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Insights into sensory and hedonic perception of wholegrain buckwheat enriched pasta

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ABSTRACT

This study investigated different wholegrain wheat/wholegrain buckwheat blends to develop functional pasta with unique sensory properties. The impact of the buckwheat flour type (native or hydrothermally treated) and ratio between wholegrain wheat and buckwheat flour in pasta formulation on the sensory profiles and hedonic perception of pasta was studied. A range of techniques (principal component analysis, preference mapping, cluster analysis, penalty analysis) have evolved to combine data from sensory panel, data collected from consumers and data related to the product to provide valuable insights into the way in which sensory properties drive consumer preferences and how pasta can be design to give the sensory properties desired by the consumer. Generally, even though buckwheat flour incorporation decreased consumer acceptability, the results indicated that hydrothermal pre-treatment of buckwheat flour has promising potential to be implemented in the production process of buckwheat containing pasta, since this treatment was efficient in reducing pasta bitterness and grittiness which were negatively evaluated and strongly penalized by consumers.

1. Introduction

Besides bread, pasta is considered as staple food worldwide. Conventional pasta products have been made of refined wheat flour and water. The chemical composition of wheat depends on variety, agronomic and climatic conditions. Wheat grain contains endosperm, germ, and bran fractions. During the milling process, bran and germ fractions, rich in vitamins, minerals, antioxidants, proteins, and dietary fibres, crucial for a balanced diet, are removed (Vignola, Bustos, & Pérez, 2018). Although in the past cereal foods were based on the wholegrain flour, industrialization and milling industry development in 1900s caused increased production and consumption of refined white flour (Heiniö et al., 2016). This led to a decrease in the intake of dietary fibre and all nutrients present in outer grain layers (Slavin, 2000). In recent two decades, thanks to recommendations of researchers, food experts and dietitians, consumers have increasingly become aware of nutritional and functional aspects of wholegrain cereal products connecting consumption of these foods with reduced risk of cardiovascular disease, type II diabetes and cancer (Liu, 2007), as well as better weight balancing owing to the absence of constipation (Katcher et al., 2008).

Despite evident growing awareness of consumers of the health benefits of wholegrain foods intake, the consumption of these types of products is still below dietary recommendation (Ferruzzi et al., 2014) mainly due to inferior sensory properties (texture, taste and colour) in comparison to the refined ones which do not meet consumer expectations (Heiniö et al., 2016). This put research focus on the development of new technologies and products that would be interesting and acceptable for consumers. One strategy to increase wholegrain consumption among different segments of consumers is to use wholegrains for the production of foods that are already widely consumed, such as pasta. There are numerous papers about cooking quality, biochemical, technological and functional properties of wholegrain durum or common wheat and wheat bran enriched pasta (Aravind, Sissons, Egan, & Fellows, 2012; Ciccoritti, Nocente, Sgrulletta, & Gazza, 2019; Sobota, Rzedzicki, Zarzycki, & Kuzawińska, 2015). Mixed-cereal pasta, produced by mixing wholegrain flours of different cereals, and multigrain pasta made with different grains (cereals, pseudocereals legumes) have also been extensively investigated (Chillo, Laverse, Falcone, Protopapa, & Del Nobile, 2008; Linares-García, Repo-Carrasco-Valencia, Paulet, & Schoenlechner, 2019; Wójtowicz & Mościcki, 2014).

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Buckwheat (*Fagopyrum* spp.) is one of the underutilized pseudocereal crops that has enormous potential to be used as a functional ingredient in various foods (Gimenez-Bastida & Zielinski, 2015). Buckwheat possesses high flavonoid content, particularly rutin and quercetin that are not found in cereals. Furthermore, it is an excellent source of antioxidants, resistant starch, vitamins, proteins, minerals, and dietary fibres (Sakač, Torbica, Sedej, & Hadnađev). In addition to unique nutritional properties, buckwheat is becoming a popular ingredient in gluten free diet. Buckwheat proteins possess a well-balanced amino acid profile rich with arginine and lysine, which are limiting amino acids in cereal proteins (Bhinder et al., 2019). Consumption of buckwheat has been associated with hypocholesterolemic effect, suppression of colon and mammary carcinogenesis, constipation, and gall stone in animal studies (Tomotake et al., 2000). Even though buckwheat has numerous nutritional benefits, its consumption is still below dietary recommendation mainly due to a distinct bitter taste (Bhinder et al., 2019).

Although pasta is a suitable matrix for the incorporation of various functional ingredients, pleasurable sensory perception, particularly textural properties and taste, are limiting factors for their selection and dosing. Thus, sensory analysis is an unavoidable segment in the development of new functional pasta tailored to the consumers. There are numerous studies investigating nutritional, functional, and technological aspects of buckwheat flour incorporation in various food products including pasta. However, there is a scarcity of scientific articles giving a comprehensive insight into effects of buckwheat flour addition on pasta sensory properties and displaying essential attributes for a good sensory qualification. The aims of this study were to examine the sensory and hedonic aspects of buckwheat flour utilization in wholegrain wheat pasta fortification. To achieve these aims, sensory properties and consumers' acceptance of wholegrain wheat pasta enriched with two types of wholegrain buckwheat flour (hydrothermally treated and native wholegrain buckwheat flour) were evaluated and compared with wholegrain wheat pasta. This study allowed a deeper understanding of consumer preferences and concomitantly suggested a development trajectory for buckwheat implementation in pasta without compromising consumer acceptance.

