = \frac{Weight\ of\ beaker - Weight\ of\ empty\ beaker}{Weight\ of\ raw\ pasta} X100$$

Sensory evaluation

The sensory evaluation of the gluten-free pasta was conducted by a trained panel consisting of ten individuals, including laboratory technicians from the Department of Nutrition Dietetics and Food Science as well as Department of Chemistry and Earth Sciences, Faculty of Science, University of Zimbabwe. The training took place at the University Food Science laboratory and was facilitated by the Chief Laboratory Scientist over a one-week period, during which the panel members were exposed to various commercial pasta samples. Texture properties such as firmness, chewiness (product of hardness, cohesiveness and springiness) and adhesiveness of the cooked pasta were determined. Sensory properties of dry and cooked pasta were evaluated on a 5-point category scale with end points labelled from 1 to 5 as shown in Table 3 (Pestorić et al., 2015).

In order to obtain the overall quality of spaghetti samples assessors used the hedonic scale with 5 quality grades: 1 – extremely dislike, 2 – moderately dislike 3 – neither like nor dislike, 4 – moderately like, 5 – extremely like. All samples were presented to each panel in the single sessions. All panellists were presented with a printed response sheet with written instructions for the tests. The order of sample presentation was completely randomized among assessors, identified with three random numbers. Dry spaghetti was presented on the paper plates, while cooked spaghetti was presented in 250-ml sealed thermal ceramic bowls and served at room temperature within 10 min after cooking.

Statistical analysis

Data were tested for normality using Shapiro-Wilk Test. Data on proximate composition of the different flours, physicochemical, sensory and nutritional properties of produced pasta were analysed statistically used GenstatVersion 18. The means were compared using ANOVA in Genstat Version 18 and where significant difference was observed, Tukey's test was used to separate the means at 95% probability.

Pasta formulation and optimisation was done using Design Expert trial version 11.1.2.0. A randomised Response Surface Methodology using the Box-Behnken design with 17 runs (Torres Vargas, Lema González & Galeano Loaiza, 2021) and a quadratic model with no blocks was used. The building time was 2.00 ms and 5 centre points. Optimisation was done based on the highest protein content and best surface appearance of individual pasta formulations.

RESULTS AND DISCUSSION

The results on protein content and optimisation are shown in Fig. 1. Protein deficiency is one of the major causes of malnutrition among the Sub-Saharan African population. It is recommended for food scientists to find affordable, sustainable and evidence-based innovations to combat this. Consumption of protein-fortified foods can help alleviate the problem of malnutrition. Bean flour had the most significant ($p<0.0001$) impact in altering the protein concentration of the developed pasta. This is supported by earlier literature by Temba, Njobeh, Adebo, Olugbile and Kayitesi (2016) whereby a combination of cereals with legumes was seen to improve the protein and nutrient density of the subsequent food products. In Fig. 1, the points on the corners represent experimental design points. Potato flour had the least significant contribution to the protein concentration in the development of pasta (Fig. 1).

Table 3.
Sensory evaluation score table. (Source: Data adopted from Pestorić et al. (2015), copyright 2015, CC BY 3.0. https:/doi.org/10.5937/ffr1502109p)

	Visual evaluation scores			**Palpatory evaluation scores**		**Gustatory evaluation**				
Scores	**Shape**	**Surface Appearance**	**Cross sectional Appearance**	**Surface Property**	**Fracture Ability**	**Surface Adhesiveness**	**Elasticity**	**Firmness**	**Chewiness**	**Adhesiveness**
5	Uniform no damage	Uncracked	Completely vitreous	Extremely smooth	Excellent resistant to fracture	Not sticky	Excellent elasticity	Excellent firmness (al dente	Excellent chewiness	Non sticky
4	Insignificant deviation of shape	Insignificantly cracked	Vitreous	Smooth	Very good resistance to fracture	Insignificantly sticky	Very good elasticity	Very good firmness	Very good chewiness	Insignificantly sticky
3	Noticeable deficiencies	Partially cracked	Partly vitreous	Slightly rough	Good resistance to fracture	Slightly sticky	Good elasticity	Good firmness	Good chewiness	Slightly sticky
2	Clearly deficiencies	Significantly cracked	Partly Mealy	Pretty rough	Poor resistance to fracture	Sticky	Poor elasticity	Poor firmness	Poor chewiness	Sticky
1	High deficiencies	Marbled	Mealy	Rough	Extremely poor resistance to fracture	Extremely sticky	Extremely poor elasticity	Extremely poor firmness	Extremely poor chewiness	Extremely sticky

An increase in potato flour resulted in a small increase in the protein content of the pasta. The little increase can be justified by the results from proximate analysis of the individual ingredients as potato flour had the lowest protein content of 10.52 % as compared to all other ingredients. The contribution of each flour is represented by equation 1 derived from the response surface methodology. A quadratic equation was generated by the model to determine the protein concentration of the pasta.

Guar gum concentration had the highest ($p<0.001$) impact on the surface appearance of the pasta (Fig. 2).

As the hydrocolloid amount increased, the surface appearance of the pasta improved significantly. The hydrocolloid mimics the function of gluten hence it creates strong smooth bonds among the ingredients. Bean flour concentration had little or no significant ($p>0.001$) effect on the surface appearance of the developed pasta.

$$P = Y + 2.85A - 1.3B - 0.0012C + 0.21AB - 0.0025AC + 0.00BC + 0.68A^2 + 1.72B^2 \text{ (equation 1)}$$

Where P= protein content
Y = 16.84
A = bean flour
B = potato flour

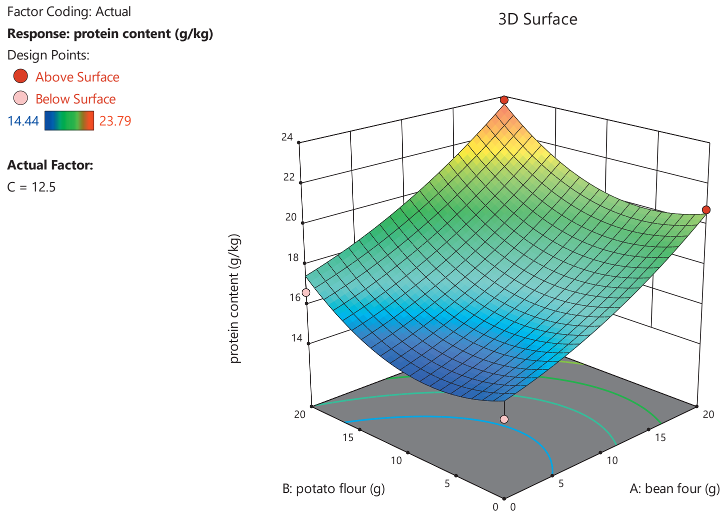


Figure 1. Response surface plot, effect of ingredients (g) on protein concentration (g/kg) of the pasta

