Fortification of durum wheat semolina with detoxified matri (*Lathyrus sativus*) flour to improve the nutritional properties of pasta

Naveed Ahmad¹ · Salim Ur-Rehman¹ · Muhammad Asim Shabbir¹ · Abdullah⁵ · Muhammad Asif Shehzad² · Zia ud-Din^{1,3} · Thomas H. Roberts⁴

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Abstract Durum wheat semolina (DWS) can be enriched with legume flours to produce more nutritious but high-quality pasta. DWS was substituted with detoxified matri (*Lathyrus sativus*) flour (DMF) at 5–25%, which in spaghetti increased the levels of protein, lipid, fibre and ash but decreased nitrogen-free extract. Water absorption, arrival time and dough development time increased from 63.1 to 69.2%, 1.7 to 2.4 and 2.3 to 3.3 min, respectively, while dough stability, consistency and tolerance index decreased. DMF addition increased cooking loss (4.8–5.8%) and hardness (13.2–16.5 N) but decreased percent rehydration. Based on farinographic (departure time), cooking quality (adhesiveness) and cooking loss thresholds for DMF at 15%, the effects of xanthan gum (XG) addition on the cooking qualities of the corresponding spaghetti were determined. XG up to 3% limited cooking loss (4.97 vs 5.4%) and improved hardness, compared to samples lacking XG. Considering functional,

cooking and nutritional properties of spaghetti, incorporation of 15% DMF and 3% XG appeared optimal.

Keywords Matri · Spaghetti · β -N-oxalyl-L- α / β -diaminopropionic acid · Diastatic behavior · Cooking quality

Introduction

Pasta ranks second after bread in global consumption as a wheat-derived staple food, perceived for ease of transport, excellent shelf-life, ease of cooking, palatability and flexible sensory properties. Pasta products provide carbohydrates with a relatively low glycaemic index. The protein content of pasta is typically around 5% (USDA National Nutrient Database) but the amino acid composition of durum wheat protein features low levels of threonine and lysine (Filip and Vidrih 2015).

Durum wheat semolina (DWS) is the dominant raw material for pasta production. Given the nutritional limitations of cereals, non-traditional sources of pasta ingredients, such as legumes, should be thoroughly investigated. Previous studies have shown that high fortification levels with legume flours, such as faba bean and split pea, can enhance the nutritional status of pasta products while retaining acceptable sensory profiles (Petitot et al. 2010a).

Among the edible legumes, matri (*Lathyrus sativus* L.), also known as Indian vetch, chickling vetch, white pea, khesari and grass pea, has potential for use in a large range of foods. It is grown primarily for stock feed as a nutritious grain with high levels of protein and essential amino acids (Rosa et al. 2000). The most evident drawback of matri is the presence of β -N-oxalyl-L- α , β -diaminopropionic acid (β -ODAP), a structural analogue of the neurotransmitter,

✉ Thomas H. Roberts
thomas.roberts@sydney.edu.au

¹ National Institute of Food Science and Technology, Faculty of Food, Nutrition and Home Sciences, University of Agriculture, Faisalabad, Punjab 38040, Pakistan

² Department of Agronomy, Muhammad Nawaz Sharif University of Agriculture, Multan, Punjab, Pakistan

³ Present Address: College of Food Science and Technology, Huazhong Agriculture University, Wuhan 430070, Hubei, China

⁴ Plant Breeding Institute, Sydney Institute of Agriculture, University of Sydney, Sydney, NSW 2006, Australia

⁵ Department of Food Science and Human Nutrition, University of Veterinary and Animal Sciences, Outfall Road, Civil Lines, Lahore, Punjab, Pakistan

glutamate. Ingestion of β -ODAP over a prolonged period causes neurolathyrism (Enneking 2011). Upon detoxification of matri grain by repeated washing, the subsequently dried and milled product has been used effectively as a partial substitute for wheat flour in pan breadmaking up to the level of 10% (100 g/kg) (Lodhi and Huma 2003).

