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Flavor and Texture as Critical Sensory Parameters of Consumer Acceptance of Barley Pasta

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ABSTRACT

The worldwide utilization of barley as an ingredient in food products like pasta or bread is appealing for its high content of β-glucan, whose positive effect in the prevention of cardiovascular disease and glycemic response is well known. Pasta samples prepared with semolina (WS) and barley flour (BF) at different substitution levels (10, 20, and 30%) were assessed for their sensory and textural properties using low and high temperature drying cycles. Consumer acceptance of different pasta samples was evaluated in order to find the best balance between perceived flavor/texture and nutritional properties (β-glucan content). Consumer liking for samples processed at low drying temperature (LT) tended to decrease with the increasing barley content, although only the sample containing 30% of barley was significantly less accepted. On contrast, pasta samples dried at high temperature (HT) were well accepted at all barley levels. A partial substitution of durum wheat semolina with barley flour in proportion of about 20–30%, provided that it is dried at HT, does not significantly affect the sensory quality, and it could be an effective way to increase soluble fiber intake (β-glucan content) in populations. An intake of one serving/day of 100 g of pasta supplemented with 30% barley in the flour mixture (WS/BF 70:30) could be suggested to provide a good level of daily soluble fiber necessary for achieving its functional effect.

INTRODUCTION

Well-being and wellness are in our everyday language, and diet is recognized to play an essential role in promoting good health, slowing the aging process, and promoting long life (29). Consumers are becoming more health-conscious and are demanding natural, wholesome, health-promoting foods (25); people interested in well-being have a conscious and controlled approach to food and look for quality products.

In this context there is a general consensus on the importance of fibers, vegetables, and whole grains. Fiber is now recognized as an important ingredient that can help consumers to fight obesity and improve their gut and general health.

A recent survey of the International Food Information Council (IFIC) reported that fiber is one of the top 10 food ingredients that consumers identified as having a health benefit beyond basic nutrition (25).

Both soluble and insoluble dietary fiber have been shown to reduce the risk of cardiovascular disease and the excessive increase in blood glucose after a meal, to lower serum cholesterol level and energy intake, and to be a preventive factor against colon cancer (19). These factors encourage the consumption of cereals, such as oat and barley, that have a good nutritional profile and represent a concentrated source of soluble fiber (β-glucans).

Barley (*Hordeum vulgare* L.) in Italy is primarily employed in feed or as raw material for malt production, a key ingredient in brewing and distilling processes and of high relevance also in the bakery products' domain. It is also used as coffee's surrogate, or as a food ingredient added to soups or potages, normally after pearling, as well as in the form of barley flakes added to muesli and other breakfast cereal mixes.

Barley is not an extensive part of the Italian diet, as is evidenced by its consumption levels compared to those of other grains. In any case, some of its nutritional properties appeal to modern consumers. This leads to the hypothesis that its market will gradually increase in the near future, especially in consideration of the booming market of functional foods, a key phenomenon to apply strategies for barley's value as food in human consumption.

Barley is a valuable source of complex carbohydrates, proteins, vitamins, minerals, and both soluble and insoluble fiber (34), and it is also a good source of antioxidants (tocotrienols) (7,14,30,31). Its utilization as human food is even more encouraged in light of the most recent recommendations of the International Dietary Guidelines that recognize the value of a significant intake of whole grain per day in the diet (18,35).

The use of barley as an ingredient in functional foods is appealing for its high level of β-glucans, a main component of soluble dietary fiber that has been recognized as having important positive effects on coronary heart disease and glycemic response (2,13,33). In fact, among all the cereal grains, barley contains the highest level of β-glucans, covering the range of 3–11% on a dry basis (8), which is equivalent to or greater than that found in whole-grain oats (26). Numerous evidences of the functional properties of barley's β-glucans are provided in the literature (3,21,22,24,28), and this thesis was assessed on grain products such as bread (6), pasta, or other products that can be easily integrated in the daily diet (5,38). Bourbon et al (5) found that carbohydrate was more slowly absorbed from high-fiber pasta test meals compared to a low-fiber test meal consisting of pasta made with durum wheat flour. Consumption of the barley-containing pasta appeared to stimulate reverse cholesterol transport, which may contribute to the cholesterol-lowering ability of barley.

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Commercial durum wheat pasta has been found to produce low postprandial blood glucose and insulin responses (4). Yokoyama et al (38) showed that such responses can be further lowered by the incorporation of β-glucans into pasta.

On May 22, 2006, the U.S. Food and Drug Administration (FDA) announced a rule allowing foods containing barley to claim that they reduce the risk of coronary heart disease (37). According to the respective interim final rule, whole grain barley as well as dry milled barley products such as pearled barley kernels, flakes, grits, and flour that provide at least 0.75 grams of soluble fiber per serving may bear the health claim (36). The efficacy of this dose of fibers in reducing serum lipid risk factors for cardiovascular disease, assuming an intake of four servings/day, has been confirmed by randomized controlled crossover trials (20).