2. Material and methods

2.1. Pasta samples

Seven types of wholegrain pasta samples were produced by substituting 10, 20, or 30% of whole wheat flour (moisture 12.02%, protein 13.60%, lipids 1.63%, ash 1.20%, reducing sugars 1.55%, and starch 72.00%) with hydrothermally treated (TBF; moisture 13.10%, protein 12.99%, lipids 3.43%, ash 2.38%, reducing sugars 1.89%, and starch 69.92%) or native wholegrain buckwheat flour (NBF; moisture 11.81%, protein 15.24%, lipids 3.24, ash 2.65%, reducing sugars 2.30%, and starch 71.60%), as described previously by Jambrec, Sakač, Mišan, Mandić, and Pestorić (2015). Briefly, TBF flour was obtained by milling buckwheat achenes 24 h h after autoclaving (120 °C and 0.2 MPa for 10 min, Autoclav STERICLAV e S AES-75, Raypa trade, Barcelona, Spain). Buckwheat flour was a mixture of the ground aleurone seed layer, germ, and a portion of hulls passed through the 0.149 mm screen sieve. The pasta samples were produced by using single screw extruder (Ital past Mac 60 Pasta Maker Extruder (Parma, Italy), capacity 80 kg/h) and dried in a dryer (Ital past D200, Parma, Italy) using a low temperature drying procedure for 13.5 h at approximately 50 °C. Pasta formulations together with physical properties are presented in Table 1. All the samples were shaped into tagliatelle. For evaluation tagliatelle was cooked according to AACC (AACC, 1995) (100 g of pasta was cooked in 1L of water with added 5 g of salt) until the optimum cooking time (OCT), was reached (Table 1). The OCT corresponded to the time necessary that the white core of tagliatelle disappear and was determined by compressing the tagliatelle sample between two transparent plastic plates at different times.

2.2. Sensory descriptive analysis

Sensory descriptive analysis was carried out both on dried and cooked pasta samples by a panel of 12 trained sensory assessors (8 females and 4 males aged 30–55 years) in the Accredited Sensory laboratory of the Institute of Food Technology, University of Novi Sad. All assessors were selected and trained following ISO 8586:2012, respecting all protocols to avoid harm and risks to the participants. All participants received written information about the study, and they signed informed consent to participate. Training sessions (3 sessions for 1.5 h) were performed with experimentally produced pasta samples and with different types of commercial wholegrain pasta ($n = 5$) to help in attributes selection and definition, scale usage and end anchors identification (Table 2). Previous methodological approach presented by Irie, K., Maeda, T., Kazami, Y., Yoshida, M., & Hayakawa, F. (2018) was used as basis for reference standards selection. Applied reference standards in our study were tailored to evaluated samples and available commercial products from the market. Panellists agreed about a list of 14 sensory attributes (3 attributes for uncooked and 11 attributes for cooked pasta; Table 2) that helped in profiling of appearance, odour, flavour, texture, and taste of pasta samples.

The intensities of perceived pasta attributes were evaluated on the 100 mm linear scale anchored with appropriate words (Table 2). The sensory evaluation was conducted as a balanced factorial design. The order of a sample presentation was specified by the Experiment design for sensory analysis with XLSTAT-MX (XLSTAT 2018.7. Addinsoft. http://www.xlstat.com/). Every panellist received 20 g of each pasta sample delivered individually on a white plastic plate (uncooked pasta) or in the thermal plastic cups (cooked pasta; served within 15 min after cooking), coded with three randomly chosen numbers. Samples were evaluated in duplicate in individual air-conditioned (22 °C) sensory booths. Room-temperature water was used for palate cleansing.

Table 1
Pasta samples formulation, dimensions and optimal cooking time.

Sample	Flour type			Pasta dimensions			OCT
	Wholegrain wheat (%)	NBF (%)	TBF (%)	Width (mm)	Thickness (mm)	Length (mm)	
Control	100	–	–	8.90 ± 0.50^a	1.30 ± 0.10^a	128 ± 3^a	11.0
10NT	90	10	–	9.20 ± 0.11^a	1.30 ± 0.10^a	124 ± 2^a	10.5
20NT	80	20	–	9.20 ± 0.13^a	1.30 ± 0.11^a	127 ± 4^a	10.0
30NT	70	30	–	9.10 ± 0.14^a	1.31 ± 0.09^a	126 ± 2^a	9.80
10T	90	–	10	8.91 ± 0.10^a	1.31 ± 0.10^a	128 ± 2^a	9.20
20T	80	–	20	8.90 ± 0.21^a	1.30 ± 0.11^a	125 ± 3^a	8.61
30T	70	–	30	8.91 ± 0.10^a	1.30 ± 0.20^a	126 ± 3^a	8.42

*NBF – native wholegrain buckwheat flour; TBF – hydrothermally treated wholegrain buckwheat flour; OCT – optimal cooking time; Control – pasta produced from wholegrain wheat flour; 10T, 20T, 30T – pasta samples containing 10, 20 or 30% of TBF; 10NT, 20NT, 30NT – pasta samples containing 10, 20 or 30% of NBF. Values in the same row marked with different small letter in superscript are statistically different ($p < 0.05$).

Table 2
Sensory attributes, definitions, end anchors and reference standards used in sensory analysis of whole grain pasta samples.

