EVALUATION OF PHYSICOCHEMICAL PROPERTIES AND SENSORY QUALITIES OF PASTA ENRICHED WITH FREEZE-DRIED SWEET WHEY

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For food industry, the production of functional pasta from non-conventional raw materials represents a challenge. This study aims to evaluate the potential of animal proteins of freeze-dried whey as a component for pasta production and its effect on the pasta qualities and consumer acceptance. Sweet whey was freeze-dried, then directly incorporated to pasta at a 20% level. Two pasta types (pasta non-enriched vs. enriched with whey powder) were manufactured following a small-scale pilot procedure, and then evaluated for their physicochemical and sensory qualities. Results of all analyses (whey, semolina and pasta) met the standards according to international legislation; however, the characteristics of enriched pasta differed. Whey addition significantly increased ash, proteins content, optimal cooking time and water uptake ($P < 0.05$); it significantly decreased moisture levels, colour parameters (CIE system: a* redness, b* yellowness) and the swelling index ($P < 0.05$). Sensory analysis revealed that overall sensory and product quality of enriched pasta was not affected by whey fortification and it was found acceptable by panelists. This study points out that whey powder could be used for the functional pasta production to increase proteins levels.

pasta fortification, whey, freeze drying, consumer acceptance, dairy by-product

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INTRODUCTION

From 1997 to 2016, the world pasta production raised by 57%, from 9.1 to 14.3 million tons (http://www.pasta-unafpa.org/test.HTM). In Algeria, as in most developing countries, pasta consumption is in constant increase, making it one of the most consumed foods (A d e l et al., 2016). The manufacturing process

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is relatively simple; pasta products are produced by mixing milled durum wheat (the main product of durum milling is semolina), water, and sometimes optional ingredients (Boudalia et al., 2016).

On the nutritional side, pasta is mainly used as an energy source due to its high content of carbohydrates (74–77% dry basis), and it is known to be a good source of low glycemic index (Giacco et al., 2016; Huang et al., 2017). However, pasta is a poor source of protein (Chillo et al., 2008). The pasta protein has a low amount of essential amino acids like lysine and threonine which are the first and second limiting amino acids in most cereal products (Filip, Vidrih, 2015). Cereal staple food diet consumption can cause protein energy malnutrition. Protein enrichment of low-protein foods can be one of the alternative approaches to solve this issue (Reddy Surasani et al., 2019).

Several studies have been conducted to improve the quantity and the quality of pasta proteins using non-traditional raw material like green olive paste, banana, meat, faba bean, tilapia (*Oreochromis niloticus*) flour, and pangas (*Pangasius pangasius*) (Zandonadi et al., 2012; Liu et al., 2016; Monteiro et al., 2016, 2019; Rizzello et al., 2017; Reddy Surasani et al., 2019; Cedola et al., 2020). Among these non-traditional raw materials, whey is the major by-product of the dairy industry that represents low cost source of high-quality nutrients due to the high levels of essential proteins. Whey is used as a fortifier for human diet (confectionery, bakery products, dairy products, surimi, hams and slimming foods) (Ramos et al., 2016; Hassanzadeh-Rostami et al., 2020). Prabhasankar et al. (2007) showed that vermicelli produced from durum wheat enriched with whey protein concentrate, with ascorbic acid and glycerol monostearate additives increased significantly proteins levels. Furthermore, several studies have reported the properties of adding supplementary whey protein to develop functional foods, with an identified health benefit for consumers. Szajewska, Horvath (2010) demonstrated that in infants fed with partially hydrolyzed whey protein instead of intact cow milk protein the risk of allergy is reduced, particularly in those with an allergy family history. Moreover, in overweight and obese patients (body mass index ≥ 25 and 30 kg m^{-2}, respectively), a 2-week to 15-month whey protein consumption improved body weight, total fat mass, lean body mass, high-density lipoprotein (HDL) cholesterol, total cholesterol, and fasting glucose (Wirunsawanya et al., 2018).

Despite its high proteins level and nutritional benefits, whey is discarded in rivers, lands or sea (without any treatment) in Algeria, which results in a serious environmental problem due to its high production volumes and organic content (Sayad et al., 2014). Wissmann et al. (2012) concluded on the environmental and economic losses caused by disposing whey in the environment that each ton of untreated whey is equivalent to the daily effluents of a settlement of 470 people.

The aim of this study was to develop a functional food (pasta), eco-friendly and more healthy after proteins fortification, using whey powder for wheat flour partial replacement. The effects of whey powder supplementation on nutritional quality and cooking characteristics of pasta were also evaluated.