Pasta is a very popular product worldwide; this success is due to the fact that it is relatively simple to manufacture, produced in a variety of shapes for different moods and needs, easy to store for long periods, easy to prepare, and has good nutritional quality. Durum wheat is the best raw material for pasta processing; other cereals can also be used but the final product is less satisfactory for traditional pasta consumers (9).

The partial substitution of durum wheat semolina with barley flour, with its high soluble fiber content, can be an effective way to increase ß-glucan intake in the population. However, barley pasta flavor and texture needs to be tailored to gain acceptability. Pasta quality has to meet certain consumer expectations and criteria for color, flavor, firmness, springiness, and to be nonsticky. Research was undertaken on long-cut pasta samples (spaghetti) prepared on a pilot plant from durum wheat semolina mixed with barley flour at 10, 20, and 30% substitution levels for monitoring texture and flavor qualities of barley pasta and modeling the influence on consumer liking in order to find the best balance between nutritional value and sensory quality.

MATERIALS AND METHODS

Materials

One naked Italian barley variety, *Zacinto*, was milled in an industrial plant. Flour including the fine bran was used in mixtures with a commercial durum wheat semolina. Replacement of semolina with barley flour was used at 10, 20, and 30% to produce the pasta samples. Samples were analyzed by standard International Association for Cereal Science and Technology (ICC) procedures for total protein (N × 5.70) (Standard method No. 167), gluten content (Standard method No. 137), and β-glucans (McCleary Method, Megazyme diagnostic kit, Megazyme International Ireland Ltd.) (Standard method No. 137). The rheological properties of the dough were determined with an alveograph (Standard method No. 121 ICC 2003), except that the dough was mixed for 4 min and, after a rest of 18 min, mixed again for 4 min. Table I reports the characterization of raw materials used for pasta production (16).

Pasta Processing

Semolina with different substitution levels of barley flour was mixed with tap water to obtain a total dough water content of 32–33%. The dough was processed into spaghetti (1.65 mm thickness) using a pilot plant constituted by a laboratory press (Serma, Italy) with a capacity of 1.5–3.5 kg and by a laboratory dryer (Afrem, France). The extrusion conditions applied were 50 ± 5°C, pressure 60 ± 10 atm, and vacuum 700 mm Hg.

Two procedures were applied for drying pasta: low temperature (LT) for about 20 h at T 50°C and high temperature (HT) for about 8 h reaching Tmax 90°C. The relative diagrams are reported in Fig. 1.

Sample Preparation

Pasta samples were cooked at the optimal cooking time, which was determined before the real test by repeated evaluations every 30 s until disappearance of the continuous white line visible at the centre of a crushed piece of pasta using a Plexiglas crushing plate (17). The cooking process was standardized for all the samples: 100 g of pasta in 1,000 ml of tap water with no salt addition (for evaluation by sensory panel) and the heat regulated to maintain a slow boil till its optimum cooking time. Pasta was then drained and soon served to the panelists or used for instrumental texture determinations.

Sensory Profiling Analysis

Evaluations took place in a sensory laboratory equipped with testing booths and a products preparation area. Descriptive profiling by nine trained assessors was used to provide the general view of the perceived flavor and textural properties of the cooked

Table I. Raw material characteristics

Sample	Protein content (% d.m.)	Gluten content (% d.m.)	Alveograph (W)	β-glucan content (% d.m.)
Semolina 100% (WS)	10.7	7.4	145	0.4
Barley flour 100% (BF)	16.0	n.d.	n.d.	4.8
WS/BF 90:10	11.3	7.0	120	0.8
WS/BF 80:20	11.5	6.0	100	1.3
WS/BF 70:30	13.2	2.9	100	1.7

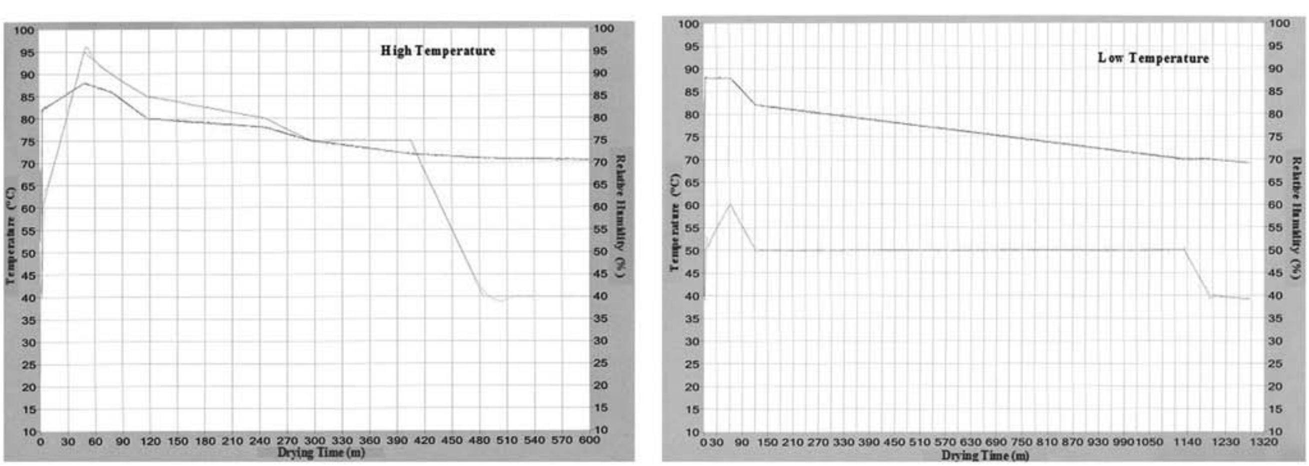

Fig. 1. Processing diagrams for low-and high-temperature drying.