Sensory attributes	Descriptors	Definition with end anchors	Reference standards
Appearance			
	Brown colour intensity (uncooked pasta)	The intensity of brown colour identified in colour standard NCS Colour AB *(S3020-Y40R – S5020-Y20R)*	0 mm*:* S3020-Y40R 100 mm*:* S5020-Y20R
	Speckledness (uncooked pasta)	Amount of brown or black specks originating from bran or germ. *(small number – large number)*	5 mm: pasta made from durum wheat flour (e.g. "Barilla" tagliatelle n16) 75 mm: pasta with brans (e.g. "Morelli Ricciolina Pasta with Bran")
Odour			
	Cereal odour intensity	The intensity of odour associated with raw cereals topped with boiling water. *(none – intensive)*	30 mm*:* pasta made from 5 cereals (e.g. "Barilla Penne rigate 5 cereali"), cooked as recommended, served in covered cups 50 mm: blend of wholegrain wheat, spelt, barley, buckwheat, and oat grains cooked in water, served in covered cups
Flavour			
	Overall cereal flavour	Overall intensity of flavour associated with cereals topped with boiling water. *(none – intensive)*	50 mm*:* pasta made from 5 cereal (e.g. "Barilla Penne rigate 5 cereali"), cooked as recommended, served in covered cups 75 ml: blend of wholegrain wheat, spelt, barley, buckwheat, and oat grains cooked in water, served in covered cups
	Wheat flavour intensity	The intensity of flavour associated with wheat topped with boiling water. *(none – intensive)*	50 mm*:* pasta made from durum wheat flour (e.g. "Barilla" tagliatelle n16), cooked as recommended, served in covered cups 75 mm*:* cooked wheat grains
	Buckwheat flavour intensity	The intensity of characteristic nutty flavour associated with buckwheat topped with boiling water. *(none – intensive)*	75 mm: cooked buckwheat grains
Taste			
	Bitterness	The intensity of bitter taste associated with caffeine solution. *(none – intensive)*	*None:* filtered water 50 mm*:* 0.05% Caffeine Solution
Texture			
	Brittleness (uncooked pasta)	Capability of being bent and returning to original structure of the pasta strands. *(not at all brittle – very brittle)*	5 mm: wheat grissini (e.g. "Pardon grisine") 75 mm*:* pasta made from durum wheat flour (e.g. "Barilla" spaghetti)
	Firmness	Force required biting down on pasta strands between the molars. *(not at all firm – very firm)*	10 mm*:* over boiled pasta made of common wheat (e.g. „Danubius tagliatelle", recommended cooking time 6 min, boiled for 12 min) 75 mm*:* under boiled pasta made of durum wheat (e.g. "Barilla" tagliatelle n16, recommended cooking time 6 min, boiled for 4 min)
	Surface stickiness	Degree to which pasta strands adhering to each other. *(not at all sticky – very sticky)*	10 mm*:* under boiled pasta made of durum wheat (e.g. "Barilla" tagliatelle n16, recommended cooking time 6 min, boiled for 4 min) 75 mm*:* over boiled pasta made of common wheat (e.g. „Danubius tagliatelle", recommended cooking time 6 min, boiled for 12 min)
	Grittiness	Feeling of some particles of grains between the teeth. *(not at all grainy – very grainy)*	10 mm*:* peanut butter (e.g. "Granum") 50 mm*:* porridge made from boiled cornmeal (e.g. "Palenta Corn Product" 100 mm*:* crystallized honey
	Adhesiveness	Degree to which pasta strands adhering to the molars during mastication. *(not at all adhesive – very adhesive)*	10 mm*:* over boiled pasta made of durum wheat coated with oil (2%) (e.g. "Barilla" tagliatelle n16, recommended cooking time 6 min, boiled for 12 min) 75 mm: corn flake cookie (e.g. "Bonžita Ravanica doo")
Residual			
	Tooth packing	The amount of sample which remains between teeth after swallowing. *(none – very much)*	10 mm*:* pasta made from durum wheat flour (e.g. "Barilla" tagliatelle n16), cooked as recommended 100 mm: poppy seed cake (homemade)
	Aftertaste intensity	The intensity of aftertaste perceived 30 s after pasta swallowing. *(none – intensive)*	*None*: filtered water *Intensive:* espresso coffee (e.g. "Starbucks® Espresso Roast")

2.3. Consumer study

A total of 70 subjects were included in consumer study, 48 females and 22 males aged 18–75 years. Inclusion criteria: regular eaters of any kind of pasta (eats pasta at least once a week), willingness to participate in research, not suffering from food allergies. Prior to the evaluation, participants were instructed in detail regarding the study and they were told that they can stop testing at any time if they feel any discomfort. They were asked to fill out an anonymous questionnaire with their demographic data (age, gender, educational level, specific food frequency questions). The study was approved by the Ethics Committee of Institute of Food Technology in Novi Sad, University of Novi Sad, Serbia (Ref. No. 175/1/6-3).

Within the liking study, participants were asked to evaluate pasta samples for the degree of liking by using a 9 point hedonic scale (where

1 = extremely dislike and 9 = extremely like; the mid-point of the scale (5) = neither like nor dislike) for overall liking, liking of colour, liking of taste and liking of texture, in the order presented here.

Furthermore, participants were asked to evaluate the appropriateness of selected pasta properties by using 5-point just-about-right (JAR) scales (1 = too little, 3 = JAR, 5 = too much). They evaluated brown colour intensity (1 = too bright, 5 = too dark), graininess (not grainy enough – too grainy), surface stickiness (not sticky enough – too sticky), firmness (too soft – too hard), overall aroma intensity (not enough – too much) and bitter taste intensity (not bitter enough – too bitter). Subsequently, participants were asked to choose the most liked pasta and to elaborate or indicate reasons for that choice, as well as to express their purchase intention on a 5-point structured scale, where 1 = certainly would not buy and 5 = certainly would buy (Meilgaard, Civille, & Carr, 2007) for the evaluated sample. Portions (20 g) of cooked pasta samples were delivered individually in the thermal plastic cups (served within 15 min after cooking), coded with three randomly chosen numbers in a monadic way.

2.4. Statistical analysis

The data were processed statistically using the software package XLSTAT 2018.7. All sensory data were expressed by means ± standard deviation (SD). Analysis of variance (ANOVA) and Tukey's HSD test for comparison of sample means were used to identify sensory attributes that significantly discriminate among samples and to analyse variations among sensory profiles of the investigated pasta samples. The descriptive sensory attributes were submitted to Principal Component Analysis (PCA) and the obtained sensory map was used as a plot for positioning consumer overall liking data grouped into homogenous clusters (PREFMAP) (McEwan, 1996). The clustering of consumers (Agglomerative Hierarchical Clustering) was performed on centred and reduced overall liking scores, based on the Euclidian distance between the individual sets of preference scores and Ward's aggregation criterion. The decision of clusters number was made after observing the liking scores for the different number of cluster groups to find meaningful liking patterns that discriminated between groups. To confirm that the clusters differed from each other, the mean liking per sample was calculated, a one-way ANOVA was carried out and Fisher's LSD for liking ratings were applied as post hoc tests.