The whey powder addition to functional food can solve the animal proteins deficit in developing countries diet and simultaneously the pollution issue associated with the disposal of whey as a by-product.

MATERIAL AND METHODS

Protocol design

Physicochemical and bacteriological tests (in triplicate) and sensory analysis were used to assess the

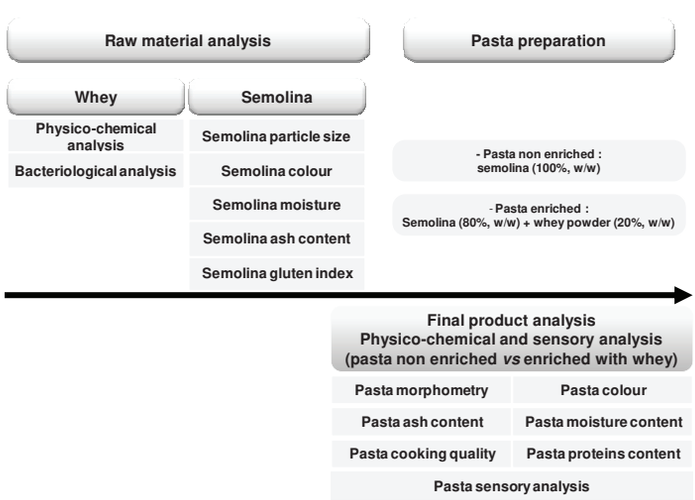

Fig. 1. Experimental design: physico-chemical, bacteriological and sensory analysis of raw material, pasta non-enriched and enriched with whey powder

overall quality of pasta (pasta non-enriched vs. enriched with whey powder). Two series of tests were carried: one for analysis of the raw material (whey and semolina), and the second for the end-product (pasta) (Fig. 1).

We have used four samples of whey from four different milk collections, which were analyzed in triplicate (physicochemical and bacteriological tests). Besides, we have used 3 lots (n = 3) of semolina durum wheat and each lot was analyzed in triplicate (physicochemical tests). These lots of semolina were used to produce pasta, which was analyzed in triplicate (pasta non-enriched vs. enriched with whey powder).

Whey analysis

Physicochemical analysis. At the dairy processing units, sweet whey was obtained from cow milk, which was used for cheese making. The temperature, acidity, fat, proteins content, lactose, density, solids and solids-non-fat were measured using a LactoScan (Milkotronic Ltd, Nova Zagora, Bulgaria).

Bacteriological analysis. Ten milliliters of whey were homogenized with 90 ml of distilled water by shaking for several minutes, 1 ml was taken from the dilution and transferred to another tube to make serial dilution up to 10^{-6}.

Total Coliform bacterial counts on plates that contained Violet Red Bile Agar (dilution 10^{-1} and 10^{-2}) were incubated at 44 °C for 24 h. Suspected colonies of coliforms are red.

Aerobic Mesophile germs were counted on plates, which contain culture medium (Agar Plate Count) and incubated at 30 °C for 48 h. Bacteria counts were recorded and converted into Colony Forming Units (CFU) (A m a r i g l i o , 1986).

Identification of S*ulfite-reducing Clostridium* was enumerated on test tube count Meat-Liver Glucose Agar (after a thermal shock). Two milliliters of paraffin were added to create the anaerobic condition of the culture. The tube was incubated at 37 °C for 48 h. *Clostridium* bacteria appear as black colonies.

For *Salmonella* detection, 100 ml of samples was incubated at 37 °C for 24 h. Then 10 ml was drawn aseptically and added to 100 ml selenite broth. The broth was incubated at 37 °C for 24 h. Then a loopful streaking was done on dried *Salmonella Shigella* (SS) plates. The plates were then incubated at 37 °C for 24 h. *Salmonella* appeared as transparent or translucent colourless small colonies.

Staphylococci were enumerated on test tube count Oxoid Giolitti-Cantoni medium, a tellurite-mannitol-glycine enrichment broth. Two ml of paraffin was added to create the anaerobic condition of the culture. The tube was incubated at 37 °C for 24 h. The culture of *Staphylococci* was indicated by the formation of a black precipitate or total blackening of the tube.

Concentration and whey freeze drying

Sweet whey was concentrated using a rotary evaporator Büchi Rotavapor R-215 (BÜCHI Labortechnik AG, Flawil, Switzerland) at 0.2 to 0.3 bar with water bath at 45–50 °C and a rotation of 125 rpm to eliminate water which constitutes 90–94% of its composition.