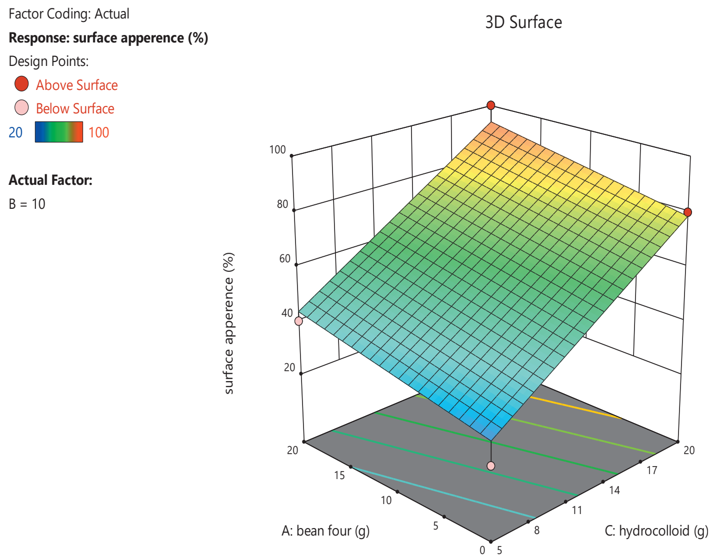


Figure 2. Response surface plot, effect of bean flour (g) and guar gum (g) on surface appearance (%) of pasta

$S = Y+0.75A-0.25B+3.3C$ (equation 2)
Where S =Surface appearance percentage
Y= 14.5 intercept
A = Bean flour
B = Potato flour
C = Hydrocolloid

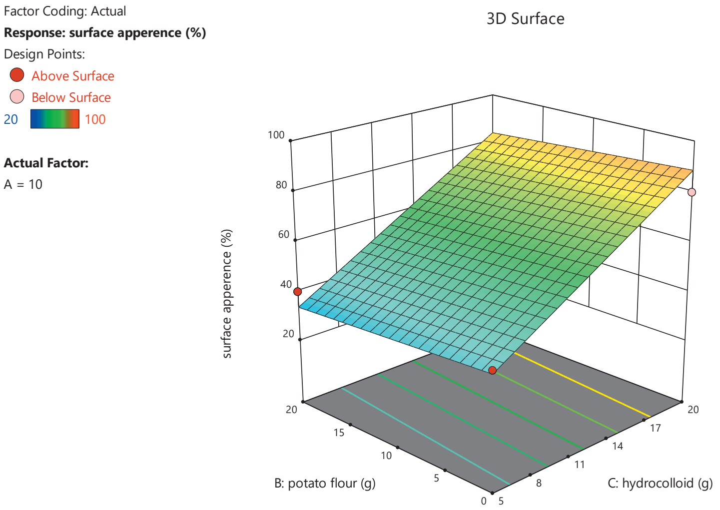


Figure 3. Response surface plot, effect of potato flour (g) and guar gum (g) on surface appearance (%) of pasta

Potato flour did not affect the surface appearance of the pasta (Fig. 3). An increase from 0 grams to 20 grams of potato flour in the ingredient mixture did not improve the surface appearance percentage of the pasta as it remained constant below 40 per cent. Guar gum addition improved the surface appearance of the pasta from 40 per cent to 90 per cent as its mass increased from 0 grams to 20 grams. Hydrocolloids are frequently used in gluten-free (GF) recipes, mimicking some rheological properties of gluten, improving dough properties, delaying starch retrogradation and improving bread/pasta texture, appearance and stability (Culetu, Duta, Papageorgiou&Varzakas, 2021).

Guar gum is a food additive that is known to have characteristics that can increase the viscosity of the dough and improve the quality of gluten-free food products (Herawati, 2019). Guar gum can make dimensional tissue structures such as gluten but in a weak gel form (Antarlina, Estiasih, Zubaidah & Harijono, 2021). Guar gum helps form smooth bonds among the ingredients. An increase in the guar gum significantly ($p<0.001$) improved the surface appearance of the pasta (Figure 3). Potato flour concentration had no significant ($p>0.001$) effect on the surface appearance of the pasta. A linear equation (Eq. 2) was generated as a model to optimise the surface appearance of the pasta. From Fig. 3 the points on the corners represent experimental design points.

Swelling index, water absorption, cooking loss and optimum cooking time of the pasta treatments

The optimum cooking time of pasta was significantly different among the three samples ($p<0.001$). Sample SHPP had a significantly higher cooking time (7 min) than sample SBP (6.2 min) and sample SHBP (5 min) ($p<0.001$).

Previous studies conducted by El-Sohaimy, Brennan, Darwish & Brennan (2020) showed an optimum cooking time of different pasta formulations ranging from 5 minutes to 6 minutes. A significant difference in the water ab-sorption of pasta samples produced was recorded ($p<0.001$), with sample SHPP having significantly higher water absorption (238%) than sample SHBP (190%) and sample SBP (210%) (Table 4). There was a significant difference in the swelling index of the three pasta samples produced ($p<0.001$).

Sample SHPP had a higher swelling index ($p<0.001$). Similarly, cooking loss (%) was significantly higher in sample SHPP with ($p<0.001$), sample SHPP had a cooking loss of 11% compared to 8% for sample SBP (Table 4).

Cooking losses are one of the main parameters taken into consideration during the assessment of pasta quality. In a high-quality product they should not exceed 8% of dry matter (Torres, Frias, Granito, Guerra & Vidal-Valverde, 2007). The cooking loss observed from the samples was 6.7% for sample SHBP, 8% for sample SBP and 11% for SHPP. Studies by Belahcen et al. (2022) showed the cooking losses of seven different pastas ranging from 11.2% to 15.1%. The results we obtained from our experiments were in the range. Pasta samples SHBP and sample SBP which had cooking losses of 8% and below were of higher acceptability and this is in line with the literature published by Jalgaonkar et al., (2017) as they concluded that good pasta should have a cooking loss below 9%.The water absorption percentage of our pasta ranged from 190% to 238%. Previous studies by Ribeiro, Bolanho, Montanuciand Ruiz (2018) showed a water absorption percentage ranging from 200.18% to 265.15%. This also validates our result on water absorption percentage.