In this study, detoxified matri flour (DMF) was incorporated into DWS to determine a level of substitution to create nutritionally enhanced pasta while maintaining acceptable functional properties. A practical concern associated with legume flour incorporation is the level of gluten dilution and hence solids loss. Thus, the addition of xanthan gum (XG), a hydrocolloid, was tested to determine its effects on the texture, stability and appearance of the DMF-substituted pasta while limiting cooking loss of water-soluble components.

In the first of two experimental phases, the impact of a stepped increase in DMF on the nutritional, diastatic and rheological properties of DWS was investigated. In the second experimental phase, the effects of XG on the cooking quality and diastatic behavior of spaghetti made from DWS substituted by DMF at 15% was evaluated.

Materials and methods

Plant materials and chemicals

The durum variety 'D-97', a hard winter wheat, was cultivated on the farms of the Wheat Research Institute, Wheat Research Section, Ayub Agriculture Research Institute, Faisalabad, Pakistan, and harvested in 2011. Matri was purchased from a local grain market in the Faisalabad district. All chemicals and reagents were analytical grade.

Grain testing

1000-kernel weight and test weight of grains were determined according to standard methods (AACC 2000).

Detoxification of matri grain

β -ODAP in the matri grains was removed by steeping the grains in a double quantity of water at 60–70 °C for 8 h, changing the water seven times and then draining and sun-drying the grains (Ur-Rehman et al. 2006).

Wheat tempering

Durum wheat grain was tempered to 15.5% moisture content.

Preparation of durum wheat semolina and matri flour

Dried detoxified matri and tempered durum wheat were milled using a Quadrumate Senior Experimental Mill (Brabender OHG, Duisburg, Germany). The DWS and DMF were then sieved through a 100- μ m mesh to obtain uniform particle size and stored in airtight polythene packages at 4 °C.

Spaghetti preparation

Spaghetti was prepared with DWS substituted with different levels of DMF according to a published method (Rho et al. 1989) with slight modifications. Distilled water (40 mL) was added to 100 g flour. The mixture was kneaded with a Hobart mixer into a dough with a moisture content of 30–35%. During the first experimental phase, DMF was added at 5, 10, 15, 20 and 25% to replace DWS. In the second experimental phase, XG was dissolved in water and added at 1, 2, 3, 4 and 5% to composite flour containing 15% DMF.

The dough was rested in plastic bags at ambient temperature for 10 min, then extruded with a hand-driven extruder with a sieve diameter of 1.7 mm into spaghetti strands of length 40 cm. The spaghetti was then oven-dried at 60–70 °C for 3–5 min, cooled at 34 °C and packed into polythene bags for further evaluation.

Proximate analysis

Moisture, ash, crude protein, crude fat and crude fibre content of DWS, DMF and composite samples were determined by standard methods (AOAC 2006). Nitrogen-free extract (NFE) was obtained by subtracting the sum of the contents (%) of ash, fat, fibre and moisture from the total.

Physical dough testing

Farinographic analysis of DWS and composite flours was performed to determine water absorption, dough development time, dough stability, departure time, tolerance index and consistency index according to a standard method (AACC 2000) using a Brabender Farinograph (Model no. SEW-6517607, OHG, Duisburg, Germany). Diastatic behavior of DWS and composite flour was assessed using a Brabender Amylograph (Model no. 3126-VS6-S, OHG, Duisburg, Germany) (AACC 2000).

Cooking quality of spaghetti

Optimal cooking time (OCT) and cooking loss were assessed according to standard methods (AACC 2000). OCT is defined as the cooking time required for the spaghetti core to disappear, as judged by squeezing the cooked spaghetti strand between two glass slides. Cooking loss is the percentage solids lost in the cooking water. Swelling index for the spaghetti was determined according to Cleary and Brennan (2006) as grams of water per gram of dry pasta. Percent rehydration in the drained spaghetti was determined as the difference between the mass of cooked and raw spaghetti, divided by the mass of raw spaghetti.