Then, whey was dried using a drum dryer CHRIST ALPHA 1-2 LO (Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz, Germany) at –60 °C and a pressure of 10 mbar. Whey powder was stored at 4 °C and sheltered from light and moisture until needed.

Semolina quality evaluation

Semolina particle size. Granularity or particle size of ground material, such as semolina, is the particle distribution of the material, which can be determined by the system of sieving. The first operation was homogenization of the semolina samples (using a rotative mixer) to obtain a representative sample. Then a 100 g sample of semolina (in triplicates) was sieved through a Rotachoc sieve (CHOPIN Technologies, Villeneuve-la-Garenne, France) for 7 min. When the sifting was completed, the fractions of all the sieves were collected and weighed to plot the granulation curve of the sample.

Semolina was distributed depending upon diameters of the sieve (decreasing diameter: 600 µm, 500 µm, 450 µm, 355 µm, 250 µm, 200 µm, 150 µm), and results were expressed as a percentage of the original weight of the sample according to the American Association of Cereal Chemists approved methods 66-20 (AACC, 2000).

Semolina colour. The colour of semolina was determined instrumentally, using a Konica Minolta colorimeter model CR-410 with a D65 illuminant (Konica Minolta, Tokyo, Japan) according to AACC (2010), approved method 14-22.01 (all 2010 AACC methods used in the study are specified at http://methods.aaccnet.org/toc.aspx.). Semolina samples were placed in the granular material attachment and colour was then measured. Results are expressed on the CIE 1976 colour space system for L* (lightness; 0 = black, 100 = white), a* (red-green; +a = redness, –a = greenness) and b* (yellow-blue; +b = yellowness, –b = blueness). Before measurement, the colorimeter was calibrated using a white calibration tile as the standard (L* = 98.45, a* = –0.10, b* = –0.13).

Semolina moisture. Semolina samples (3 g) were introduced into a halogen moisture HG63 analyzer (Mettler Toledo, Greifensee, Switzerland) at 130 °C. At the end of the drying process, the mass loss observed was equivalent to the amount of water present in the product. Results were expressed as the percentage (%) of the product mass.

Semolina ash content. To determine the semolina ash content, AACC method 08-01.01 was used.

Table 1. Formulations for pasta made with semolina (pasta non enriched) and pasta made with semolina enriched with whey powder

Ingredients	Non enriched pasta (100 g)	Enriched pasta (100 g)
Semolina	100	80
Whey powder	0	20

Semolina samples (5 g) were incinerated overnight in a muffle furnace at 600° C (AACC, 2010). Results were expressed as the percentage (%) of the product mass.

Semolina gluten index. Durum semolina gluten index was determined using AACC method 38-12.02 (AACC, 2010). Gluten was separated from semolina using a Glutomatic (Perten, Haguenau, France), then, it was centrifuged to force wet gluten through a specially constructed sieve under standardized conditions (6 000 ± 5 rpm for 30 s). The percentage of wet gluten remaining on the sieve after centrifugation was defined as the gluten index calculated using the following equation:

Gluten index (%) = [(Total wet gluten weight – Gluten remaining on the centrifuge sieve)/Total wet gluten weight] × 100

Pasta preparation

A small-scale standardized laboratory procedure was used for the pasta manufacture. Two different types of pasta were manufactured: pasta with semolina wheat durum and pasta with semolina wheat durum enriched with whey powder (20% (w/w)) (Table 1). Dried components of the two pasta types were mixed in a kMix KMX51 top mixer (Kenwood, Treviso, Italy) at low speed (22 rpm for 1 min) until a uniform mix was achieved. The amount of water added was calculated to achieve a dough of 31 g per 100 g moisture on a wet weight basis. Tap water was added and mixed at low speed (22 rpm for 10 min) until the dough had an adequate consistency for lamination. The dough was divided by hand into appropriate pieces and was laminated using a pasta home scale size lamination machine (Drago, Inc., Shanghai, China) using a 3-step procedure: hand lamination, up to approximately a 10 mm thickness; roll lamination, up to a 5 mm thickness; and final roll lamination to a 2 mm thickness (final pasta thickness). Then, pasta samples were allowed to cool at room temperature for drying (25 ± 2 °C for 24 h). Pasta (enriched or non-enriched) were packed in polypropylene packaging and then stored at room temperature until needed.