Penalty analysis was performed on the combination of JAR and overall liking data, for each product separately by using overall liking data and data collected on a JAR 5-point scale. Raw JAR data were grouped into three levels: 1 and 2 = too little, 3 = JAR, 4 and 5 = too much. The average liking was calculated for each level and the mean drops for the "too much" or "too little" levels. The penalty is computed as a weighted difference between the means of liking for JAR and for the two other levels taken together.

The parametric k proportion test (Chi-square test followed by Marascuilo procedure), was applied for responses on purchase intention to determine significant differences between samples.

The level of statistical significance for all performed statistical analyses was set at 0.05.

3. Results and discussion

3.1. Sensory descriptive analysis

Descriptive sensory are summarised in Table 3. According to the results, all selected attributes significantly ($p < 0.05$) discriminate among pasta samples and were useful in characterizing differences among them.

The samples significantly differed in appearance, both in brown colour intensity and in amount of brown or black specks originating from bran or germ. The control pasta sample was characterised with light brown colour, which was significantly lighter in comparison to the buckwheat-containing samples. Furthermore, the samples containing hydrothermally treated buckwheat flour were noticeable darker compared to the native buckwheat-containing counterparts. These colour differences could be attributed to the development of Maillard reaction brown polymers that are formed during heat treatment (Alongi, Melchior, & Anese, 2019). Zielinski, Michalska, Amigo-Benavent, del Castillo, & Piskula (2009) reported that, due to buckwheat roasting, the browning index of roasted samples was 33–36% higher in comparison to the unroasted samples. The darkening of colour of buckwheat groats during heat treatment was observed by Wronkowska, Piskuła, and Zieliński (2016), as well. The specks visibility was barely noticeable in the Control sample, while with increasing content of both types of

Table 3
Sensory descriptive analysis data and one-way ANOVA parameters for whole grain pasta samples.

Sensory attributes	Samples							One-way ANOVA		
	Control	10NT	20NT	30NT	10T	20T	30T	SS	F	p
Appearance										
Brown colour intensity	21.3 ± 2.5^{f}	28.9 ± 2.7^{e}	37.2 ± 2.2^{d}	45.1 ± 0.5^{c}	48.4 ± 2.3^{c}	55.9 ± 3.8^{b}	67.9 ± 3.4^{a}	4572	112	<0.0001
Speckledness	23.4 ± 3.2^{d}	37.5 ± 2.5^{c}	39.9 ± 1.4^{bc}	43.0 ± 1.0^{abc}	39.7 ± 2.5^{bc}	44.6 ± 2.5^{ab}	47.7 ± 2.5^{a}	1106	33.7	<0.0001
Odour										
Cereal odour intensity	27.8 ± 2.5^{e}	49.9 ± 2.6^{d}	61.9 ± 2.4^{c}	66.8 ± 3.3^{bc}	53.9 ± 2.5^{d}	72.6 ± 2.5^{b}	87.7 ± 2.5^{a}	6445	155	<0.0001
Flavor										
Overall cereal flavor	50.7 ± 2.6^{e}	62.9 ± 3.4^{d}	75.8 ± 2.6^{c}	95.5 ± 2.3^{a}	61.3 ± 1.9^{d}	67.3 ± 1.1^{d}	84.7 ± 4.2^{b}	4184	91.9	<0.0001
Wheat flavor intensity	48.6 ± 1.6^{a}	41.6 ± 0.6^{b}	35.5 ± 1.5^{c}	24.3 ± 2.2^{d}	23.9 ± 2.0^{d}	22.8 ± 3.7^{d}	16.2 ± 0.3^{e}	2464	104	<0.0001
Buckwheat flavor intensity	0.0^{e}	15.2 ± 1.1^{d}	30.9 ± 2.7^{c}	48.6 ± 5.1^{b}	33.9 ± 4.7^{c}	50.3 ± 3.4^{b}	70.1 ± 3.6^{a}	9855	141	<0.0001
Taste										
Bitterness	10.7 ± 2.5^{e}	32.9 ± 3.6^{c}	44.8 ± 2.2^{b}	64.7 ± 3.7^{a}	13.9 ± 0.0^{e}	15.3 ± 0.9^{e}	23.3 ± 3.9^{d}	6964	148	<0.0001
Texture										
Brittleness (uncooked)	56.8 ± 2.6^{a}	53.3 ± 2.7^{a}	44.1 ± 1.8^{b}	34.6 ± 3.8^{cd}	36.4 ± 1.3^{c}	34.8 ± 1.6^{cd}	28.4 ± 2.7^{d}	2011	53.5	<0.0001
Surface stickiness	52.4 ± 2.4^{c}	45.1 ± 2.3^{c}	28.6 ± 3.2^{d}	31.2 ± 2.2^{d}	64.8 ± 3.6^{b}	73.4 ± 1.9^{a}	51.9 ± 2.2^{c}	4832	119	<0.0001
Firmness (cooked)	24.7 ± 2.2^{d}	65.5 ± 2.6^{a}	58.0 ± 1.9^{a}	46.9 ± 1.7^{b}	43.9 ± 4.4^{b}	39.6 ± 3.0^{bc}	35.3 ± 2.2^{c}	3398	77.6	<0.0001
Grittiness	16.7 ± 2.5^{e}	35.4 ± 2.9^{c}	44.4 ± 3.2^{b}	54.3 ± 2.1^{a}	25.5 ± 2.7^{d}	29.1 ± 1.0^{cd}	32.7 ± 1.7^{c}	2757	78.8	<0.0001
Adhesiveness	32.9 ± 2.9^{c}	41.8 ± 2.8^{b}	36.6 ± 2.4^{bc}	20.9 ± 1.4^{d}	55.2 ± 3.3^{a}	53.9 ± 2.4^{a}	44.1 ± 4.4^{b}	2604	50.3	<0.0001
Residual										
Tooth packing	22.5 ± 2.5^{d}	25.7 ± 1.9^{cd}	31.8 ± 3.0^{bc}	33.3 ± 2.8^{abc}	33.4 ± 3.4^{ab}	34.3 ± 3.2^{ab}	40.5 ± 2.1^{a}	633	14.0	<0.0001
Aftertaste intensity	17.2 ± 1.4^{d}	25.9 ± 1.3^{c}	34.5 ± 1.1^{b}	50.9 ± 2.7^{a}	20.2 ± 1.6^{cd}	24.5 ± 1.7^{c}	34.4 ± 4.2^{b}	2344	76.6	<0.0001

Values are arithmetic mean ± standard deviation (N = 24, 12 assessors in two replicates; evaluated in a continuous 100 mm linear scale).
Values in the same row marked with different small letter in superscript are statistically different ($p < 0.05$).
10NT, 20NT, 30NT – pasta samples with added 10, 20, or 30% of common whole grain buckwheat flour; 10T, 20T, 30T – pasta samples with added 10, 20, or 30% of hydrothermally treated whole grain buckwheat flour.

buckwheat flour, speckledness became more noticeable.