pasta samples evaluated under red light to mask the samples' color, done to avoid any association of flavor or texture properties to differences in appearance. Texture attributes were evaluated either orally or manually. The descriptor definitions, scale anchors, and evaluation techniques were agreed upon by assessors during training (Table II). Reference pasta samples were prepared using 100% high or low quality durum wheat semolina, and 100% barley pasta samples, produced either at low or HT drying and used during the training sessions for panel calibration.

For the test sessions a randomized complete block design was used with two repetitions in different sessions (days). Each day the six samples were presented one at a time.

Hedonic Evaluations

To be eligible consumers had to meet the following requirements: ages of 21–60 years, regular consumption of durum wheat pasta (between four and seven times per week), and consumers of pasta prepared with other cereals than durum wheat (minimum frequency once a month). Eighty consumers that met these requirements were recruited for a liking test, but the experiment concluded with seventy-two respondents (22% male; 78% female; ages 25–50) who participated in two evaluation sessions. Samples were rated for overall liking on a nine-point hedonic scale from one meaning dislike extremely to nine meaning like extremely, with five meaning neither like nor dislike (32). Separate scores for visual attractiveness, flavor, and texture liking were also collected on a nine-point scale with the same anchor points as overall liking. No reference sample was

Table II. Definition of sensory attributes

Descriptors	Definition/description	Scale anchors 0	Scale anchors 9
Springiness	Texture attribute evaluated by manipulating samples using hands. (Evaluate the degree of deformation [length extension] of one strand of spaghetti before breaking by applying a constant light tensile strength with fingers positioned about 10 cm apart.)	It breaks with no deformation	Large deformation
Total odor	The overall aromatics impression perceived by the sense of smell (orthonasal).	Null	Strong
Semolina-like odor	Olfactive impression associated with cooked durum wheat semolina perceived via orthonasal.	Null	Strong
Cooked odor	Olfactive impression associated with temperature treatment perceived via orthonasal.	Null	Strong
Barley-like odor	Olfactive impression associated with barley cereal perceived via orthonasal.	Null	Strong
Sweet	Basic taste produced by dilute solution of various substances (e.g., glucose) perceived on the tip of the tongue. (Measured during chewing, blocking the olfaction through the use of nose clips.)	Null	Strong
Astringent	Describes the sensation of tingling, prickling, or shrinking on the tongue or mucosal surface in the mouth that persists after swallowing.	Null	Strong
Bitter	Basic taste produced by dilute solutions of various substances (e.g., caffeine) perceived at the back of the tongue. (Measured during chewing, blocking the olfaction through the use of nose clips.)	Null	Strong
Total flavor	Intensity of the overall impression originated by the volatile (retronasal), taste, and mouthfeel sensations released during chewing.	Null	Strong
Semolina-like flavor	Aroma associated with cooked durum wheat semolina perceived by olfactory receptors via orthonasal.	Null	Strong
Barley-like flavor	Aroma associated with barley cereal perceived by olfactory receptors via retronasal.	Null	Strong
Surface roughness	Geometric texture property that describes the impression of a smooth or rough pasta surface, perceived by manipulating a strand of spaghetti in the mouth before chewing.	Smooth	Rough, coarse
Firmness	The force required to compress the spaghetti between the molar teeth when biting down evenly during the first bite. (Evaluate the force required to compress two strands of standard-length spaghetti rolled up with a fork between molar teeth when biting down evenly.	Soft	Firm
Fiber	Describes a perception during chewing that the product contains fibrous particles of different shape and dimension (hard, coarse).	Null	Abundant
Stickiness	The degree of strand to strand adhesion. (Roll up with a fork a portion of 2–3 strands of spaghetti and chew normally. Evaluate the characteristic of the pasta pieces to slide smoothly or adhere to each other).	Loose	Sticky
Adhesiveness (to teeth)	Characteristic of the pasta pieces to adhere to teeth during chewing. (Roll up with a fork a portion of 2–3 strands of spaghetti, chew normally, and evaluate the amount of product adhering to teeth during and after chewing).	Nonadhesive	Adhesive
Homogeneous texture	Uniformity of the pasta texture. (Roll up with a fork a portion of 2–3 strands of spaghetti, chew normally, and evaluate the texture for evenness from surface to the central part of the strands of spaghetti).	Totally uneven	Completely even

provided to the consumers. A minimum of information about the test material was given. Assessment was performed in a test room for sensory evaluations with separate booths. Samples were prepared the same way as for objective evaluations by trained panel, except for the addition of salt (5 g/l). A randomized complete block design was used with no repeated assessment.