Dried pasta quality evaluation

Pasta morphometry. To detect any morphometric abnormalities after pasta preparation, lengths, widths, thicknesses of 100 g of pasta were measured with a digital caliper (TACTIX, Shanghai, China).

Pasta ash content. Dried pasta samples (100 g) were crushed using a crushing mill Miag MLI-204 (Bühler AG, Uzwil, Switzerland); ash content of dried pasta was measured in the same way as semolina according to the AACC method 08-01.01 (AACC, 2010).

Pasta moisture content. Dried pasta samples (100 g) were crushed using a crushing mill Miag MLI-204 (Bühler AG); moisture content of dried pasta was measured in the same way as for semolina using a halogen moisture HG63 analyzer (Mettler Toledo).

Pasta colour. Dried pasta samples (100 g) were crushed using a crushing mill Miag MLI-204 (Bühler AG); values of the surface colour of raw pasta were measured in the same way as for semolina using a Konica Minolta colorimeter model CR-410 with a D65 illuminant according to AACC approved method 14-22.01 (AACC, 2010).

Pasta proteins content. Dried pasta samples (100 g) were crushed using a crushing mill Miag MLI-204 (Bühler AG); then proteins content rate of dried pasta was measured using Infraneo near-infrared spectroscopy (NIRs) (CHOPIN Technologies), which reads instantaneously nitrogen content and converts it into protein content.

Pasta cooking qualities

Optimal cooking time. According to AACC approved method 66-50.01, describing an approved procedure for cooking pasta and determining firmness, 100 g of pasta was put into a beaker containing 1000 ml of boiling water (without salt addition). Each minute (during the first five minutes), then every 10 s (since the fifth minute), some pieces were taken out and pressed between two glass plates (2.5 × 2.5 cm) because according to AACC (2010) the optimal cooking time corresponds to the time when the centre core of pasta just disappears when pressed between two glass plates.

Table 2. Physicochemical analysis of whey

Parameter	Results
T (°C)	24.5 ± 0.50
pH	6.49 ± 0.06
Acidity (°D)	11.5 ± 0.58
Solids-non-fat (g l^{-1})	65.22 ± 1.91
Solids (g l^{-1})	4.60 ± 0.46
Fat (g l^{-1})	4.75 ± 1.79
Lactose (g l^{-1})	33.35 ± 0.80
Proteins (g l^{-1})	22.10 ± 1.41

Results are expressed as the mean ± standard deviation (n = 3–4 samples).

Table 3. Bacteriological analysis of whey

Assay	Results
Total Coliform	2 colonies or 20 germs ml^{-1}
Aerobic mesophile	absence
Sulfite-reducing Clostridium	absence
Salmonella	absence
Staphylococci	absence

Table 4. Physicochemical analysis of semolina

Semolina colour	L*	83.25 ± 0.09
	a*	–2.77 ± 0.04
	b*	33.64 ± 0.54
Moisture (%)		13.31 ± 0.06
Ash (%)		1.08 ± 0.01
Gluten index		74.87 ± 2.81

Results are expressed as the mean ± standard deviation (n = 3–4 samples)

Water uptake. According to the method described by Petitot et al. (2009), dry samples were weighed before and after cooking at an optimal cooking time. Water uptake was calculated using the equation:

Water uptake = [(Weight of cooked pasta/Weight of dry pasta) – 1] × 100

Swelling index. The swelling index (SI) of both types of cooked pasta (grams of water per gram of dry pasta) was determined according to Cleary, Brennan (2006). The pasta samples were cooked at the optimum cooking time and dried at 105 °C until a constant weight was reached. The swelling index was expressed as:

SI = [(Weight of cooked pasta – Weight of pasta after drying)/Weight of pasta after drying] × 100

Sensory analysis

A modified procedure of Boudalia et al. (2016) was used to evaluate the pasta sensory qualities. Pasta was evaluated at the end of experimentation by a consumer panel consisting of 25 members (17 men, 18 women, aged 21–53 years, all academic or scientific staff and Ph.D. students from Guelma University). Before testing, all participants were enquired for possible food allergies to wheat, wheat components or milk products. Pasta (200 g) were cooked freshly in water (2 000 ml) depending on the optimal cooking time for each type of pasta, rinsed and cooled in water at 20 °C for 2 min. Cooked pasta was placed in plastic cups and presented to the panelists.