Buckwheat containing pasta samples were considered more bitter in comparison to the Control sample. However, samples containing TBF were significantly less bitter in comparison to pasta with NBF. The pasta with 30% of NBF possessed the most profound bitter taste. Buckwheat is reported to have a bitter taste that is usually connected with the presence of quercetin which is naturally present in buckwheat to some extent but it also occurs in rutin degradation usually when buckwheat flour is mixed with water (Li, Li, Ding, & Park, 2008). In our previous work (Jambrec et al., 2015), authors reported that hydrothermal treatment of buckwheat grains reduced rutin conversion into quercetin to a great extent, thus pasta samples containing hydrothermally treated buckwheat flour possess lower content of quercetin. Accordingly, the less intense bitter taste observed in pasta samples with this flour can be attributed to that finding.

The wheat flavour was significantly ($p < 0.05$) more intense in the Control in comparison to the buckwheat containing samples. The buckwheat flour presence gives pasta a characteristic nutty flavour which caused a decrease in the wheat flavour intensity. The pasta samples containing different buckwheat flour were perceived as different in the intensity of buckwheat flavour. Namely, the addition of TBF contributed to a more intense buckwheat flavour. The pasta sample with 30% of TBF had significantly higher buckwheat flavour intensity in comparison to the other buckwheat containing counterparts.

Buckwheat flour addition significantly contributed to changes in textural properties of pasta, as well. Buckwheat containing pasta samples were significantly ($p < 0.05$) less brittle before cooking and more firm after cooking in comparison to the Control. Although results from some researchers indicated lower firmness of pasta enriched with brans (Chillo et al., 2008; Ciccoritti et al., 2019), our results are more in accordance with Aravind et al. (2012) and Vignola et al. (2018) who observed increase in firmness of cooked wholegrain pasta. Namely, these authors found a direct relationship between aleurone content, bran and germ incorporation and cooked pasta firmness. Moreover, they assumed that a high amount of lipid content present in wholegrains is binding to the starch granules making a firm starch gel in the pasta and making a firmer product. The higher lipid content of both types of used buckwheat flour (TBF 3.43%, NBF 3.24%), compared to the whole grain wheat flour (1.63%), could be explanation for the obtained results. Furthermore, the addition of NBF gave significantly ($p < 0.05$) less sticky, less adhesive pasta, with pronounced grittiness in comparison to the Control. Similar findings were reported by Chillo et al. (2008) who observed that spaghetti containing wholegrain buckwheat flour and brans in different ratios were less sticky in comparison to the control semolina spaghetti. According to Ciccoritti et al. (2019), lower stickiness of durum pasta enriched with wheat brans was due to the presence of fibres in brans which partially restricts the starch release during cooking. Contrary to this, in this study TBF containing pasta were perceived as stickier and more adhesive in comparison to the other samples. This may be explained with lower protein content found in used raw materials since pasta textural properties are mainly influenced by protein content (Wood, 2009). Although the perceived grittiness of these samples was higher in comparison to the Control, it was significantly reduced compared to the NBF containing samples.

The Control was almost evaluated without an aftertaste, while the samples with buckwheat flour were described with a noticeable more intense aftertaste, especially those with NBF. Similarly, Sobota et al. (2015) reported a specific aftertaste of the bran which remained in the mouth after swallowing durum wheat pasta enriched with common wheat brans.

3.2. Consumer study

3.2.1. Liking data

Overall and colour, taste and texture liking data were calculated for all consumers and per clusters, which was followed by one-way ANOVA analysis. Mean differences between pasta samples per clusters of consumers were compared by using Fisher's LSD ($p < 0.05$) (Table 4).

Analysing results for all consumers together, highly significant differences were found in consumers' overall liking ($F = 13.04$, $p < 0.0001$, for the product effect in the ANOVA), liking of colour ($F = 4.95$, $p < 0.0001$), liking of taste ($F = 13.93$, $p < 0.0001$) and liking of texture ($F = 12.94$, $p < 0.0001$) of the pasta samples, which suggests that samples caused varying affective responses to consumers. Scores for overall liking ranged from 5.35 to 7.35, showing that samples were classified as indifferent or moderately liked. The Control sample was the most liked, while sample 20NT was the most disliked. A similar pattern was observed for the other analysed properties. For the pasta samples containing 20 and 30% of NBF, analysed hedonic data were mostly classified as indifferent, except for liking of colour, for which scores indicated that it was slightly liked. Colour, taste and texture of the samples containing TBF was generally classified as slightly liked.

Comparing results for liking scores between clusters, it can be observed that the score of overall liking of pasta samples by identified clusters was mostly significantly different ($p < 0.05$). Considering the liking of the single attributes, clusters' hedonic response was significantly different only for the taste of sample 20NT and texture of the sample 20T.

3.2.2. External preference map

An External preference map (Fig. 1) illustrates consumer liking data related to the descriptive sensory data. Sensory attributes were overimposed as supplementary variables on the map. Results were presented in a two-dimensional factor plane which explains 89.42% of data variability. Factor 1 was positively correlated with brown colour intensity, speckledness, cereal odour, overall cereal flavour, buckwheat flavour and tooth packing; whereas it was negatively correlated with brittleness and wheat flavour intensity. Factor 2 was positively correlated with surface stickiness and adhesiveness, and negatively correlated with bitterness, grittiness and after taste intensity.