Instrumental Texture Determination

The analysis of the textural characteristics of the samples of pasta was performed using a Stable Micro System (SMS) (TA-XT2i, Godalming, Surrey, UK). The following parameters were determined:

Firmness. Five strands of cooked spaghetti were aligned side by side on the plate of the SMS instrument. The instrument was equipped with a Perspex blade (1 mm thickness; code A/LKB-F) to cut the spaghetti strands. The blade was lowered into the sample at a crosshead speed of 0.17 mm/s. The shear work (area under the curve) was the parameter determined and used as a measure of firmness (1). Five replicates of each sample were carried out.

Elasticity. One end of a strand of cooked spaghetti was fixed at the crosshead and the other fixed to the instrument platform using tensile grips (code A/SPR). The test was carried out at a crosshead speed of 3 mm/s. The elastic modulus (evaluated from the initial slope of the stress-strain curve), the force at the strand rupture (tensile strength), and the elongation at the strand rupture were measured. Ten replicates of each sample were performed (10).

Adhesiveness. For the measurement of this parameter, 10 strands of cooked spaghetti were aligned side by side on the plate of the SMS instrument. The instrument was equipped with a plunger (38×50 mm^2 contact surface; code HDP/PFS). A Plexiglas plate with an opening (40×52 mm^2) for plunger-to-sample contact was placed on the spaghetti as a sample retainer. The weight of the plate was sufficient to prevent changes in the spaghetti strand alignment. The plunger moved down at a speed of 5 mm/s onto the spaghetti surface. Once a compression force of 1,000 g was reached, the plunger stopped for 2 seconds and then lifted from the surface at a speed of 10 mm/s. The maximum tensile force recorded during the separation of the plunger from the sample surface was taken as a measure of adhesiveness. Three replicates of each sample were performed (39).

Statistics

To study sample variation, analysis of variance (ANOVA) of sensory attributes and physical parameters and principal component analysis (PCA) to the whole matrices of descriptive sensory data and instrumental data were applied.

The relationships between sensory data, physical data (x-variables), and overall liking (y-variable) by consumers were investigated by partial least square regression (PLSR). Regression coefficients were estimated and significance determined.

In multivariate analysis, average responses over replicates were used. Variables were mean centered and scaled at unit variance prior to analysis. All analyses were performed by Unscrumbler v. 9.2 software (Camo AS Trondheim, Norway).

RESULTS AND DISCUSSION

Raw Materials

As shown in Table I, there was a low content of β-glucans in the durum wheat semolina, whereas it reached the value of about 1.7% (d.m.) in the flour mixture with 30% barley. Protein content rose with the increase of barley in the flour mixture because of the barley's high endogenous protein content with respect to durum wheat flour. However, barley does not contain gluten; consequently, an increase of barley in the flour mixture induced a decrease in the gluten content, with a relative difference of 58.6% between WS/BF 90:10 and WS/BF 70:30 substitutions, as well as a reduction of the alveographic area.

Sensory Evaluations

Each of the 17 sensory attributes evaluated by the trained panel were examined by mixed model ANOVA, including the effect of barley content (X), drying condition (Y), and replicate evaluations (K) as fixed treatment effects and barley content and drying condition as an interaction term (XY). Mean values and ANOVA results of the sensory data are summarized in Table III. The Duncan mean separation test was used to differentiate samples at $P = 0.05$. Barley content was significant for all descriptors (except firmness), as well as the drying process, for most attributes. Only two attributes showed a significant replicate effect (springiness and homogeneous texture).

Attributes of aroma (total odor/flavor, semolina-like odor/flavor, cooked odor, barley-like odor/flavor) via both olfactive or gustative perceptions were equally affected by the barley addition (X) and drying condition (Y) in pasta processing; however, generally, barley addition had an equal or greater effect compared to drying. The basic tastes sweet and bitter and the mouthfeel sensation of astringent were dependent on

Table III. Mean, F values, and significant effects of factors on sensory properties