Participants were instructed to rinse their mouth with tap water (20 °C) before they began testing and between samples. Pasta samples were evaluated for their colour, smell, taste, texture, and overall quality. Sensory attributes were evaluated using a nine-point hedonic scale, and values ranged from 1 to 9, wherein: (1) extremely unpleasant, (2) very unpleasant, (3) moderately unpleasant, (4) slightly unpleasant, (5) neither pleasant nor unpleasant, (6) slightly pleasant, (7) moderately pleasant, (8) very pleasant, and (9) extremely pleasant.

Statistical analysis

The research protocol for the sensory study was developed and validated by the Ethics Committee of the University of Guelma, Algeria. The results were expressed as the mean ± SD (standard deviation). The experiments were carried out in triplicates. Significant differences between the two pasta types were evaluated using one-way analysis of variance (ANOVA).

Sensory data were analyzed using ANOVAs, and the experimental design was built to allow the estimation of the main effect (composition and sex) and interaction (sex × composition). Significant effects were reported.

Significance was considered at $P < 0.05$ using Minitab software, Version 16 (Minitab Ltd, Coventry, UK).

RESULTS

Physicochemical and bacteriological analysis of raw materials (whey and semolina)

Raw materials (whey and semolina) used for the preparation of two pasta types were analyzed for proximate composition. As shown in Table 2, the physicochemical analysis of sweet whey obtained from cheese making has revealed a relative acidity equivalent to 0.115% (v/v) of lactic acid (pH = 6.49). High concentrations of lactose and protein have also been recorded.

Bacteriological analyses of whey samples are presented in Table 3. *Aerobic mesophile*, *Sulfite-reducing Clostridium, Salmonella* and *Staphylococci* have not been detected, which confirms the safety of sweet whey.

Results of physicochemical analyses of semolina used for pasta preparation are presented in Table 4 and Table 5. Ash and moisture content, gluten index and colour values are compatible with those of the semolina used for pasta production in North Africa (Gruber, Sarkar, 2012). Particle size repartition (percentage from 100 g during 7 min) was carried out to check coarseness or fineness of the semolina; results show that it was retained mostly in 150-, 200-, and 250-µm sieves.

Table 5. Granularity or particle size distribution (%) of semolina

Semolina retained by sieves	600 µm	0
	500 µm	0.11 ± 0.03
	450 µm	0.62 ± 0.12
	355 µm	14.89 ± 0.14
	250 µm	35.85 ± 0.66
	200 µm	26.13 ± 0.78
	150 µm	19.33 ± 0.30
Semolina passing through sieves	150 µm	3.23 ± 0.37

Results are expressed as the mean ± standard deviation (n = 3–4 samples).

Physicochemical analysis of pasta (control pasta vs. enriched pasta)

Morphometric analysis (pasta thickness) revealed that the whole thickness is less than 1.5 mm in both pasta types. However, fortification leads to a significant thickness increase in pasta enriched with whey powder ($P < 0.05$) (Fig. 2a). Also, results revealed that the ash content in enriched pasta is greater than its quantity in non-enriched pasta ($P < 0.05$). Nonetheless, enriched pasta has a lower moisture content than non-enriched pasta ($P < 0.05$) (Fig. 2a).

Pasta colour is amber-yellow for both pasta types (non-enriched vs. enriched with whey powder). Statistical analysis showed a significant decreasing in a* and b* values in enriched compared to non-enriched pasta ($P < 0.05$) (Fig. 2b).

The proteins quantification results revealed that the proteins level in enriched pasta were higher than that in non-enriched pasta ($P < 0.05$) (Fig. 3a).

Pasta cooking qualities (control pasta vs. enriched pasta)

Pasta fortification significantly increased the optimal cooking time ($P < 0.05$) that was accompanied by a significantly higher water uptake and a lower swelling index in enriched pasta ($P < 0.05$) (Fig. 3b).

Sensory analysis (control pasta vs. enriched pasta)

The sensory attributes of cooked pasta (colour, smell, taste, texture and overall quality) as perceived by our panelists are given in Fig. 4. Statistical analysis showed no difference between control pasta and enriched pasta for all the attributes in both sexes. In addition, for enriched pasta, percentages of participants with a score greater than or equal to a hedonic score of 6 are as follows: 85.71; 65.71; 74.29; 62.86; 48.57 for the five descriptors (overall assessment, taste, texture, smell, colour), respectively. This indicates that our panelists (Fig. 4) accept pasta enriched with whey powder.