Spaghetti strands of specified length (40 cm) were assessed for adhesiveness and hardness after cooking at OCT using a Texture Analyzer (Zwick/Roell, model Z 0.5, Germany) with a stainless-steel cylinder probe (diameter 2.0 cm). The sample was placed on the plate surface and force applied downwards. Hardness was measured as mean maximum force (N) and adhesiveness expressed as mean negative area (Nmm). The Texture Analyzer was used with the following operating parameters: crosshead constant speed 0.25 mm s⁻¹; preload 0.3 N; percentage deformation 30%; load cell 1 kN.

Statistical analysis

All laboratory experiments were performed with triplicate samples. Mean values were calculated and results were expressed as mean $\pm$ standard error (SE). Data were statistically analysed via a linear model of analysis of variance (ANOVA). Significant differences between treatments were determined by the Tukey HSD all-pairwise comparison test ($\alpha = 0.05$). Statistical analyses were carried out using Statistix 8.1.

Results and discussion

Experimental phase 1: Impact of a stepped increase in DMF on the nutritional, diastatic and rheological properties of DWS

Grain properties

The average 1000-kernel weight and test weight for the durum wheat grain were 42.13 g and 80 kg/hl, respectively.

Proximate analysis

Increasing incorporation of DMF significantly increased moisture, lipid, fibre, protein and ash contents of the

spaghetti while decreasing NFE (Table 1). This was a similar trend to that previously reported (Ur-Rehman et al. 2006).

The lipid content values obtained here (1.29% for DWS up to 1.39% for composite flour containing 25% DMF; Table 1) were in accordance with those of a similar study (Ur-Rehman et al. 2006). The quality of pasta products can be substantially enhanced by lipid but a high lipid content may increase the risk of rancidity (Ahmed et al. 2015). Fibre content, which was also significantly increased upon addition of DMF, is associated with several health benefits. Increased fibre may also alter food structure by physical disruption of the gluten fraction, thereby altering processing behavior (Wood 2009).

Protein content was increased significantly from 11.99% for DWS to 15.50% for 25% DMF (Table 1). Protein influences product development and has many nutritional benefits. Textural and cooking properties are also affected by protein content. The protein content values obtained were in accordance with an earlier study (Kaur et al. 2013) in which pasta was made by incorporating different high-protein flours, namely defatted soy, bengal gram and mushroom flour. The significant impact on ash content (0.53% for DWS vs 0.96% for 25% DMF; Table 1) was in agreement with results of a study in which spaghetti was prepared by incorporating soy flour (Shogren et al. 2006). The NFE content of the DMF-substituted flour (e.g., 70.05% for 25% DMF) was significantly lower than the DWS control (74.89%) due to the relatively low NFE of the matri flour (57.46%) (Table 1).

Farinographic properties

Farinographic properties of the composite flours were significantly influenced by the level of DMF (5–25%). Water absorption, arrival time and dough development time were gradually increased upon matri flour addition, while the departure time, dough stability, consistency index and tolerance index were significantly decreased (Table 2).

The increase in water absorption (63.1% for DWS vs 69.2% for 25% DMF) and arrival time (1.7 min for DWS vs 2.4 min for 25% DMF) (Table 2) is probably due to a higher protein content from the matri flour incorporation into the wheat flour, enhancing hydration capability. Water absorption also depends on proximate composition, as well as interactions between legume starch and fibre, non-gluten protein and the gluten matrix, respectively.

Starch granules also play a key role in water absorption of pasta. The increase in volume upon cooking is desirable for pasta producers because the amount of flour required is minimised to produce baked items of the same volume. Decline in departure time (14.0 min for DWS vs 6.5 min

Table 1 Proximate composition (%) of durum wheat semolina (DWS), detoxified matri flour (DMF) and composite flour at different substitution rates of DMF

