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Original article

Influence of pre-gelatinization in conjunction with guar gum addition on texture functionality, bioactive profile, *in vitro* nutrient digestibility, morphology and secondary structure of protein of quality protein maize pasta

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Summary The current investigation aimed to develop quality protein maize (QPM) specialty pasta (partial: 50% QPM and full replacement of semolina: 100% QPM) and study the influence of pre-gelatinization in conjunction with guar gum addition (1.5% or 3%) on bio-techno-functional properties of pasta. Scanning electron microscopy depicted the encapsulation of swollen starch within a protective sheet developed as a result of gum addition and starch gelatinisation. The Fourier transform infrared spectra denoted a shift from crystalline towards amorphous state in starch as a consequence of partial gelatinisation. The secondary structure of protein signified a drop in the alpha-helix structure and thereby enhanced the *in vitro* protein digestibility of the pregelatinised samples. Multivariate principal component analysis was utilised to validate the differences between the parameters. The overall study inferred that the QPM owned an excellent potentiality for the development of nutrient-dense pasta by employing the functionality of gums and pre-gelatinisation treatment.

Keywords FTIR spectra, *in vitro* digestibility, pasta, pregelatinisation, quality protein maize, scanning electron microscopy.

Introduction

Quality protein maize (QPM), a nutritionally superior hybrid maize variety, was developed by the International Maize and Wheat Improvement Center (CIMMYT). It has properties similar to ordinary maize in terms of taste, grain texture and colour but possesses higher tryptophan, lysine and better yield than maize (Hossain *et al*., 2019). QPM contains about 0.33–0.54 per cent lysine, which is 46 per cent higher when compared to lysine in maize. It has two times better essential amino acid profile in comparison with conventional maize and its bioavailability is also comparable to casein protein in the milk (Nyakurwa *et al*., 2017). Also, it has a better biological value (80 per cent) which is almost twice of normal maize (45 per cent). The human body utilises 74 per cent of the total ingested QPM protein owing to its superior protein digestibility and overall protein quality than maize (Nyakurwa *et al*., 2017). Also, regular intake of QPM can reduce the symptoms of a serious protein deficiency illness, protein energy malnutrition (PEM) that has affected 20% of the child population in India (Reddy Surasani *et al*., 2019).

Pasta is a versatile, convenient, shelf stable and a nutrient-dense food, that fulfils the demand of modern and dynamic lifestyle. Pasta products are usually prepared using durum wheat semolina, thus deficient in essential fatty acids and amino acids and minerals. In recent years, non-conventional pasta developed from alternative cereals and millet has gained massive attention due to a drastic rise in the patients of metabolic disorders, gluten intolerance and severe protein deficiencies globally thus demanding innovative approaches for the development of such products. In recent years, several experiments have been conducted to enhance the functional and nutritional properties of extruded products, through supplementation with millets (Gupta *et al*., 2021), vegetables and fruits (Sobota *et al*., 2020) and by-products from food processing industries (Reddy Surasani *et al*., 2019).

The utilisation of QPM for the development of extruded products for enhanced nutritional profiles has not been comprehensively explored. Hence, the

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present investigation was proposed to explore the possibility of utilising QPM as a potential ingredient in pasta. The objectives of the present investigation were aimed to (i) to evaluate the impact of processing aids (pre-gelatinization and gum addition) on the cooking quality, textural parameters, antioxidant properties, morphological attributes and biological (*in vitro* protein and starch digestibility) properties of the developed product and (ii) to study the macromolecular interactions during given treatments and the correlations among different variables and observations.