DISCUSSION

This study presents a new approach to functional pasta development exploiting whey powder for proteins fortification. The production is eco-friendly, cutting down whey discharge into nature, which contributes to pollution reduction. Fortified pasta will be more healthy because whey is a rich source of bioactive molecules playing a very important role to address many metabolic imbalance-caused diseases like obesity (Tahavorgar et al., 2014), high blood pressure, cardiovascular risks (Sheikholeslami

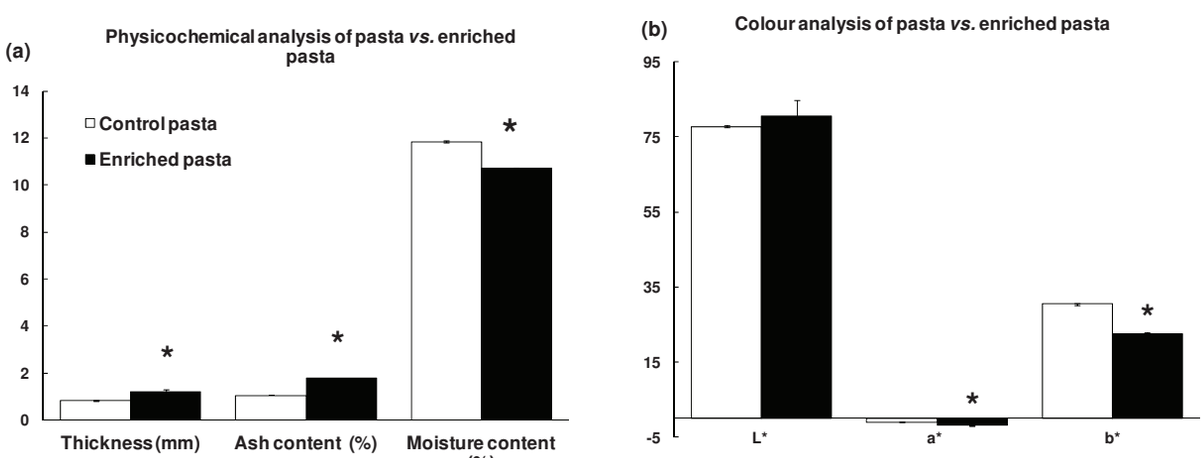

Fig. 2. (a) Physical and chemical analysis of pasta (non-enriched vs. enriched pasta), (b) colour analysis of pasta (non-enriched vs. enriched pasta); results are expressed as the mean ± standard deviation (n = 6 samples)
*significant difference between non-enriched and enriched pasta (one way ANOVA; P < 0.05)

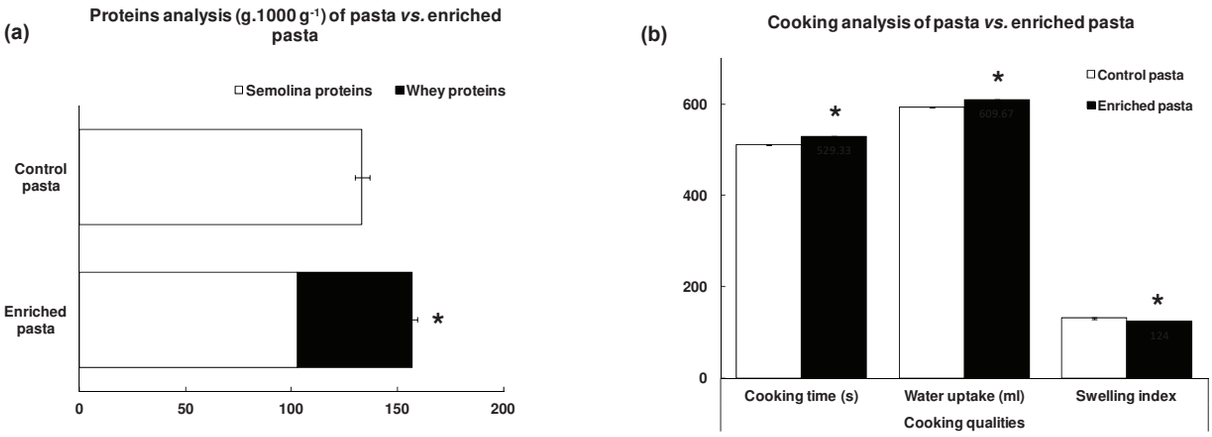

Fig. 3. (a) Proteins content (non-enriched vs. enriched pasta), (b) cooking qualities analysis of pasta (non-enriched vs. enriched pasta); results are expressed as the mean ± standard deviation (n = 6 samples)
*significant difference between non-enriched and enriched pasta (one way ANOVA; $P < 0.05$)

Vatani, Ahmadi Kani Golzar, 2012) and diabetes (Akhavan et al., 2014).