Proximate composition of the different flours used in the pasta production.

Significant (p<0.001) differences in the proximate composition of the four different flours used in the study were recorded (Table 5). There was a significant (p<0.001) difference in the ash content of the four samples, with sorghum flour having the highest ash content (4.23%), while pearl millet had the lowest quantity of ash content (1.11%). Moisture content in the four flours varied significantly (p<0.001) and ranged from 8.10% to 9.14%.

Pearl millet flour had significantly higher moisture content (9.14%) than the other flours. Significant (p<0.001) difference in fat content was observed across the flours, with pearl millet having the highest fat content of 4.22% while beans had the lowest fat content of 1.42%. The protein content in the four different flours ranged from 10.52% to 22%. There was no significant difference in the protein content between sorghum and pearl millet flour (p>0.05).

Bean flour had significantly higher protein content than the other flour, while potato flour had the lowest protein content. On the contrary, potato flour had significantly (p<0.001) higher carbohydrate content (73.82%) as compared to other flours. Bean flour had significantly lower carbohydrate content (65.85%) than the other flours. No significant difference in carbohydrate content was recorded between bean flour and pearl millet flour (p>0.05) (Table 5).

Table 4.
Optimum cooking time, water absorption, swelling index and cooking lossof the experimental pasta samples.

Pasta	Optimum cooking time (min)	Water absorption (%)	Swelling Index (%)	Cooking loss (%)
SHBP	5.0 ± 0.03^{a}	190.0 ± 0.04^{a}	1.02 ± 0.01^{a}	6.7 ± 0.03^{a}
SBP	6.2 ± 0.02^{b}		1.15 ± 0.02^{b}	8.0 ± 0.06^{b}
SHPP	7.0 ± 0.04^{c}	238.0 ± 0.03^{c}	1.24 ± 0.05^{c}	11.0 ± 0.01^{c}
P value	< 0.001	< 0.001	< 0.001	< 0.001

Results are given as mean ± standard deviation (n = 3.) ^{a,b,c} *Superscripts with different letters within a column signify that the values are statistically different at p value <0.05*

Table 5.
Proximate composition of different flours used in the pasta production

Flour	**Nutrients**				
	Ash	**Moisture**	**fat**	**Protein**	**Carbohydrates (%)**
Sorghum	4.23 ± 0.05^{a}	8.92 ± 0.02^{a}	3.23 ± 0.01^{a}	19.82 ± 0.03^{a}	70.65 ± 0.09^{a}
Pearl Millet	1.11 ± 0.08^{b}	9.14 ± 0.05^{b}	4.22 ± 0.08^{b}	20.44 ± 0.02^{a}	66.24 ± 0.06^{b}
Bean	3.06 ± 0.02^{c}	8.10 ± 0.04^{c}	1.42 ± 0.05^{c}	22.0 ± 0.06^{b}	65.85 ± 0.02^{b}
Potato	2.20 ± 0.04^{d}	8.20 ± 0.06^{d}	0.95 ± 0.04^{d}	10.52 ± 0.06^{c}	73.82 ± 004^{c}
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Results are given as mean ± standard deviation (n = 3). ^{a,b,c} *Superscripts with different letters within a column signify that the values are statistically different with a p <0.05*

Nutritional values of the prepared sorghum pastas

The nutritional values of the formulated pasta samples are shown in Table 6. The utilization of various types of flours through blending contributes to the enhancement of the product's nutritional quality. This is because different ingredients possess distinct nutritional compositions, so one ingredient may compensate for the deficiency of a particular nutrient found in another ingredient. The difference in the values is mainly due to the different flour ratios used in the production process. Sample SBP which contains a high proportion of legumes had the highest protein content compared to the other two samples. Sample SHBP had the highest carbohydrate content compared to the other two samples, SBP and SHPP. There was a significant difference in the nutritional content of the three-sorghum pasta except for phosphorus content which had a p-value of 0.055.

The moisture content of the three pasta samples produced ranged from 6.70% to 7.74%, with sample SBP containing beans having significantly ($p<0.001$) higher moisture content than the other samples ($p<0.001$). The ash content varied significantly among the three pasta samples. Sample SBP, pasta produced from a flour blend constituting sorghum, pearl millet and bio-fortified beans had significantly higher ash content (4.36%) than samples SHBP and SHPP. The protein content of the pasta produced varied significantly ($p<0.001$) from 14.44% to 20.78%. Sample SBP had significantly ($p<0.001$) higher fat and fibre content 9.67% and 1.35%, respectively than the other samples. Sample SHBP had significantly ($p<0.001$) higher carbohydrate content (66%) than the other samples, while sample SBP had the lowest carbohydrate content (Table 6).

Table 7 shows the nutritional content of 3 commercial pastas on the Zimbabwean market. These pastas are wheat-based and were used to compare the nutritional content of selected nutrients with our sorghum-based pastas in the absence of sorghum pasta on the market for comparison. Comparing the three macrontrients, carbohydrates, protein and fibre of the commercial pasta and our three pastas, it was observed that all our pastas had a higher protein content than all the commercial pastas, 14.44-20.78% compared to 11-16% (commercial pasta). This can be attributed to the fermentation and roasting of sorghum and pearl millet which increase the protein content of these millets as unfermented flours of the two have lower protein content. The fibre content of our pasta samples was higher than that of the

Table 6.
Proximate composition of the experimental pasta samples

Pasta	Proximate composition (%)					
	Moisture	Ash	Protein	Fat	Fibre	Carbohydrate
SHBP	6.71 ± 0.01^{b}	2.03 ± 0.06^{a}	14.44 ± 0.07^{a}	9.46 ± 0.08^{b}	5.44 ± 0.06^{a}	66.00 ± 0.02^{c}
SBP	7.74 ± 0.04^{c}	4.36 ± 0.03^{c}	20.78 ± 0.04^{c}	5.44 ± 0.06^{a}	1.28 ± 0.02^{a}	60.40 ± 0.04^{a}
SHPP	6.70 ± 0.05^{a}	3.69 ± 0.02^{b}	16.63 ± 0.05^{b}	9.67 ± 0.05^{c}	1.35 ± 0.07^{b}	61.96 ± 0.06^{b}
P Value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.05	< 0.001

Results are given as mean ± standard deviation (n = 3). ^{a,b,c} *Superscripts with different letters on values within a column signify that the values are statistically different at* $p < 0.05$

Table 7.
Nutritional information of 3 commercial pastas available from the market

Pasta	Nutritional Information (%)		
	Carbohydrate content	Protein content	Dietary fibre content
A	74	11	0.4
B	78	16	0.8
C	78	16	0.8

commercial pasta - it ranged from 1.28% to 5.44% when compared to 0.4% to 0.8%. Our pasta had low carbohydrate content (60.4-66.0%) as compared to the commercial pasta, (74-78%). This could be due to the fermentation process which converts some of the carbohydrates to simple sugars during fermentation.