Materials and methods

Raw materials and processing of pasta

HQPM1 variety of quality protein maize was procured from the Indian Institute of Maize Research, Punjab Agricultural University, Ludhiana. The grains were dried and milled using domestic mill (Perten Company, Manitoba, Canada) and passed through sieve (mesh size 20.0 or 840 μm). different blends with varying QPM levels (50% and 100%), semolina (0% and 50%) and guar gum levels (1.5% and 3%) were prepared. 0.5 kg of each blend was mixed with the calculated amount of water to attain a hydration level of 35 percent followed by thorough mixing for 10–15 min in the mixing chamber of the pasta extruder (La Monferrrina, S.R.L 14033, Castell Alfero, Masoero Arturo and C.S.N.C., Statale, Italy). The spiral-shaped die (No. 469) was used, and the cutter speed was adjusted to obtain uniform pasta length of 2.5 cm. The freshly prepared pasta was exposed to immediate steaming for about 25 min for pre-gelatinization and dried in a tray drier at 45–50 °C for 5 h.

Functional properties of pasta

Water absorption capacity (WAC), water solubility index (WSI), swelling power (SP) and oil absorption capacity (OAC)

The sample (2.0 g) was taken in a pre-weighed centrifuge tube and WAC was estimated by the method suggested by Elkhalifa & Bernhardt (2010). OAC and SP were determined by the procedure suggested by (Reddy Surasani *et al*., 2019) and (Elkhalifa & Bernhardt, 2013), respectively. The detailed procedure has been provided in supp. file.

Cooking quality of pasta

Optimum cooking time (OCT), volume expansion (VE), water absorption and gruel solid loss (GSL) were determined as per the method described in (AACC, 2000). The detailed procedure has been provided in supp. file.

Bioactive constituents and antioxidant activity

Total phenolic content (TPC) and flavonoid content (TFC)

Bioactive constituents were extracted (procedure mentioned in supp. file) and estimated using the method described by (Žilić *et al*., 2012). TPC and TFC were estimated results were expressed in terms of mg of gallic acid equivalents (GAE) per g and mg of quercetin equivalent (QE) per 100 g of the dried sample weight.

DPPH radical scavenging activity (%)

Methanolic extract (0.1 mL) was added to 3.9 mL of freshly prepared 2-diphenyl-1-picrylhydrazyl (DPPH) dye solution (0.1 mM) followed by incubation in dark for 30 min (Žilić *et al*., 2012).

In vitro starch and protein digestibility (IVSD, IVPD)

In vitro starch and protein digestibility of both raw and cooked pasta samples was assessed by estimating the amount of free maltose formed after starch digestion (Bernfeld, 1955). Further, IVPD of pasta samples was determined as per the two-step protein hydrolysis method described by Sharma *et al.* (2019). The detailed procedure has been provided in supp. file.

Colour and texture analysis

Hunter Lab Colorimeter (ColorFlex EZ Hunter Associates Inc., Sunset Hills Reston, Virginia, USA), D65 illuminant was used to perform the colour analysis of the QPM pasta. The reflectance values and colour parameters were recorded by measuring L^*, a^*, and b^* values (Gupta *et al*., 2021). The colour difference (ΔE) can be calculated using

$$\Delta E = \sqrt{\Delta a2 + \Delta b2 + \Delta c2}.$$

The firmness of the pasta was determined using the Texture Analyser (Model: TA-XT plus, Stable Micro Systems, Godalming, Surrey GU7 1YL, USA) using (75 mm) probe and 50 kg load cell. The detailed procedure has been provided in supp. file.

Sensory evaluation

Sensory evaluation of the cooked pasta was done by twenty semi-trained panellists in the Department of Food Science and Technology, PAU, Ludhiana, Punjab, India, on a 9-point hedonic scale for different sensory attributes *viz* texture/mouthfeel, appearance, flavour and overall acceptability.

Scanning electron microscopy (SEM)

The microstructure morphology of raw and pregelatinized pasta was studied using the scanning electron microscopy using (JSM 6100) manufactured by JEOL, Akishima, Tokyo, Japan. A holding pan was employed to hold the dried pasta samples and were sputter-coated with gold with the help of a vacuum evaporator for about 2 min. Gold-coated pasta sample was then shifted into the microscope stage to examine the samples at an accelerating voltage of about 1 kV (Gupta *et al*., 2021).