Physicochemical and bacteriological analysis of raw materials (whey and semolina)

The results of physicochemical and bacteriological analyses of raw materials (whey and semolina) are in accordance with data from literature (Boudalia et al., 2016; Tadjine et al., 2019) and the Codex Alimentarius standards (Codex Alimentarius, 2002), except for whey lactose with a value slightly lower than the reference level quoted in Codex Alimentarius (1995).

For the protein content, the detected value is higher than that given by Casper et al. (1998) for sweet whey collected from cow milk (8.95%). Theses variations in physicochemical parameters may be due to milk composition used in cheese production, which can influence the characteristics of the produced cheese whey (Carvalho et al., 2013).

Bacteriological analysis of whey samples indicated the proper sanitary conditions in which the cheese was made with the absence of pathogenic flora (*Sulfite-reducing Clostridium, Salmonella* and *Staphylococci*). The microbial counts are in accordance with those recommended by the Algerian legislation (JORADP, 1998).

Concerning the physicochemical analysis of semolina, results are in line with those from literature: moisture ≤ 14.5%, ash content < 1.1%, gluten index ≥ 65%, + 50% of semolina with grain size: 200 µm < diameter < 250 µm (Aalami et al., 2007; Petitot et al., 2010; Boudalia et al., 2016).

As for the colour analysis, the lightness (L*) value of semolina samples is close to the perfect white

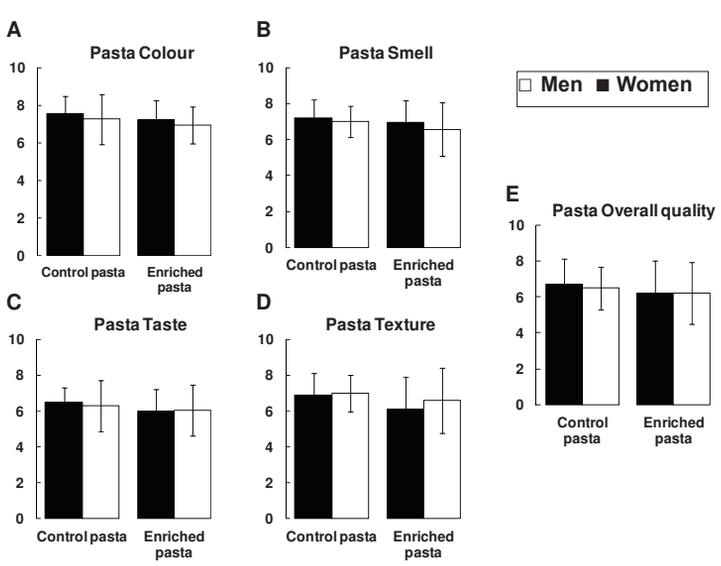

Fig. 4. Sensory evaluation of pasta (non-enriched vs. enriched pasta)
results are mean values ± standard deviation of panelists (n = 17–18 per sex per group)

(100), this means that it is light semolina. The yellowness (b*) value is greater than 0 (= neutral colour), meaning an intense yellow colour of the semolina, which predetermines the pasta to meet consumers' sensory requirements. These results are in accordance with literature (L*: 82 minimum, a*: –2.5 minimum, b*: 34 minimum) (Aalami et al., 2007; Petitot et al., 2010; Boudalia et al., 2016).

Physicochemical analysis of pasta (control pasta vs. enriched pasta)

Moisture remained within the safety limits, which should be around 13%. In enriched pasta, the moisture level was decreased significantly compared to the control pasta ($P < 0.05$), which is probably due to the moisture level in whey (2% and 3% (weight/weight)) (Schuck, 2014). The values were similar to those recorded in pasta enriched with animal protein (Reddy Surasani et al., 2019). For pasta colour, the a* and b* parameters of raw materials determine the yellowness of both pasta types (non-enriched and enriched with whey); this can be due to the amount of carotenoid pigment and to enzymatic reactions (Acquistucci, 2000). A significant decrease ($P < 0.05$) in the indices (a* and b*) recorded between pasta non-enriched vs. pasta enriched with whey powder, giving to the enriched pasta a light yellow colour with a b* index lower than that of the non-enriched pasta. For the redness index (a*), the significant decrease could be due to the presence of lactose in whey, which can develop reactions between proteins and sugars, and therefore cause a colour change (Feillet et al., 2000).