Treatments	Moisture	Lipid	Fibre	Protein	Ash	NFE
DWS	10.21 ± 0.11 ^f	1.29 ± 0.01 ^e	1.09 ± 0.00 ^f	11.99 ± 0.26 ^f	0.53 ± 0.01 ^e	74.89 ± 0.21
DMF	11.50 ± 0.12	1.60 ± 0.00	1.22 ± 0.02	25.95 ± 0.01	2.27 ± 0.11	57.46 ± 0.12
5% DMF	10.26 ± 0.10 ^e	1.31 ± 0.17 ^d	1.09 ± 0.10 ^e	12.68 ± 0.01 ^e	0.62 ± 0.00 ^e	73.93 ± 0.31
10% DMF	10.33 ± 0.08 ^d	1.33 ± 0.10 ^c	1.10 ± 0.01 ^d	13.39 ± 0.01 ^d	0.71 ± 0.13 ^d	72.95 ± 0.19
15% DMF	10.37 ± 0.07 ^c	1.35 ± 0.09 ^c	1.11 ± 0.05 ^c	14.04 ± 0.02 ^c	0.79 ± 0.01 ^c	72.01 ± 0.20
20% DMF	10.49 ± 0.14 ^b	1.37 ± 0.00 ^b	1.12 ± 0.00 ^b	14.80 ± 0.19 ^b	0.88 ± 0.00 ^b	71.02 ± 0.11
25% DMF	10.50 ± 0.03 ^a	1.39 ± 0.01 ^a	1.13 ± 0.11 ^a	15.50 ± 0.21 ^a	0.96 ± 0.01 ^a	70.05 ± 0.17

Results are presented as mean values ± standard error (SE) for three replicate samples. Mean values within the same column with different superscript letters are significantly different ($\alpha = 0.05$)

NFE nitrogen-free extract

Table 2 Farinographic characteristics of durum wheat semolina (DWS) substituted with different levels of detoxified matri flour (DMF)

Treatments	WA (%)	AT (min)	DT (min)	DDT (min)	DS (min)	CI (BU)	TI (BU)
DWS	63.1 ± 1.5 ^f	1.7 ± 0.0 ^e	14.0 ± 0.2 ^a	2.3 ± 0.0 ^f	10.2 ± 0.1 ^a	540 ± 4 ^a	110 ± 2 ^a
5% DMF	63.2 ± 1.9 ^e	1.8 ± 0.0 ^d	11.5 ± 0.2 ^b	2.3 ± 0.0 ^e	10.1 ± 0.1 ^a	531 ± 3 ^b	105 ± 1 ^b
10% DMF	66.1 ± 1.0 ^d	2.0 ± 0.1 ^c	10.5 ± 0.2 ^c	2.6 ± 0.1 ^d	9.7 ± 0.0 ^b	522 ± 1 ^c	100 ± 2 ^c
15% DMF	67.2 ± 2.1 ^c	2.0 ± 0.1 ^c	9.4 ± 0.2 ^d	2.6 ± 0.0 ^c	9.2 ± 0.1 ^c	516 ± 5 ^d	97 ± 2 ^c
20% DMF	69.0 ± 1.1 ^b	2.2 ± 0.2 ^b	6.5 ± 0.3 ^e	3.1 ± 0.0 ^b	6.9 ± 0.2 ^d	509 ± 3 ^e	80 ± 2 ^d
25% DMF	69.2 ± 1.2 ^a	2.4 ± 0.0 ^a	6.5 ± 0.1 ^c	3.3 ± 0.1 ^a	5.2 ± 0.2 ^e	501 ± 3 ^f	61 ± 2 ^e

Results are presented as mean values ± SE for three replicate samples. Mean values within the same column with different superscript letters are significant different ($\alpha = 0.05$)

WA water absorption, AT arrival time, DT departure time, DDT dough development time, DS dough stability, CI consistency index, TI tolerance index

for 25% DMF; Table 2) is associated mainly with gluten dilution (Padalino et al. 2013).

The increase in dough development time (2.3 min for DWS vs 3.3 min for 25% DMF; Table 2) was most likely due to an interaction between the gluten fraction and non-wheat protein (Padalino et al. 2014). Increased incorporation of legume flour enhances the protein content, consequently increasing the absolute amount of insoluble protein and protein size distribution, leading to an altered protein network development at the macromolecular level.