	LT			HT			X	Y	K	XY
	10%	20%	30%	10%	20%	30%				
Springiness	2.9^{bc}	2.8^{bc}	1.5^{a}	4.2^{d}	3.3^{c}	2.5^{b}	32.5***	27.7***	6.8*	2.1
Total odor	5.7^{a}	5.8^{a}	7.1^{c}	6.1^{ab}	6.3^{b}	7.0^{c}	18.8***	6.4*	0.6	0.5
Semolina-like odor	4.4^{c}	4.0^{c}	1.0^{a}	4.0^{c}	2.2^{b}	1.2^{a}	121.3***	30.1***	0.4	10.9***
Cooked odor	0.1^{a}	0.9^{b}	2.8^{d}	2.0^{c}	3.6^{e}	4.4^{f}	82.7**	257.0***	3.6	2.6
Barley-like odor	3.4^{a}	4.0^{b}	6.4^{d}	4.0^{b}	5.3^{c}	6.3^{d}	113.2***	29.9***	0.7	5.6**
Sweet	2.6^{a}	3.1^{bc}	3.1^{bc}	2.9^{ab}	3.2^{bc}	3.4^{c}	4.6*	7.1**	0.6	0.9
Astringent	0.4^{a}	0.6^{a}	2.0^{b}	0.5^{a}	0.8^{a}	1.7^{b}	40.6***	0.1	0.2	3.3*
Bitter	0.3^{a}	0.5^{ab}	1.5^{c}	0.3^{a}	0.8^{ab}	0.9^{b}	19.3***	1.5	0.0	6.3 **
Total flavor	5.1^{a}	5.5^{a}	6.7^{c}	5.6^{a}	6.1^{b}	6.7^{c}	34.1***	12.2***	0.4	0.5
Semolina-like flavor	3.3^{c}	3.3^{c}	0.9^{a}	3.4^{c}	2.1^{b}	1.2^{a}	71.9 ***	8.1**	0.1	5.6 **
Barley-like flavor	2.6^{a}	3.8^{c}	6.1^{e}	3.3^{b}	5.1^{d}	5.7^{e}	157.2***	14.8***	1.8	11.4***
Surface roughness	2.5^{a}	2.9^{a}	5.1^{c}	2.6^{a}	3.7^{b}	4.7^{c}	85.0***	3.1	0.1	5.5**
Firmness	3.1^{a}	3.4^{a}	3.5^{a}	4.3^{b}	4.3^{b}	4.3^{b}	2.3	26.9***	0.6	3.2*
Fiber	2.1^{a}	2.6^{b}	6.0^{e}	2.2^{ab}	3.9c	4.9^{d}	148.7***	5.5*	0.3	13.3***
Stickiness	4.4^{b}	4.2^{b}	5.9^{c}	3.7^{a}	4.1^{ab}	4.3^{b}	11.6***	19.9***	1.4	2.5
Adhesiveness (to teeth)	4.3^{ab}	4.5^{b}	5.3^{c}	3.9^{a}	4.3^{ab}	4.8^{bc}	10.3***	2.6	0.1	0.4
Homogeneous texture	5.8^{bc}	5.7^{bc}	4.7^{a}	6.0^{c}	5.4^{b}	4.7^{a}	31.6 **	0.1	3.9 *	1.4

X—barley content; Y—drying; K—replicate; LT—low temperature drying cycle; HT—high temperature drying cycle; *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$. Different letters in the row indicate significant differences at $P \leq 0.05$ (Duncan's test).

the barley content and the sweet taste was affected also by the drying process. A slight astringent sensation was significantly higher only in the samples with 30% barley. All texture parameters except firmness were affected by the barley content. Differences of mean values are evident for the samples with 30% barley but in some cases are not significant between samples containing barley at 10% and 20%. Firmness was only affected by the drying process. Significant barley content and drying condition interactions were found for about half of the descriptors and texture parameters.

ANOVA performed on the hedonic responses indicated that the overall liking varied significantly ($P < 0.05$) among the pasta samples with respect to barley content and drying process. The lowest mean overall liking score (5.5) was for the sample supplemented at 30% barley and dried at LT conditions (Table IV). The HT drying cycle generated good acceptability of the samples at all substitution levels and higher scores than the LT drying.

Instrumental Texture Evaluations

The results of the instrumental determinations of texture characteristics are shown in Table V. Barley content had an effect on the elastic modulus, but it was not possible to individuate a clear trend. There was no difference between the samples containing 20% and 30% of barley when the HT drying cycle was applied, but the elastic modulus was lower for the sample with 10% barley. For the LT drying treatment, no difference was found between the samples with 10% and 20% barley, whereas a higher value was obtained for the sample with 30% of barley. Drying temperature did not influence the elastic modulus. Samples dried at HT had significantly higher tensile strength than the samples dried at LT. No effect of barley content was observed.

HT pasta generally resulted in higher elongation. A decrease of the values of this parameter was observed in relation to the barley content: the sample with 30% barley showed lower values than those of 10%.

The content of barley had no effect on the firmness of LT samples, whereas in the HT samples the firmness of the 20% barley sample was slightly lower. All the HT samples were firmer than the LT samples. Finally, no difference in the adhesiveness was detected among the samples tested. Significant barley content per drying interactions were found for the elastic modulus and firmness. Structural and textural properties of cooked pasta depend on changes in protein and starch fractions during drying. HT drying increases the extent of protein denaturation. The denaturation of wheat protein promotes cross-linking of the two gluten proteins, glutenin and gliadin, through disulfide bonds, which increases the rigidity and the strength of the protein network (11,15,27,39). It is likely that firmness, measured by a cutting test, is primarily affected by changes in the protein fraction (39). That can explain the higher values of firmness showed by the HT pasta. It has been reported also that pasta dried at HT presented lower stickiness due to the reinforcement of protein structure, reduced swelling of starch, and disintegration of, granules (12,23). However, in our samples the adhesiveness was affected neither by barley content nor drying temperature.