Enriched pasta contains a higher proteins level compared to the control pasta; this is explained by the richness of whey in proteins which represent one-third of total proteins in enriched pasta.

From literature, pasta enriched with a whey protein concentrate had a higher protein content (+ 9.4%) compared to the control group (McIntosh et al., 1998). Yadav et al. (2014) reported an increase in the protein content after pasta fortification with a whey protein concentrate (5–15%) (11.30 vs. 16.47 g per 100 g). Also, Prabhasankar et al. (2007) showed that vermicelli produced from durum wheat and enriched with a whey protein concentrate at a 5% level displayed significantly increased proteins levels (from 11.5 to 16%).

In the traditional pasta production process, eggs can be added. This addition of eggs to the basic ingredients increases the protein and fat content (Giacco et al., 2016), but it can also cause allergic syndromes such as atopic dermatitis and eosinophilic esophagitis mediated by five major allergenic proteins (Heine et al., 2006; Caubet, Wang, 2011). This makes our approach more interesting because whey proteins can reduce allergy risk (Szajewska, Horvath, 2010).

Pasta cooking qualities (control pasta vs. enriched pasta)

As defined by the American Association of Cereal Chemists (AACC), the optimal cooking time is when the centre core of the pasta, when pressed between two glass plates, just disappears. The fortification of pasta increased the optimal cooking time and water uptake and decreased the swelling index. The thickness of dry enriched pasta compared to that of control pasta was not similar and could explain the difference in the optimal cooking time between both pasta types.

From literature, a physical disturbance of the gluten matrix due to the presence of fibres may have facilitated the penetration of water to the core of pasta (Chillo et al., 2008). Whey contains high molecular weight serum proteins (lactoferrin, serum albumin and a heavy chain of immunoglobulin), which can affect cooking qualities (Miloradovic et al., 2018). Vermicelli fortification by a whey protein concentrate increased cooked weight, which could be due to leaching of sugars from whey into gruel (Prabhasankar et al., 2007). Cooking qualities were also disturbed after a whey protein concentrate addition to pasta due to the water absorption property and soluble barley fibres (β-glucan), which makes less available water to diffuse (Yadav et al., 2014). The addition of non-gluten material diluted the gluten strength and probably affected the overall pasta structure.

Brennan et al. (2004) reported that in inulin-enriched pasta, water absorption index and swelling index were decreased. Indeed, inulin preferentially absorbs water; it can inhibit starch gelatinization and disturb the protein-starch matrix.

Sensory analysis (control pasta vs. enriched pasta)

From sensory studies of fortified pasta it follows that, besides enriched pasta nutritional properties, the sensory attributes are important factors for consumer's acceptability. Semolina replacement with plant-based products is the most studied. Seczyk et al. (2016) reported that the addition of carob flour to pasta at the level 1–5% had no significant influence on its sensory attributes and consequently on consumer's acceptance. Carob fibre enrichment (up to 4 g per 100 g of wheat flour) had little effect on pasta overall acceptability (Biernacka et al., 2017) and pasta fortified up to a 10% substitution with lupin flour (Torres et al., 2007) or chickpea flour (Wood, 2009) were well accepted. In the last decade, wheat pasta has been prepared incorporating animal-based products to enhance the product with high protein and other bioactive ingredients including red cod (*Pseudophycis bachus*) fish powder (Desai et al., 2018), beef meat (Liu et al., 2016), shrimp meat (Ramya et al., 2015), green mussel (Vijaykrishnaraj, 2015) and shrimp mince (Kadam, Prabhasankar, 2011). Prabhasankar et al. (2007) showed that

vermicelli fortified with a combination of whey protein concentrate and additives were perceived better and yielded better sensory data than control vermicelli without whey protein concentrate.

These fortified products were accepted by consumers, which is in agreement with our results.

CONCLUSION

Whey powder addition to pasta can result in the reduction of nature pollution by whey, and simultaneously of the animal proteins deficit in developing countries diet. Freeze-dried whey incorporated pasta increased proteins levels; however, this addition affected physicochemical properties and cooking qualities. The sensory analysis revealed that sensory attributes (colour, smell, taste, texture, and overall quality) of enriched pasta were not disturbed, and when whey powder added at acceptable proportion, the results were comparable with control group pasta. Before launching the production of functional pasta enriched with whey powder, a market survey and further studies are needed.

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CONFLICT OF INTEREST

The authors declare no potential conflicts of interest.

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