Decline in dough stability (10.2 min for DWS vs 5.2 for 25% DMF) and increase in dough development time are mostly associated with a decrease in gluten content. During kneading, a decrease in dough stability time and increase in dough development time demonstrate a weak gluten network. This affirms the limited compatibility between wheat protein and legume protein (Bojnanská et al. 2012). Decline in consistency index (540 BU for DWS vs 501 BU for 25% DMF) and mixing tolerance index (110 BU for DWS vs 61 BU for 25% DMF) (Table 2) might be attributed to heterogeneous particle sizes. The non-glutenous fraction diluting the wheat protein, as well as increased fibre fraction from the legume (which imparts

discontinuities in the dough), are likely to affect the dough quality (Mohammed et al. 2012).

Diastatic behavior

Maximum viscosity and pasting temperature were significantly different among treatments ($\alpha = 0.05$). Maximum viscosity is the point at which starch granules are at their maximum level of swelling, which decreases on further heating due to granule rupture. Maximum viscosity and pasting temperature were decreased upon 25% DMF addition (Fig. 1). Similar results were reported in studies of the impact of legume flour addition on the properties of spaghetti (Petitot et al. 2010b). Final viscosity and wheat flour hydration ultimately depend on polysaccharides, as the starch granules are disrupted by legume flour addition, affecting the pasting temperature (Petitot et al. 2010b). Similarly, addition of matri flour decreases the crystallinity of DWS, ultimately lowering the maximum viscosity of the pastes. The higher ratio of larger to smaller granules of wheat starch also leads to a higher paste viscosity (Kaur et al. 2015).

Fig. 1 Diastatic behaviour of durum wheat semolina (DWS) substituted with different levels of detoxified matri flour (DMF). Results are presented as mean values $\pm$ standard error (SE) for three replicate samples. Mean values with different letters are significantly different ($\alpha = 0.05$)

Increased hardness was attributed to higher protein content, which changes the gluten-legume protein interaction upon hydration (Wood 2009). Spaghetti samples containing up to 15% DMF had a yellowish colour, in contrast to the rich yellow for those containing higher levels of DMF. Colour variations were possibly associated with the higher ash fraction of DMF, since heat, along with the polyphenol and carotenoid content, darkens the colour, especially in cooked spaghetti.

Differences in particle sizes of starch and non-starch fractions present in flours of various plant sources affect pasting, frictional and physicochemical properties (Kaur et al. 2015). Particle size differences between the gluten and a non-gluten fraction affect the structural integrity of pasta products (Wood 2009; Petitot et al. 2010a, b). The effects of DMF inclusion on hardness and viscoelasticity among cooked samples were significant, making the cooked sample harder. This was accredited to the higher protein and higher fibre from the matri flour.

Cooking quality

Quality parameters were significantly influenced by DMF addition (Table 3). With 25% DMF substitution, OCT dropped from 12.1 to 10.0 min, hardness increased from 13.2 to 16.5 N, adhesiveness increased from 1.43 to 2.00 Nmm, percent rehydration dropped from 133 to 103%, cooking loss rose from 4.8 to 5.8%, and swelling index decreased from 1.93 to 1.50 g/g.

Similar results to those above regarding cooking time were reported for the preparation of wheat-based noodles (Ritthiruangdej et al. 2011). Decreased OCT is caused by the physical disruption and reduction of the gluten fraction due to fibre inclusion, which is likely to facilitate water penetration inside the spaghetti core (such diffusion is

rapid in the case of higher protein content) (Del Nobile et al. 2005). The higher cooking time of DWS represents the compactness of spaghetti and higher gelatinisation temperature of durum wheat starch. Variation in cooking time may also be accredited to the difference in gelatinisation temperatures of the starch fractions from durum and matri flour (Kaur et al. 2015). Hardness and adhesiveness of DMF-substituted spaghetti were significantly higher than in the durum wheat sample. A similar trend was observed in the preparation of pasta using yellow pea flour (Shreenithee and Prabhasankar 2013).

Another factor that enhances spaghetti hardness is the propagation rate from the outer swollen region to the unpenetrated core (Shreenithee and Prabhasankar 2013). An increase in adhesiveness due to legume addition has been attributed to the non-gluten protein interfering with the gluten (Shreenithee and Prabhasankar 2013).