Micronutrient composition of experimental pasta

Micronutrients are important for a good functional immune system and general growth. Calcium is very essential in muscle contraction, oocyte activation, building strong bones and teeth, blood clotting, nerve impulse, transmission, regulating the heartbeat and fluid balance within cells. The requirements are greatest during periods of growth such as childhood, pregnancy and breastfeeding (Pravina, Sayaji&Avinash, 2015). Phosphorus functions as a structural component of bones and teeth and DNA/RNA and enables the bipolarity of lipid membranes and circulating lipoproteins. Metabolically, phosphorus functions in critical pathways to produce and store energy in phosphate bonds (ATP), buffer blood, regulate gene transcription, activate enzyme catalysis, and enable signal transduction of regulatory pathways affecting a variety of organ functions ranging from renal excretion to immune response (Calvo & Lamberg-Allardt, 2015). A comparison of selected micronutrients of the formulated pastas was done. At ($p<0.001$) differences in the micronutrient composition of produced pastas were recorded (Table 8). The calcium content of the three different pastas produced ranged from 0.50% to 1.10%. Sample SBP had significantly lower calcium content than the other samples ($p<0.05$), while sample SHBP had the highest calcium content. No significant differences in phosphorus content were recorded among the three pasta treatments produced ($p>0.05$) (Table 8).

Sensory evaluation of raw pasta

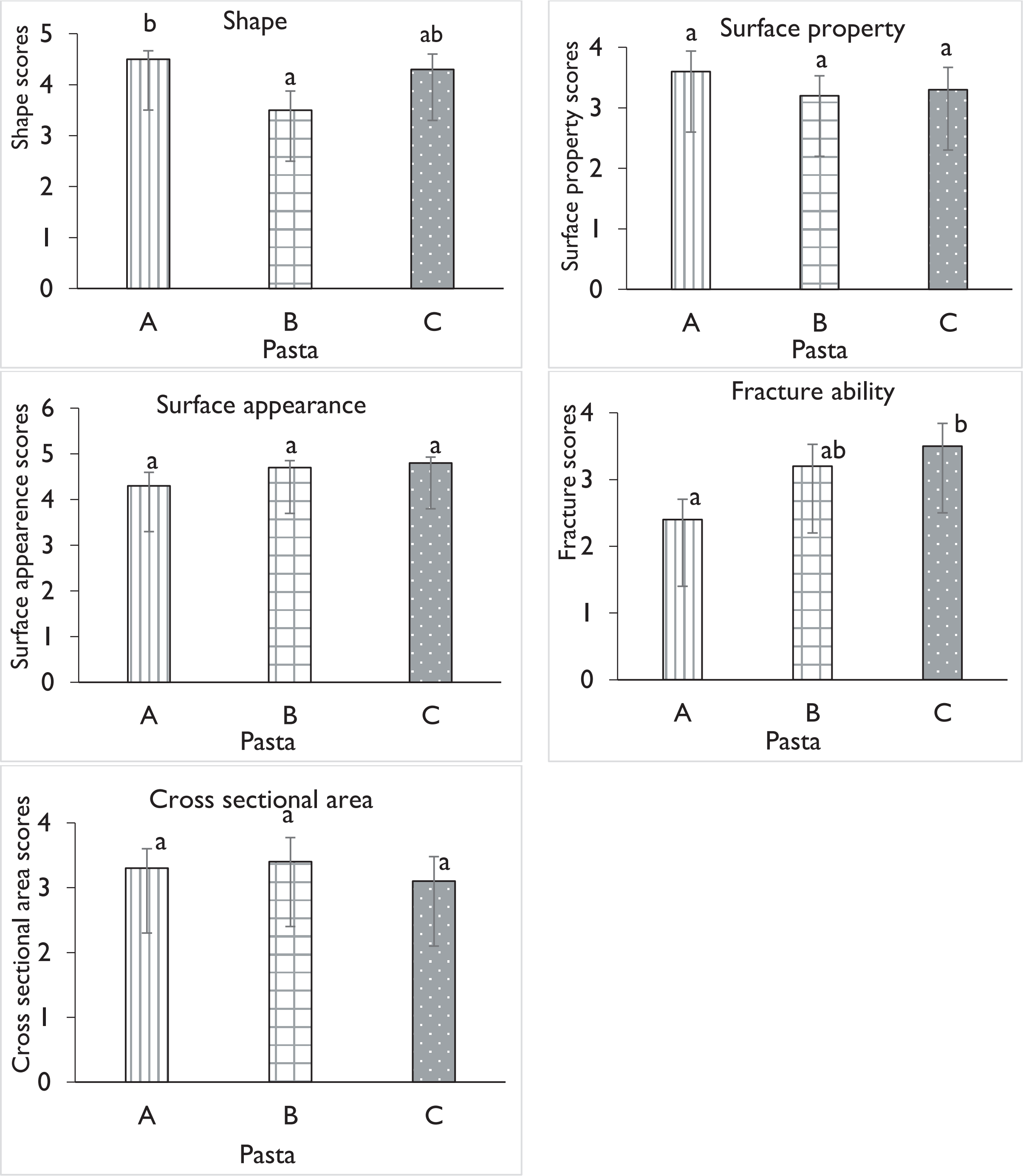
Sensory evaluation is a tool employed to evoke, measure, analyse and interpret typical product attributes which can be perceived by human senses and also to curtail the possible influence of brand identity on the end user (Sahay Meena et al., 2019). There was a significant difference in shape between sample SHBP (sorghum high bean pasta) and sample SBP (sorghum, bean pasta) ($p<0.05$). No significant difference in shape was observed between sample SHPP (sorghum high potato pasta) ($p>0.05$) and samples SHBP and SBP.