Relationships Between Sensory and Physical Measurements and Consumer Liking

Multivariate analyses (PCA, PLSR) were applied to better study the relationships between sensory data from the trained panel's physical measurements of cooking quality and consumer overall liking. The averaged descriptive attributes and physical parameters were preprocessed by mean-centering (subtract mean from each variable) and standardization (weighted by standard deviation) and subjected to principal component analysis (cross-validation). The first two principal components accounted for 92% of the total variance. The first component (67% of explained variance) distinguished the samples for their odor, taste, and flavor properties, from positive to negative semi-axis with the increase of barley flour content in the formulation of pasta samples (Fig. 2A). The parameters that contributed most to the first dimension were the sensory attributes total odor (89% of variance), barley odor (97%), astringent (95%), bitter taste (91%), total flavor (94%), barley flavor (95%), surface roughness (99%), fiber (99%), and the instrumental parameter elastic modulus (67%), all negatively loaded, and semolina odor (97%), semolina flavor (99%), homogeneous texture (96%), positively loaded (Fig.2B). The second principal component (25% of

Table VI. Regression coefficients for prediction of overall liking

Sensory descriptors	
Springiness	0.123
Total odor	0.012
Semolina-like odor	–0.009
Cooked odor	0.094
Barley-like odor	0.009
Sweet	0.037
Astringent	–0.039
Bitter	–0.052
Total flavor	0.011
Semolina-like flavor	0.011
Barley-like flavor	–0.001
Surface roughness	–0.021
Firmness	0.151
Fiber	–0.027
Stickiness	–0.124
Adhesiveness (to teeth)	–0.099
Homogeneous texture	0.022
Elastic properties	
Tensile strength (N)	0.172
Elastic modulus (N/mm)	0.055
Elongation (mm)	0.140
Adhesiveness (N)	–0.094
Firmness (g)	0.147

Table IV. Mean score of hedonic evaluations by the consumer panel

	LT			HT			
	10%	20%	30%	10%	20%	30%	F
Overall liking	6.1^{bc}	5.9^{b}	5.5^{a}	6.8^{cd}	6.9^{d}	6.5^{bcd}	3.1*
Visual attractiveness	5.6^{a}	5.5^{a}	5.5^{a}	6.7^{b}	6.9^{b}	6.8^{b}	6.3***
Liking of flavor	6.1	5.9	5.7	6.7	6.6	6.3	1.6
Liking of texture	5.8^{a}	5.4^{a}	5.6^{a}	6.6^{b}	6.9^{b}	6.9^{b}	6.5***

LT—low temperature drying cycle; HT—high temperature drying cycle; ***$P \le 0.001$; **$P \le 0.01$; *$P \le 0.05$. Different letters in the row indicate significant differences at $P \le 0.05$ (Duncan's test).

Table V. Results of the instrumental texture determinations

	LT			HT			X	Y	XY
	10%	20%	30%	10%	20%	30%			
Elasticity (elastic modulus)	0.020^{ab}	0.017^{a}	0.023^{bc}	0.019^{a}	0.023^{bc}	0.024^{c}	6.09**.	3.48	3.82*
Elasticity (tensile strength)	0.260^{a}	0.250^{a}	0.242^{a}	0.351^{b}	0.343^{b}	0.329^{b}	1.72	108.45***	0.05
Elasticity (elongation)	26.01^{b}	25.82^{b}	14.36^{a}	33.60^{c}	31.24^{bc}	25.72^{b}	11.45***	20.09***	0.82
Firmness	223.21^{a}	228.56^{a}	220.50^{a}	299.73^{c}	262.59^{b}	282.35^{c}	3.80*	145.67***	7.17**
Adhesiveness	494	445	434	451	361	435	1.94	2.11.	0.72

X—barley content; Y—drying; K—replicate; LT—low temperature drying cycle; HT—high temperature drying cycle; ***$P \le 0.001$; **$P \le 0.01$; *$P \le 0.05$. Different letters in the row indicate significant differences at $P \le 0.05$ (Duncan's test).

variance) separates the products for drying process. Samples manufactured under HT drying cycle distinguished for higher firmness (93%) and for the physical parameters tensile strength (96%) and firmness (86%), positively loaded, demonstrating that these quality parameters were dependent of the drying cycle, but not of the barley flour addition in the range considered in the samples' formulation.

The variance of the other textural sensory properties (adhesiveness to teeth, stickiness, and springiness), of sweet taste, of cooked flavor, and of the physical measurements elastic modulus and elongation was distributed on both the dimensions, whereas for the instrumental adhesiveness three dimensions were necessary to explain the total variance (96%) (Fig. 2B). The results have show a strong correlation between texture parameters measured by instrumental and sensory methods. Correlations of the perceived firmness to tensile strength (0.96; $P < 0.01$), and to the instrumental firmness (0.91; $P < 0.05$) were observed. The textural parameter elongation correlated positively to springiness (0.96; $P < 0.01$) and negatively to stickiness (–0.97; $P < 0.001$) and adhesiveness to teeth (–0.91; $P < 0.01$). There was no correlation between