Percent rehydration relates the weight of cooked spaghetti to the weight of uncooked spaghetti. The increased in percent rehydration for DMF-substituted spaghetti was similar to the corresponding result for split pea-substituted spaghetti (Petitot et al. 2010a). Increased water absorption may be accredited to an altered gluten network (Ahmed et al. 2015).

Here, the cooking loss results were in line with several studies associated with solubilisation and leaching of albumins and globulins (Petitot et al. 2010a; Mohammed et al. 2012). Texture and appearance of the final product depends upon cooking loss of soluble solids. A positive correlation between amylose content and solids loss has been reported (Kaur et al. 2015). It is likely that the structural integrity of the starch and gluten network was disrupted by substitution with DMF, hence increasing the cooking loss.

Swelling index values were in accordance with a study on breadmaking using chickpea-wheat composite flour (Mohammed et al. 2012). Swelling index was significantly decreased by substituting DWS with DMF, most probably due to the higher hydrophilicity of the legume flour, leading to preferential water absorption and inhibition of starch granule swelling (Petitot et al. 2010a; Mohammed et al. 2012). Excessive formation of protein links with most of the available water during cooking leaves less water for starch to swell. Starch granules thus take more time to absorb water, ultimately decreasing the swelling index and rehydration percentage as the legume flour level is increased. Decline in swelling index due to addition of matri flour may also be accredited to differences in amylopectin chains. The higher lipid content of the matri flour also highlights the presence of amylose–lipid complexes, which hinders granule swelling (Kaur et al. 2015).

Table 3 Cooking qualities of spaghetti made from durum wheat semolina (DWS) substituted with different levels of detoxified matri flour (DMF)

Treatments	OCT (min)	Hardness (N)	Adhesiveness (Nmm)	Percent rehydration	Cooking loss (%)	Swelling index (g/g)
DWS	12.1	13.2 ± 0.7 ^e	1.43 ± 0.08 ^e	133 ± 5 ^a	4.8 ± 0.3 ^d	1.93 ± 0.00 ^a
5% DMF	11.9	15.3 ± 0.5 ^d	1.55 ± 0.11 ^d	130 ± 3 ^{ab}	5.3 ± 0.3 ^c	1.90 ± 0.03 ^a
10% DMF	11.8	15.6 ± 0.5 ^c	1.66 ± 0.19 ^c	123 ± 3 ^{bc}	5.3 ± 0.2 ^{bc}	1.84 ± 0.06 ^{ab}
15% DMF	10.7	16.1 ± 0.4 ^b	1.80 ± 0.07 ^b	115 ± 2 ^{cd}	5.4 ± 0.2 ^b	1.75 ± 0.02 ^b
20% DMF	10.1	16.2 ± 0.2 ^b	1.98 ± 0.05 ^a	109 ± 4 ^{de}	5.7 ± 0.3 ^a	1.54 ± 0.04 ^c
25% DMF	10.0	16.5 ± 0.4 ^a	2.00 ± 0.13 ^a	103 ± 2 ^e	5.8 ± 0.1 ^a	1.50 ± 0.01 ^c

Results are presented as mean values ± SE for three replicate samples. Mean values within the same column with different superscript letters are significantly different ($\alpha = 0.05$)

OCT optimal cooking time

Experimental phase 2: Effects of xanthan gum (XG) on the cooking quality and diastatic behavior of spaghetti made from DWS substituted with DMF at 15%

On the basis of a substantial decrease in departure time (Table 2), as well as an increase in adhesiveness and cooking loss (Table 3), between the 15 and 20% substitution rates, spaghetti with 15% DMF was chosen as the standard reference sample. The aim here was to determine the modifications of the cooking and functional properties of 15% DMF-enriched spaghetti by incorporating XG.