Table 8.
Micronutrient composition of the experimental pasta samples

Pasta	Micronutrient content	
	Calcium (%)	Phosphorus (%)
SHBP	1.10 ± 0.04^c	0.47 ± 0.01
SBP	0.50 ± 0.03^a	0.42 ± 0.01
SHPP	0.90 ± 0.04^b	0.5 ± 0.04
P value	0.008	0.055

Results are given as mean ± standard deviation (n = 3)
^{a,b,c} *Superscripts with different letters within a column signify the values are statistically different at* $p < 0.05$

Surface property, cross-sectional area and surface appearance ranking of the three produced pasta samples SHBP, sample SBP and sample SHPP were not statistically significantly different ($p>0.05$). Sample SHBP had a significantly lower fracture ability score as compared to sample SHPP ($P<0.05$) but no significant difference with sample SBP (Fig. 4). Cooked pasta is always evaluated for certain parameters to rank its quality attributes. Özyurt et al. (2015) evaluated their pasta enriched with spirulina for cooking quality (weight increase, cooking loss, volume increase). Axentii, Stroe and Codină (2023) evaluated their pasta samples for cooking loss (CL), optimal cooking time (OCT), water absorption (WA) and swelling index (SI). We also evaluated our pasta samples for the following parameters, surface appearance, firmness, surface adhesiveness, chewiness, elasticity and adhesiveness. There was no significant difference ($p>0.05$) in the surface appearance, firmness, surface adhesiveness, chewiness, elasticity and adhesiveness of the cooked pasta treatments (Fig. 5).Although the results did not show any statistically significant difference between the evaluated parameters of the samples SHBP, SBP and SHPP, the pasta products were of high acceptable quality as all the parameters ranked scored high on the evaluation table as shown in (Fig. 5). This is in line with existing literature according to (Padalino et al., 2016). Hydrocolloid incorporation can be an easy solution for enhancing pasta-cooking quality. The observed cooking time of treatments SHBP, SBP and SHPP is very convenient for fast-cooking food with cooking time below ten minutes.

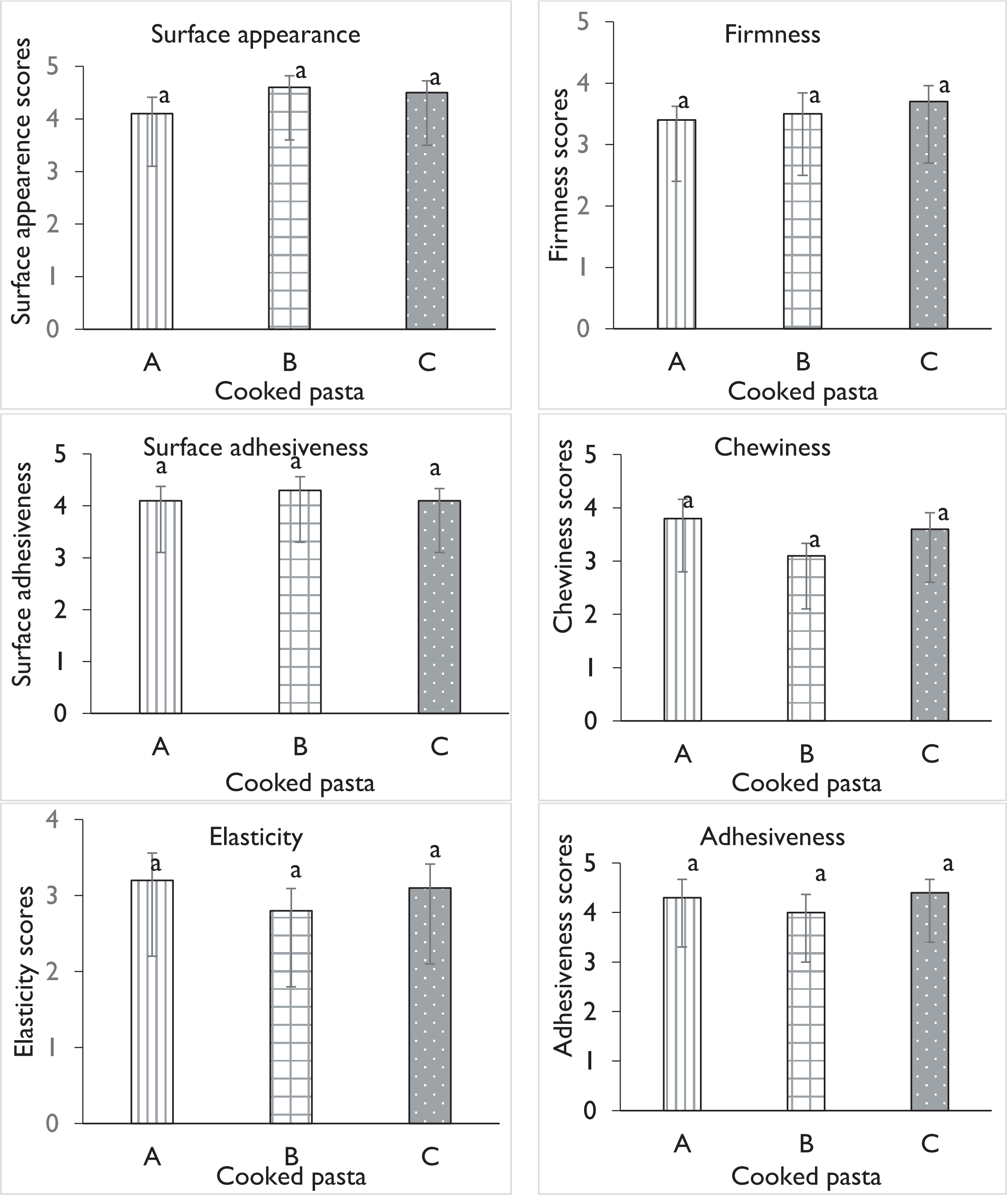


Sample A is sorghum-high bean pasta (SHBP), Sample B is sorghum-bean pasta (SBP), and sample C is sorghum-high potato pasta (SHPP)

^{a,b} *Different letters on bars signify that the values are statistically different,* $p < 0.05$

Figure 4**.** Sensory evaluation of uncooked pasta

A primary challenge for the currently formulated pasta lies in penetrating the market. This may be attributed to people's inclination toward familiar tastes, as individuals often gravitate towards flavours they are accustomed to. Among the quality properties of spaghetti, texture is one of the most important factors affecting pasta quality and consumer acceptance. Dry spaghetti must appeal to the consumer at the point of purchase, whilst cooked spaghetti must meet consumer criteria, such as smooth surface and firmness (Pestorić et al., 2015). Blending sorghum/pearl millet flour with potato flour and bean flour did not affect the cooking properties



Sample A is sorghum-high bean pasta (SHBP), sample B is sorghum-bean pasta (SBP), and sample C is sorghum-high potato pasta (SHPP)

[a]Different letters on bars signify that the values are statistically different, $p < 0.05$

Figure 5. Sensory evaluation of cooked pasta

of the pasta as there are no significant differences observed from the sensory evaluation results obtained from the trained panel.