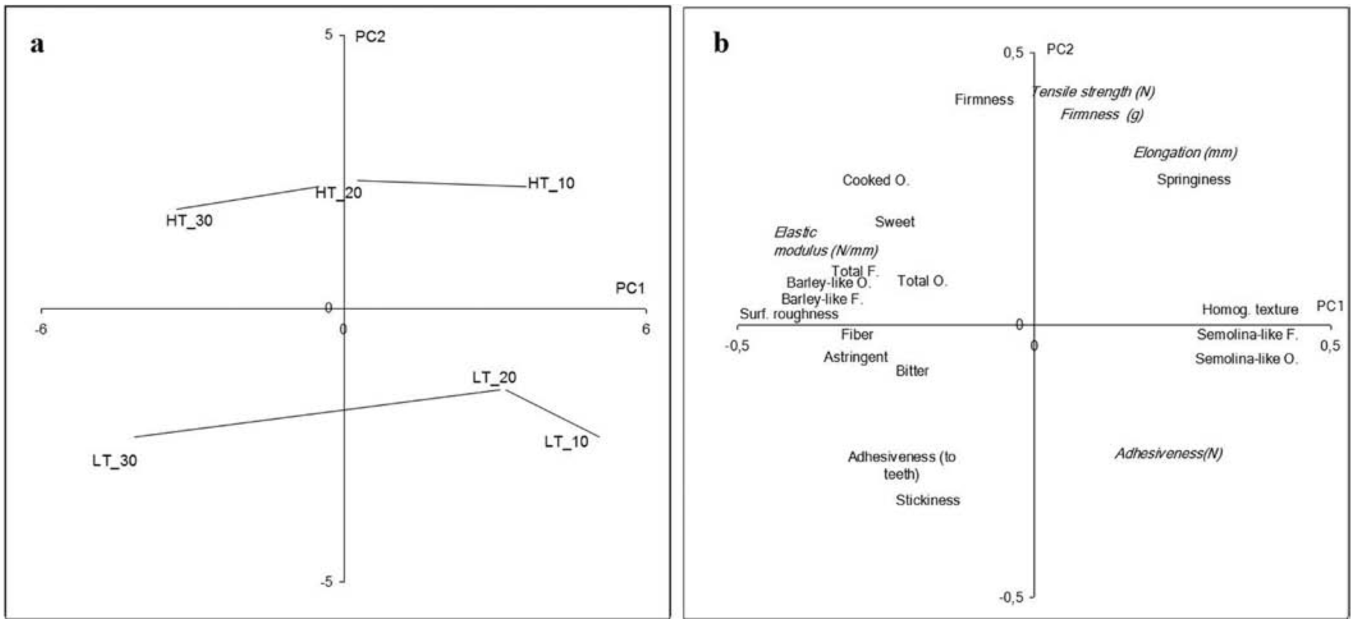

Fig. 2. Principal component analysis sample scores (a) and variables correlation loading (b) plots of PC2 (abscissa) vs PC2 (ordinate) (matrix of sensory attributes and instrumental variables). PC1—Explained variance 67%; PC2—Explained variance 25%; HT_10—high drying temperature cycle, barley flour at 10%; HT_20—high drying temperature cycle, barley flour at 20%; HT_30—high drying temperature cycle, barley flour at 30%; LT_10—low drying temperature cycle, barley flour at 10%; LT_20—low drying temperature cycle, barley flour at 20%; LT_30—low drying temperature cycle, barley flour at 30%.