The three clusters of consumers were identified with different liking patterns. Demographic data for each cluster are presented in Table 5. All three cluster groups were modelled as vectors, and this model was not significant ($p > 0.05$) only for Cluster 3 ($p = 0.216$). A Prefmap (Fig. 1) depicted that consumers within Cluster 1 (40%) and Cluster 2 (31.43%) preferred the Control pasta, which has sensory properties that most resemble regular pasta with recognizable wheat flavour, without bitter taste and with low grittiness, moderate surface stickiness and adhesiveness. For these two clusters, especially for Cluster 1, buckwheat flavour is acceptable only if it is not too strong. In contrast to these two clusters, consumers in Cluster 3 (28.57%) showed the highest preference for the two pasta samples with TBF (10T and 20T) which had darker brown colour with noticeable specks originating from wheat and buckwheat brans, more intense cereal odour, pronounced buckwheat flavour, bitter taste and grittiness noticeable to a certain extent. Common to all clusters is that too intense bitterness and profound grittiness are strong detractors of liking.

3.2.3. Penalty and mean drop analysis

Penalty and Mean drop analysis reflect to what extent the product did not meet consumer's expectations. This analysis is used to identify potential directions for the improvement of pasta products since it identifies those attributes that are most penalising product performances. A point in the plot that shows a statistically significant mean drop and a percentage of consumers above the cut-off point (20%) is a cause for concern and suggests that the product has to be modified in the appropriate direction (Tomić et al., 2017).

Fig. 2 shows Mean drop analysis for the Control and pasta samples fortified with NBF and TBF. Those attributes in the figure that are highlighted suggest that the mean drop and overall penalty are significant, so that their adjustment is most needed. Although Control sample was most preferred by consumers (overall liking 7.35), results indicate

Table 4
Overall liking, and liking of colour, taste, and texture and samples sorted by decreasing preference order per cluster and for all consumers.

Sample	Liking score	Cluster 1 (40%)	Cluster 2 (31.43%)	Cluster 3 (28.57%)	All consumers
Control	Overall	7.57 ± 1.20	7.45 ± 1.29	6.94 ± 1.33	7.35 ± 1.30^{a}
	Colour	7.08 ± 1.14	7.38 ± 0.85	6.93 ± 1.56	7.13 ± 1.22^{a}
	Taste	7.31 ± 1.41	7.12 ± 1.32	7.03 ± 1.44	7.17 ± 1.40^{a}
	Texture	7.06 ± 1.32	7.23 ± 0.96	6.58 ± 1.94	6.98 ± 1.47^{a}
10NT	Overall	6.87 ± 1.43A	5.42 ± 1.70B	5.64 ± 1.40B	6.06 ± 1.67^{bc}
	Colour	6.76 ± 1.08	6.28 ± 1.63	6.59 ± 1.20	6.56 ± 1.33^{b}
	Taste	6.58 ± 1.52	6.1 ± 1.4	6.32 ± 1.36	6.35 ± 1.47^{b}
	Texture	5.91 ± 1.37	5.36 ± 1.59	5.55 ± 1.31	5.64 ± 1.46^{c}
20NT	Overall	6.04 ± 1.56A	5.26 ± 1.70AB	4.48 ± 1.40B	5.35 ± 1.69^{d}
	Colour	6.22 ± 1.32	6.17 ± 1.11	5.8 ± 1.2	6.08 ± 1.25^{c}
	Taste	5.64 ± 1.60A	5.39 ± 1.55AB	4.65 ± 1.27B	5.28 ± 1.56^{d}
	Texture	5.4 ± 1.5	5.4 ± 1.5	5.04 ± 1.42	5.29 ± 1.50^{c}
30NT	Overall	6.04 ± 1.40A	4.75 ± 1.86B	5.67 ± 1.17AB	5.53 ± 1.60^{d}
	Colour	6.58 ± 1.17	6.15 ± 1.34	6.35 ± 1.40	6.38 ± 1.27^{bc}
	Taste	5.4 ± 1.7	4.62 ± 1.93	5.61 ± 1.19	5.22 ± 1.70^{d}
	Texture	5.49 ± 1.48	4.98 ± 1.76	5.37 ± 1.36	5.3 ± 1.6^{c}
10T	Overall	6.12 ± 1.59	6.72 ± 1.41	6.22 ± 1.40	6.34 ± 1.51^{b}
	Colour	6.33 ± 1.40	6.6 ± 1.1	6.43 ± 1.11	6.44 ± 1.25^{bc}
	Taste	5.88 ± 1.59	6.24 ± 1.45	6.03 ± 1.32	6.04 ± 1.49^{bc}
	Texture	6.03 ± 1.55	6.53 ± 1.43	6.2 ± 1.2	6.23 ± 1.43^{b}
20T	Overall	6.18 ± 1.73B	6.1 ± 1.9B	7.27 ± 0.97A	6.47 ± 1.71^{b}
	Colour	6.44 ± 1.45	6.38 ± 1.27	6.78 ± 0.98	6.52 ± 1.29^{b}
	Taste	6.19 ± 1.80	6.14 ± 1.84	6.98 ± 1.05	6.4 ± 1.7^{b}
	Texture	6.17 ± 1.64B	6.27 ± 1.45AB	7.09 ± 0.89A	6.47 ± 1.48^{b}
30T	Overall	5.45 ± 1.63	5.61 ± 1.87	5.96 ± 1.41	5.65 ± 1.68^{cd}
	Colour	6.02 ± 1.43	6.21 ± 1.28	6.35 ± 1.09	6.17 ± 1.31^{bc}
	Taste	5.44 ± 1.66	5.8 ± 1.6	5.87 ± 1.24	5.68 ± 1.55^{cd}
	Texture	5.52 ± 1.56	5.9 ± 1.4	5.8 ± 1.0	5.72 ± 1.39^{c}
		Objects sorted by decreasing preference order			
	The most liked	Control	Control	10T	Control
		10NT	10T	20T	20T
		20NT	20T	Control	10T
		10T	10NT	30T	10NT
		20T	30T	10NT	30T
		30NT	20NT	20NT	30NT
	The most disliked	30T	30NT	30NT	20NT

Values are arithmetic mean ± standard deviation (N = 70 consumers, evaluated in a structured nine-point hedonic scale).
Different superscript letters within column (for all consumers only, within the same sensory attribute) indicate significant ($p < 0.05$) difference according to Fisher's LSD test.
Different capital letters within row indicate significant ($p < 0.05$) difference between clusters response, according to Fisher's LSD test (only cases where difference was significant are marked).