This could be attributed to pre-processing of the flours before they were used in pasta making. The absence of gluten in the flours used may also be another factor contributing to the observed cooking properties.

Comparison of the formulated pastas

The SHBP pasta had the shortest cooking time compared to all the other two pasta formulations had the highest micro-nutrient content on the tested micronutrients i.e. calcium and phosphorous. It also had the highest fibre and carbohydrate content as compared to the other two pastas. The SBP had the highest protein content as compared to the other two pastas formulated, it had the least carbohydrate content and also the lowest levels of micronutrients tested. The SHPP had the highest fat content and the longest optimum cooking time. One of its major disadvantages was the high cooking loss. Although, with all these differences all the three formulated pastas were of an acceptable quality.

CONCLUSIONS

The making of gluten-free pasta was achieved using sorghum/pearl millet flour blended with some other non-gluten-containing flours, namely potato flour and NUA 45 bean flour. The best pasta formulation, according to the physical and sensory properties as scored by the sensory evaluation panel, contained sorghum flour, pearl millet flour and a high percentage of NUA 45 bean flour (Sorghum high bean pasta treatment (SHBP). Based on the results obtained from the experiments it can be concluded that sorghum can be used for producing quality gluten-free pasta products. The pasta had higher protein content ranging from 14.44% to 20.78%, which is more than most of the commercial pasta on the market whose protein content ranges from 11% to 16%. It also contained a high fibre content which ranged from 1.28% to 5.44%, more than most commercial pastas on the market which are mostly at 0.4%. The experimental pasta had lower carbohydrate content than most commercial pasta on the market. Good cooking attributes and high consumer acceptability are expected from the produced pasta.

ACKNOWLEDGEMENTS

The authors are grateful to the Department of Dietetics, Nutrition and Food Sciences, University of Zimbabwe, Ministry of Higher and Tertiary Education Innovation Science and Technology Development, for the financial support in the form of the Future Grains for Africa fellowship grant. Special thanks go to Prof. J. Chifamba, the University of Zimbabwe Innovation HUB manager and Dr A. Nhamo, HUB Research Specialist for their unwavering support through the research period.

REFERENCES

AACC. (2009). AACC Approved Methods of Analysis, 11th Ed. Method 66-50.01. Pasta and Noodle Cooking Quality—Firmness. Approved Nov. 3, (1999). Cereals & Grains Association, St. Paul, MN, U.S.A. http://dx.doi.org/10.1094/AACCIntMethod-66-50.01.

Adeyeye, S. A. O., & Yildiz, F. (2016). Assessment of quality and sensory properties of sorghum-wheat flour cookies. *Cogent Food and Agriculture*, *2*(1). 12450. https://doi.org/10.1080/23311932.2016.1245059

Adiamo, O. Q., Fawale, O. S., & Olawoye, B. (2018). Recent trends in the formulation of gluten-free sorghum products. *Journal of Culinary Science and Technology*, *16*(4), 311-325. https://doi.org/10.1080/15428052.2017.1388896

Anitha, S., Esther Magdalene Sharon, M., Marx Nirmal, R., & Mathanghi, S. K. (2023). Optimization of pearl millet and carrot based gluten-free pasta using response surface methodology. *Biological Forum*, *15*(2), 461-466.

Antarlina, S. S., Estiasih, T., Zubaidah, E., & Harijono. (2021). The physicochemical properties of white sorghum (Sorghum bicolor L.) flour in various particle sizes by soaking the seeds before and after dehulling. *Food Research*, *5*(3), 129-143. https://doi.org/10.26656/fr.2017.5(3).541

Anyobodeh, R., Spio-Kwofie, A., & Anaman, S. (2016). Preparation and production of pasta using composite cassava flour as a substitute of wheat flour. *International Journal of Novel Research in Marketing Management and Economics*, *3*(1), 97-105.

Axentii, M., Stroe, S. G., & Codină, G. G. (2023). Development and quality evaluation of rigatoni pasta enriched with hemp seed meal. *Foods*, *12*(9). https://doi.org/10.3390/foods12091774

Belahcen, L., Cassan, D., Canaguier, E., Robin, M-H., Chiffoleau, Y., Samson, M-F., & Jard, G. (2022). Physicochemical and sensorial characterization of artisanal pasta from the Occitanie region in France. *Foods*, *11*(20) 3208.
https://doi.org/10.3390/foods11203208

Biró, B., Fodor, R., Szedljak, I., Pásztor-Huszár, K., & Gere, A. (2019). Buckwheat-pasta enriched with silkworm powder: Technological analysis and sensory evaluation. *LWT - Food Science and Technology*, *116*, 108542. https://doi.org/10.1016/j.lwt.2019.108542

Calvo, M. S., & Lamberg-Allardt, C. J. (2015). Phosphorus. *Advances in Nutrition*, *6*(6), 860-862. https://doi.org/10.3945/an.115.008516

Cayres, C. A., Ramirez Ascheri, J. L., Couto, G., Almeida, E. L., & Melo, L. (2020). Consumers' acceptance of optimized gluten-free sorghum-based cakes and their drivers of liking and disliking. *Journal of Cereal Science, 93*, 102938. https://doi.org/10.1016/j.jcs.2020.102938

Cervini, M., Gruppi, A., Bassani, A., Spigno, G.& Giuberti, G. (2021). Potential application of resistant starch sorghum in gluten-free pasta: Nutritional, structural and sensory evaluations. *Foods, 10*(5), 908. https://doi.org/10.3390/foods10050908

Culetu, A., Duta, D. E., Papageorgiou, M., & Varzakas, T. (2021). The role of hydrocolloids in gluten-free bread and pasta; rheology, characteristics, staling and glycemic index. *Foods*, *10*(12), 3121.

https://doi.org/10.3390/foods10123121

de Oliveira, L. D. L., de Oliveira, G. T., de Alencar, E. R., Queiroz, V. A. V., & de Alencar Figueiredo, L. F. (2022). Physical, chemical, and antioxidant analysis of sorghum grain and flour from five hybrids to determine the drivers of liking of gluten-free sorghum breads. *Lwt*, *153, 112407*. https://doi.org/10.1016/j.lwt.2021.112407

El-Sohaimy, S. A., Brennan, M., Darwish, A. M. G., & Brennan, C. (2020). Physicochemical, texture and sensorial evaluation of pasta enriched with chickpea flour and protein isolate. *Annals of Agricultural Sciences*, *65*(1), 28-34. https://doi.org/10.1016/j.aoas.2020.05.005