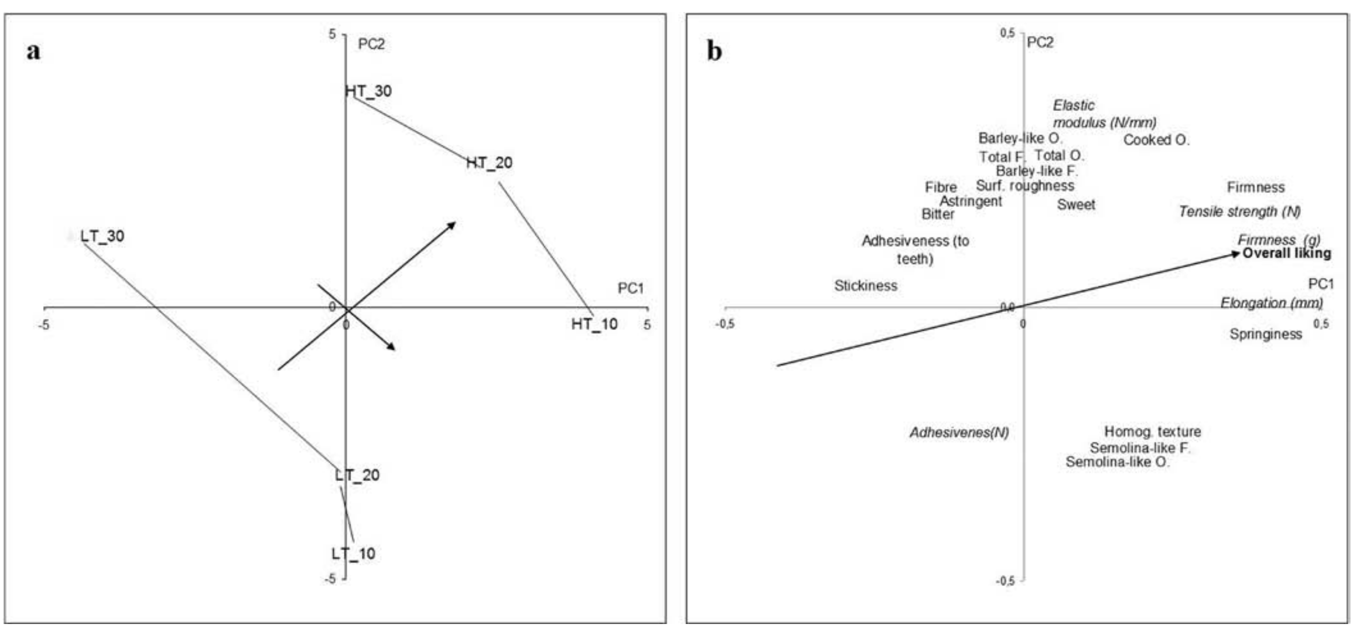

Fig. 3. Partial least square regression sample score (a) and correlation loading (b) plots of PC1 (abscissa) vs PC2 (ordinate) (X = sensory attributes and instrumental texture parameters; Y = overall liking). PC1—Explained variance, X = 43%, Y = 81%; PC2—Explained variance, X = 50%, Y = 14%; HT_10—high drying temperature cycle, barley flour at 10%; HT_20—high drying temperature cycle, barley flour at 20%; HT_30—high drying temperature cycle, barley flour at 30%; LT_10—low drying temperature cycle, barley flour at 10%; LT_20—low drying temperature cycle, barley flour at 20%; LT_30—low drying temperature cycle, barley flour at 30%.

instrumental adhesiveness and any sensory texture descriptor.

For the consumer liking data set only the response to overall liking is discussed here, since it was well correlated to the other hedonic parameters, i.e., visual attractiveness (0.93; $P < 0.01$), liking of flavor (0.99; $P < 0.001$), and liking of texture (0.91; $P < 0.05$).

Overall liking scores (Y) averaged over consumers were linked to the averaged sensory and physical data (X) by PLSR. It is a modeling approach that proceeds by extracting latent variables (orthogonal dimensions) as linear combinations of the independent variables from both predictive (X) and response (Y) data sets. Data were preprocessed by mean-centering (subtract mean from each variable) and standardization (weighted by standard deviation). Cross validation suggested two PLS dimensions explaining 93% of the variation in sensory and physical variables and 95% of the total variation in the liking data (Fig. 3). Figure 3B shows the relationships between the averaged overall liking and predictive sensory and instrumental variables in the loading plot on the first two dimensions. The arrow shows the direction of variation of the overall liking. The uncertainty of the PLS regression coefficient b was estimated by Martens' uncertainty test (23). The weighted regression coefficients (Table VI) of the full model suggested that, of the X-variables, only some of the sensory and instrumental parameters were good predictors of the overall liking (Y). The sensory attributes firmness, springiness, and cooked odor and the physical measurements tensile strength, elongation, and firmness were positive relevant variables related to the hedonistic dimension and accounted for most of the variation in overall liking. In contrast, adhesiveness and stickiness had a negative impact. All these variables, as also shown by the analysis of variance (Tables III and V), were affected only by the drying process or to a higher extent than the amount of barley flour employed in the sample. Figure 3A shows the sample score plot. The long arrow shows the direction of sample variation related to the HT drying treatment. The small arrow shows the direction of sample variation related to the amount of barley flour in sample formulation. Only the sample prepared with 30% barley flour and dried at HT (HT_30) lies negative position on dimension 1 and was essentially discriminated. By comparison of the two plots, the impact of drying on the hedonic scores is quite evident, although also barley flour content was also affected.

One important finding of this study is that the best predictors of profiling are texture parameters like firmness and springiness, either measured through sensory perception or instrumentally measured as firmness, tensile strength, and elongation. These parameters are all well correlated along the first dimension of the PLS analysis. This means that they covaried in the sample set and that the differences measured by instrumental methods were determined also by sensory evaluation. Odor, taste, and flavor attribute do not affect liking much, except for the cooked odor perceived and appreciated in the samples dried at HT.

CONCLUSIONS

Drying processing affected some key sensory attributes for consumer liking of barley pasta, with higher scores for the samples treated at the HT drying cycle. Consumer liking of barley pasta was a little penalized for all the samples processed at low drying temperature and proportionally with the increase of barley content. In contrast, all the samples dried at HT were accepted by consumers, with no relevant differences between 10, 20, and 30% barley addition despite differences found in these samples. This can be explained by the fact that consumer liking was mainly determined by firmness, which did not vary based upon barley content but rather only for the drying process. Therefore, an intake of one serving/day of 100 g of pasta supplemented with 30% barley in the flour mixture (WS/BF 70:30) could be suggested to provide a good level of the daily soluble fiber dose necessary for achieving its functional effect.

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