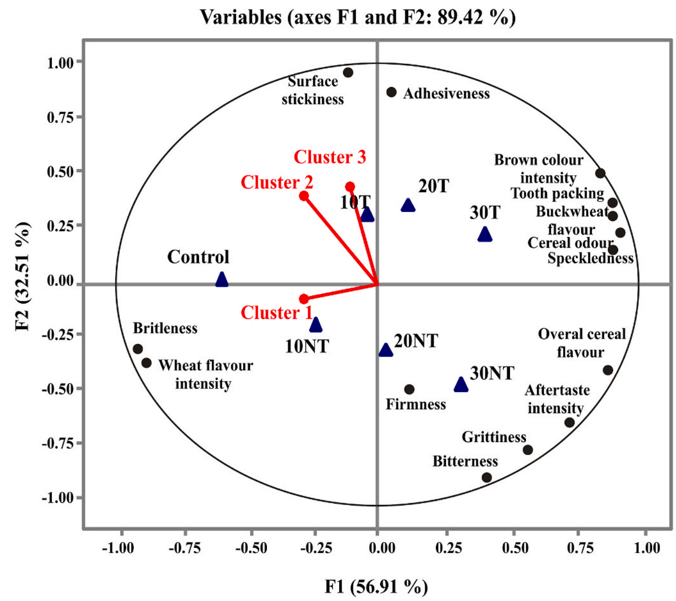

Fig. 1. External preference map – Projection of pasta samples, sensory attributes, and consumers clusters preferences.

Table 5
Demographic characteristic of consumer clusters.

Demographic parameter	Category	Cluster 1 (%)	Cluster 2 (%)	Cluster 3 (%)	Overall (%)
Gender	Female	64.3	59.1	85.0	68.6
	Male	35.7	40.9	15.0	31.4
Age	18–24	3.57	9.09	5.00	5.71
	25–34	25.0	31.8	40.0	31.4
	35–44	28.6	9.09	20.0	20.0
	45–54	28.6	36.4	30.0	31.4
	>55	14.3	13.6	5.00	11.4
Education	Secondary school	28.6	50.0	40.0	38.6
	Bachelor/MSc	25.0	22.7	35.0	27.1
	PhD	46.4	22.7	25.0	34.3
Have you ever heard for buckwheat?	Never	3.57	4.54	–	2.86
	I am informed that it exists	10.7	13.6	15.0	13.0
	I have read about it in magazines	39.3	31.8	50.0	40.0
	I have read about it in scientific literature	46.4	50.0	35.0	44.3
Eat wholegrain wheat pasta	Never	28.6	27.3	35.0	30.0
	Once	10.7	22.7	20.0	17.1
	Several times	60.7	50.0	45.0	53.0
Eat pasta with buckwheat	Never	46.4	36.3	20.0	35.7
	Once	14.3	36.3	35.0	27.1
	Several times	39.3	27.3	45.0	37.1

that consumers strongly penalized this sample since they consider it not aromatic enough. For all samples containing buckwheat flour at 20% and 30%, regardless of its type, consumers strongly penalize "too grainy" texture. Hence, for product optimisation, the finding of Hoppert et al. (2013) should be considered, reporting that when the product is