Fabbri, A., Angioloni, A., Di Stefano, A., Fava, E., Guarnieri, A., & Lorenzini, G. (2007). Preliminary investigation of pasta extrusion process: Rheological characterization of semolina dough. *Journal of Agricultural Engineering*, *38*(2), 21. https://doi.org/10.4081/jae.2007.2.21

Girard, A. L., & Awika, J. M. (2018). Sorghum polyphenols and other bioactive components as functional and health promoting food ingredients. *Journal of Cereal Science*, *84*, 112-124. https://doi.org/10.1016/j.jcs.2018.10.009

Herawati, H. (2019). Hydrocolloids to the effects of gluten free bakery products. *Journal of Physics: Conference Series*, *1295*(1). https://doi.org/10.1088/1742-6596/1295/1/012052

Jalgaonkar, K., Jha, S. K., Nain, L., & Iquebal, M. A. (2017). Quality changes in pearl millet based pasta during storage in flexible packaging. *Journal of Agricultural Engineering*, *54*(3), 22-31. https://doi.org/10.52151/jae2017543.1628

Jood, S., Khetarpaul, N., & Goyal, R. (2012). Effect of germination and probiotic fermentation on pH, titratable acidity, dietary fibre, β-glucan and vitamin content of sorghum based food mixtures. *Journal of Nutrition & Food Sciences*, *2*(9), 2-5. https://doi.org/10.4172/2155-9600.1000164

McCann, T., Krause, D., & Sanguansri, P. (2015). Cereals and grains: Sorghum – new glutenfree ingredient and applications. *Food Australia, 67*(6)*,* 24-26.

Minarovičová, L., Lauková, M., Kohajdová, Z., Karovičová, J., Dobrovická, D., & Kuchtová, V. (2018). Qualitative properties of pasta enriched with celery root and sugar beet by-products.*Czech Journal of Food Sciences, 36*(1), 66-72. http://dx.doi.org/10.17221/242/2017-CJFS

Mortensen, A., Aguilar, F., Crebelli, R., Di Domenico, A., Frutos, M. J., Galtier, P., Gott, D., Gundert-Remy, U., Lambré , C., Leblanc, J., Lindtner, O., Moldeus, P., Mosesso, P., Oskarsson, A., Parent-Massin, D., Stankovic, I., Waalkens-Berendsen, I., Woutersen, R. A., Wright, M., Younes, M., Brimer, L., Christodoulidou, A., Lodi, F., Tard, A., & Dusemund, B. (2017). Re-evaluation of guar gum (E 412) as a food additive. *EFSA Journal*, *15*(2). https://doi.org/10.2903/j.efsa.2017.4669

Ndungutse, V., Ngoda, P. M. N., Vasanthakaalam, H., Shakala, E. K., & Faraj, A. K. (2019). Functional properties of flour from selected potato (Solanum tuberosum L.) cultivars grown in Rwanda. *Potato Journal*, *46*(2), 115-123.

Özyurt, G., Uslu, L., Yuvka, I., Gökdoğan, S., Atci, G., Ak, B., & Işik, O. (2015). Evaluation of the cooking quality characteristics of pasta enriched with spirulina platensis. *Journal of Food Quality*, *38*(4), 268-272. https://doi.org/10.1111/jfq.12142

Padalino, L., Conte, A., & Del Nobile, M. A. (2016). Overview on the general approaches to improve gluten-free pasta and bread. *Foods*, *5*(4), 5040087. https://doi.org/10.3390/foods5040087

Palavecino, P. M., Bustos, M. C., Alabi, M. B. H., Nicolazzi, M. S., Penci, M. C., & Ribotta, P. D. (2017). Effect of ingredients on the quality of gluten-free sorghum pasta. *Journal of Food Science, 82*(9), 2085-2093. https://doi.org/10.1111/1750-3841.13821

Palavecino, P. M., Curti, M. I., Bustos, M. C., Penci, M. C., & Ribotta, P. D. (2020). Sorghum pasta and noodles: Technological and nutritional aspects.*Plant Foods for Human Nutrition, 75*(3), 326-336. https://doi.org/10.1007/s11130-020-00829-9

Pestorić, M., Pojić, M., Filipčev, B., Šimurina, O., Torbica, A., & Janić-Hajnal, E. (2015). Sensory differentiation of commercially produced spaghetti. *Food and Feed Research*, *42*(2), 109-117. https://doi.org/10.5937/ffr1502109p

Pravina, P., Sayaji, D., & Avinash, M. (2013). Calcium and its role in human body. *International Journal of Research in Pharmaceutical and Biomedical Sciences, 4*(2), 659-668. http://www.academia.edu/download/32830082/8.pdf

Raleng, A., Singh, A., Singh, B., &Attkan, A. K. (2016). Response surface methodology for development and characterization of extruded snack developed from food-by-products. *International Journal of Bio-Resource and Stress Management*, *7*(6), 1321-1329. https://doi.org/10.23910/ijbsm/2016.7.6.1691a

Ribeiro, T. H. S., Bolanho, B. C., Montanuci, F. D., & Ruiz, S. P. (2018). Physicochemical and sensory characterization of gluten-free fresh pasta with addition of passion fruit peel flour. *Ciencia Rural*, *48*(12), 1-9. https://doi.org/10.1590/0103-8478cr20180508

Sahay Meena, G., Dewan, A., Upadhyay, N., Barapatre, R., Kumar, N., Kumar Singh, A., & JS, R. (2019). Fuzzy analysis of sensory attributes of gluten free pasta prepared from brown rice, amaranth, flaxseed flours and whey protein concentrates. *Journal of Food Science and Nutrition Research*, *2*(1), 22-37. https://doi.org/10.26502/jfsnr.2642-1100006

Suhendro, E. L., Kunetz, C. F., McDonough, C. M., Rooney, L. W., & Waniska, R. D. (2000). Cooking characteristics and quality of noodles from food sorghum. *Cereal Chemistry*, *77*(2), 96–100. https://doi.org/10.1094/CCHEM.2000.77.2.96

Sycheva, O., Skorbina, E., Trubina, I., Omarov, R., & Sarbatova, N. (2019). Functional pasta on the basis of combining the food raw materials. *IOP Conference Series: Earth and Environmental Science*, *403*(1). https://doi.org/10.1088/1755-1315/403/1/012096