Diastatic behavior

Pasting temperature and maximum viscosity were significantly increased for spaghetti containing increasing levels of XG in comparison to the reference spaghetti (Fig. 2). These increases were attributed to a substantial

Fig. 2 Diastatic behaviour of spaghetti made from durum wheat semolina (DWS) substituted with detoxified matri flour (DMF) at 15%. Results are presented as mean values ± SE for three replicate samples. Mean values with different letters are significantly different ($\alpha = 0.05$)

concentration of the gum in the liquid phase of the biphasic pasta matrix, ultimately reducing the swelling of starch granules during gelatinisation. The effect of gums on starch properties is a function of both concentration of the gum and type of starch used.

Hardness was decreased because gum absorbs more water and entraps starch granules, ultimately positively affecting surface appeal, shape and viscoelasticity of the spaghetti (Rayas-Duarte et al. 1996; Cleary and Brennan 2006). It was observed previously that textural properties of spaghetti are also affected by macroscopic modifications in the gluten network, which changes the moisture content with different formulations and stabilises the hydrated network (Purnima et al. 2012).

Cooking quality

OCT, cooking loss, swelling index, percent rehydration and hardness/adhesiveness were significantly affected by adding XG (Fig. 3). Similar results were documented in an assessment of spaghetti quality prepared from DWS (Padalino et al. 2014). Similar spaghetti behavior upon addition of flour and fibre from various sources has also been reported (Rayas-Duarte et al. 1996; Tudorica et al. 2002). Most likely, OCT was reduced (Fig. 3a) due to decreased water diffusion in the spaghetti matrix by adding XG, hence increasing hydration time (Padalino et al. 2014).

Decrease in cooking loss (Fig. 3b) was attributed to the ability of gums to form a network around starch granules, thereby hampering excessive swelling and amylose diffusion from the core of the spaghetti strand (Chillo et al. 2007; Padalino et al. 2014). Decreased cooking loss may be accredited to the formation of amylose-hydrocolloid complexes. It has also been suggested that, within the starch granules, the solubility of starch polymer molecules is decreased. Disruption of the protein-starch matrix, causing uneven water distribution and a competitive tendency for

Fig. 3 Effect of different levels of xanthan gum (XG) on cooking qualities of spaghetti made from durum wheat semolina (DWS) substituted with detoxified matri flour (DMF) at 15%. **a** optimal cooking time (OCT), **b** cooking loss, **c** swelling index, **d** percent rehydration, **e** hardness and **f** adhesiveness. Results are presented as mean values $\pm$ SE for three replicate samples. For **b–f**, mean values with different letters are significantly different ($\alpha = 0.05$)

hydration, also occurs (Chillo et al. 2007). When the reference spaghetti (15% DMF) was assessed for cooking loss beyond the 3% XG level, the cooking loss did not change significantly. Excessive gum addition also changes the properties of the pasta matrix (Purnima et al. 2012; Carini et al. 2012).

Swelling index (Fig. 3c) and percent rehydration (Fig. 3d) increased due to the capacity of XG for water absorption and to form a well-developed starch-protein network (Rayas-Duarte et al. 1996; Cleary and Brennan 2006).

The decrease in hardness (Fig. 3e) and adhesiveness (Fig. 3f) due to XG addition is attributed to the ability of gums to form a stronger network with gluten, entrapping starch granules, thus hampering amylose release (Rayas-Duarte et al. 1996; Cleary and Brennan 2006). A strong gluten network lowers adhesiveness while hydrocolloids increase cohesiveness (Howard et al. 2011). Gums usually exhibit good compatibility in relation to the gluten network (Kovacs and Vamos 1993).

Conclusion

This study showed that spaghetti prepared by blending DMF and DWS exhibited an acceptable quality profile. The levels of all components measured in the proximate analysis significantly increased following supplementation with DMF. Rheology aspects were also significantly modified, making the spaghetti harder and more adhesive than the control product. XG was shown to improve the cooking quality, cooking loss, percent rehydration and swelling index of the 15% DMF spaghetti. Taken together, the results here show that high-quality spaghetti can be prepared from DWS:DMF:XG in proportion 82:15:3. Our findings may encourage the use of non-conventional ingredients in developing pasta products with enhanced functional and nutritional value.

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