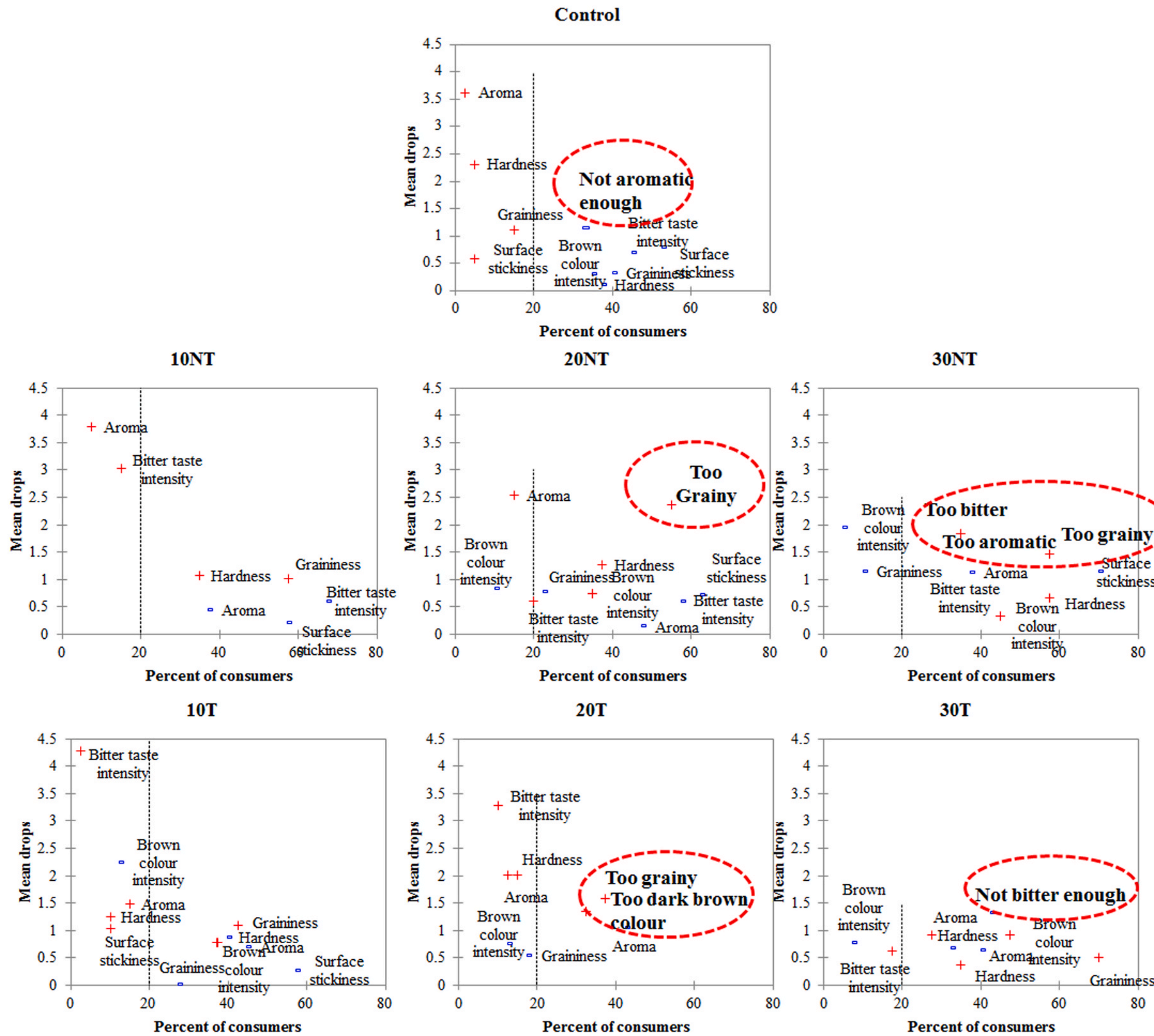

Fig. 2. Mean Drop analysis for whole grain wheat pasta (Control) fortified with native (10, 20 and 30NT) and hydrothermally treated (10, 20, and 30T) buckwheat flour (Mean drop and overall penalty are significant ($p < 0.05$) for highlighted attributes).

enriched with fibres from cereals, it is of great importance to pay special attention to the size of the particles incorporated in the product. Besides too noticeable graininess, the pasta 30NT is highly penalized being "too bitter" taste and "too aromatic". Interestingly, consumers considered pasta 30T as "not bitter enough". We suppose that this may be due to crossmodal correspondence between colour and taste (Spence et al., 2015), so that consumers expected stronger bitter taste due to intensive brown colour of this sample.

3.2.4. *Consumers purchase intention*

The results of the consumers' purchase intention of the pasta samples are presented in Table 6. The consumers' responses are related to their preferences and opinion about the most preferred sample. The Control sample was selected by 30% of consumers as the most liked pasta sample, elaborating that this sample is "close to the sensory profile of regular pasta", and that it possesses "good taste and texture". Accordingly, more than 65% of consumers responded that were willing to buy the Control sample. Among pasta samples supplemented with buckwheat flour, the most liked was the one with 20% of TBF (20T). More than 27% of consumers chose this sample as the best due to "nicely balanced all sensory properties although it contained buckwheat" and "good taste", and 68% of consumers stated that they "would certainly" or "would probably" buy this sample. On the other hand, 30NT pasta sample was chosen as the most liked only by 5% of consumers who

Table 6
Purchase intention of pasta samples (%).

Sample	Buying WDB + WPB	Not sure	Not buying WPNB + WDNB
Control	$(15 + 50)^{b}$	20^{a}	$(10 + 5)^{a}$
10NT	$(8 + 43)^{ab}$	20^{a}	$(28 + 3)^{a}$
20NT	$(8 + 28)^{ab}$	25^{a}	$(33 + 8)^{a}$
30NT	$(10 + 18)^{a}$	28^{a}	$(23 + 23)^{a}$
10T	$(5 + 43)^{ab}$	25^{a}	$(18 + 10)^{a}$
20T	$(5 + 63)^{b}$	10^{a}	$(18 + 5)^{a}$
30T	$(15 + 33)^{ab}$	20^{a}	$(30 + 3)$

*NBF – native wholegrain buckwheat flour; TBF – hydrothermally treated wholegrain buckwheat flour; OCT – optimal cooking time; Control – pasta produced from wholegrain wheat flour; 10T, 20T, 30T – pasta samples containing 10, 20 or 30% of TBF; 10NT, 20NT, 30NT – pasta samples containing 10, 20 or 30% of NBF; WDB – would definitely buy; WPB – would probably buy; WPNB – Would probably not buy; WDNB – would definitely not buy.
Values in the same column marked with different small letter in superscript correspond to significant difference between samples according to Chi-square test ($p < 0.05$) followed by Marascuilo procedure.

preferred “stronger aroma”, while consumers were generally not interested in its purchase, citing that it was “too bitter and grainy”.

4. Conclusions

This study indicates that the hydrothermal treatment of buckwheat flour seems to be efficient to defeat bitterness and grittiness, which were negatively evaluated and strongly penalized by pasta consumers. Control pasta sample was the most liked by consumers, followed by pasta containing 20 and 10% of hydrothermally treated buckwheat flour. The most disliked samples were those containing 20 and 30% of native buckwheat flour suggesting that hydrothermal treatment has the potential to be implemented as a pre-treatment for buckwheat that will be used not only for the fortification of pasta but also for different food products.

CRediT authorship contribution statement

Dubravka Škrobot: Conceptualization, Formal analysis, Writing – original draft, Investigation, Writing – review & editing. **Lato Pezo:** Formal analysis, Visualization, Writing – review & editing. **Jelena Tomić:** Conceptualization, Writing – original draft, Writing – review & editing. **Mladenka Pestorić:** Data curation, Methodology. **Marijana Sakač:** Supervision, Writing – original draft, Writing – review & editing. **Anamarija Mandić:** Resources, Supervision, Project administration.

Declaration of competing interest

The manuscript is original, and it strictly followed all ethical procedures. No part of the manuscript has been published before, nor is any part of it under consideration for publication in another journal. The authors declare that there is not any conflict of interest.

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