Temba, M. C., Njobeh, P. B., Adebo, O. A., Olugbile, A. O., & Kayitesi, E. (2016). The role of compositing cereals with legumes to alleviate protein energy malnutrition in Africa. *International Journal of Food Science and Technology*, *51*(3), 543-554. https://doi.org/10.1111/ijfs.13035

Thilakarathna, R. C. N., Madhusankha, G. D. M. P., & Navaratne, S. B. (2022). Potential food applications of sorghum *(Sorghum bicolor)* and rapid screening methods of nutritional traits by spectroscopic platforms. *Journal of Food Science*, *87*(1), 36-51. https://doi.org/10.1111/1750-3841.16008

Torres, A., Frias, J., Granito, M., Guerra, M. & Vidal-Valverde, C. (2007). Chemical, biological and sensory evaluation of pasta products supplemented with α-galactoside-free lupin flours.*Journalof the Science of Food and Agriculture 87*(1), 74-81. https://doi.org/10.1002/jsfa.2673

Torres Vargas, O. L., Lema González, M., & Galeano Loaiza, Y. V. (2021). Optimization study of pasta extruded with quinoa flour (Chenopodium quinoa willd). *CyTA - Journal of Food*, *19*(1), 220-227. https://doi.org/10.1080/19476337.2021.1883116

Tudorică, C. M., Kuri, V., & Brennan, C. S. (2002). Nutritional and physicochemical characteristics of dietary fiber enriched pasta. *Journal of Agricultural and Food Chemistry*, *50*(2), 347-356. https://doi.org/10.1021/jf0106953

Winger, M., Khouryieh, H., Aramouni, F., & Herald, T. (2014). Sorghum flour characterization and evaluation in *gluten-free flour tortilla*. *Journal of Food Quality, 37*(2), 95-106. https://doi.org/10.1111/jfq.12080

Xiong, Y., Zhang, P., Warner, R. D., & Fang, Z. (2019). Sorghum grain: From genotype, nutrition and phenolic profile to its health benefits and food applications. *Comprehensive Reviews in Food Science and Food Safety*, *18*(6), 2025-2046. https://doi.org/10.1111/1541-4337.12506

Yang, S. (2020). The utilisation of potato flour in pasta production: the effect of starch-protein interactions on the physical chemical properties, and in vitro digestion behaviour, of potato enriched pasta (PhD thesis). Lincoln University, New Zealand.

RAZVOJ RECEPTURE I SENZORSKA SVOJSTVA EKSTRUDIRANE BEZGLUTENSKE TESTENINE NA BAZI SIRKA

Blessing Gwekwe[1],Loveness K. Nyanga[1],Tonderayi M. Matsungo[1], Cathrine Chidewe[2], Stanley Mukanganyama[2], Elijah Nyakudya[3], Florence Mtambanengwe[3], Paul Mapfumo[3], Prosper Chopera[*1]

[1]Univerzitet u Zimbabveu, Fakultet nauka, Katedra za ishranu i prehrambene nauke, Harare, 630 Avenija Čerčil, Maunt Plezant, Zimbabve
[2]Univerzitet u Zimbabveu, Fakultet nauka, Katedra za biotehnologiju i biohemiju, Harare, 630 Avenija Čerčil, Maunt Plezant, Zimbabve
[3]Univerzitet u Zimbabveu, Fakultet poljoprivrede i prehrambenih sistema, Harare, 630 Avenija Čerčil, Maunt Plezant, Zimbabve

Sažetak: Testenina spada u grupu namirnica koje se najviše konzumiraju u svetu. U proizvodnji testenine uobičajeno je stvaranje novih formulacija uvođenjem novih sirovina. Cilj ovog rada je formulisanje, optimizacija i senzorska ocena ekstrudirane bezglutenske testenine na bazi sirka. Određen je hemijski sastav i sadržaj mikronutrijenata osnovnih sirovina koje su korišćene u stvaranju novih eksperimentalnih formulacija ekstrudiranih testenina: brašno sirka, proseno brašno, brašno pasulja sa visokim sadržajem gvožđa (Biofortified NUA 45 beans) i brašno od krompira sorte Hermes. Tri formulacije testenine na bazi sirka su odabrane za proizvodnju testenine: sirak-obogaćeni pasulj (SHBP), sirak-pasulj (SBP) i sirak-obogaćeni-krompir (SHPP) i ispitani su njihovi senzorski atributi (vizuelno, palpatorno i gustatorno). Za optimizaciju formulacije sa najboljim senzorskim svojstvima i svojstvima pri kuvanju korišćen je Box-Benhkenov dizajn (BBD) u kombinaciji sa metodom odzivne površine (RSM). Sadržaj proteina u 4 bezglutenska brašna koja su korišćena u formulacijama testenina kretao se od 10,52% do 22,00%. Brašno od NUA 45 pasulja je statistički značajno ($p<0.05$) sadržalo više proteina u odnosu na ostala bezglutenska brašna. Krompirovo brašno je imalo najveći sadržaj ugljenih hidrata (73,82%) u odnosu na ostala brašna. Testenina SHPP je imala značajno ($p<0.001$) duže optimalno vreme kuvanja (7 min) u poređenju sa SHBP (5 min) i SBP (6,2 min). SHPP je takođe pokazalo značajno ($p<0.001$) viši kapacitet apsorpcije vode (238%) u odnosu na SHBP (190%) i SBP (210%). Postojale su značajne razlike u stepenu bubrenja testenine: SHBP sa najmanjim stepenom bubrenja od 1,02% u odnosu na SBP 1,15% i SHPP 1,24%. Gubitak pri kuvanju je bio značajno viši ($p<0.001$) kod testenine SHPP (11%) dok se SHBP karakterisala najmanjim gubitkom pri kuvanju. Nisu postojale značajne ($p>0.05$) razlike u površinskim svojstvima, izgledu površine i izgledu poprečnog preseka kuvanih testenina. Uočene su značajne razlike u obliku između testenina formulacije SHBP i SBP. Testirane formulacije bezglutenske testenine su uspešno proizvedene. Testenina SHPP (sirak-obogaćeni-krompir) je imala najbolja senzorska svojstva, fizička svojstva i prehrambenu vrednost u poređenju sa ostalim formulacijama i pokazala je najveći potencijal za komercijalizaciju.

Ključne reči: *bezglutenska testenina, sirak, ekstruzija, organoleptička svojstva, osobine pri kuvanju*

Received: *11 October 2023/* ***Received in revised form:*** *21 December 2023/ 31. January 2024/* ***Accepted:*** *21. February 2024*

Available online: *April 2024*