Fourier transform infrared spectroscopy (FTIR)

The infrared spectra of the pasta samples were studied with FTIR spectrophotometer (Tensor 27 spectrophotometer) designed by 38 McPherson St., Markham, Canada. Samples were finely ground and placed into the FTIR sample holder, and the spectrum was noted in 600–4000 cm^{-1} wavenumber ranges using ATR crystal.

Statistical analysis

Analysis was carried out in triplicate unless stated differently, and the results were expressed as mean ± standard deviation. The data were subjected to statistical analysis using Statistical Package for Social Science (SPSS) software (Version 22.0, IBM Corporation, New York, NY, USA). One-way analysis of variance (ANOVA) was performed to determine the statistical significance between the treatments followed by Tukey's *post hoc* test to determine the degree of variation in the samples. Pearson's correlation matrix was developed to establish a significant ($P < 0.05$) relation between the different parameters. Principal component analysis (PCA) was utilised to conduct multivariate analysis. The detailed procedure has been provided in supp. file.

Results and discussion

Functional properties

Functional properties directly or indirectly influence the processing applications, quality and potentiality of an ingredient to be utilised in food formulations. Samples with 3% guar gum had higher WAC than the pasta samples with 1.5% guar gum concentration as denoted in Table 1. Also, WAC was found to exhibit a positive correlation with the cooking time ($r = 0.807$, $P < 0.05$). However, a significant decrease in WAC of pregelatinized samples when compared to raw samples was observed. This might be due to low water absorption by starch already gelatinized by steam treatment. However, OAC declined with an increase in guar gum levels. A significant reduction in WSI of pasta samples was observed as the concentration of guar gum increased from 1.5% to 3%. Similarly, a lower WSI in noodles with the addition of hydrocolloids/binders was reported (Shere *et al*., 2020). A significant reduction in WSI of pregelatinized samples compared to its raw counterpart owing to the induced association and bridging between the gelatinized starch granules was observed. A significant increase in the SP with an increase in guar gum concentration was observed which may be attributed to the hydrophilic nature and high WAC of guar gum. However, a significant reduction in the SP, on pre-gelatinization was obtained.

Cooking quality

Pasta with 1.5% guar gum had lower OCT compared to those incorporated with 3% guar gum. The prolonged cooking time with an increase in guar gum level may be attributed to the fact that gums encapsulate the starch granules and limit the access of water to them. Additionally, competition for water between starch and hydrocolloid molecules led to an increase in the onset gelatinization temperature of the maize starch. A prominent increase in the water absorption of pasta with an increase in guar gum concentration was observed. However, steaming declined the water absorption by the pasta samples which can be attributed to low water uptake by the pregelatinized starch. The water absorption trend was accurately reflected in the VE capacity of the cooked pasta as denoted by the positive correlation ($r = 0.754$, $P < 0.05$) between the two parameters. A pronounced decrease in GSL with an increase in the guar gum concentration was observed as indicated in Table 1. It can be attributed to the polysaccharide network formed by gums on hydration that encapsulated the starch granules within it and led to a stable-starch matrix system. The gums/hydrocolloids enhanced the viscosity of the system and formed a very strong association of soluble starch mainly amylose, thereby reducing amylose leaching when the sample was cooked. A similar trend was documented by (Pongpichaiudom & Songsermpong, 2018) where the noodles formulated with hydrocolloids had significantly lower solid losses than the control. WSI showed a strong positive correlation ($r = 0.968$, $P < 0.05$) with the firmness of the cooked pasta samples. The findings were supported by the negative correlation ($r = 0.968$, $P < 0.05$) between GSL and WSI of the cooked samples.

Antioxidant assay and bioactive compounds

Drastic upsurge in the TPC, TFC and antioxidant activity with an increase in QPM flour concentration from 50% to 100% as indicated in Table 2. Significant

Table 1 Functional properties and cooking quality of quality protein maize pasta as affected by pre-gelatinization and guar gum addition

Samples	Water absorption capacity (g per 100 g)	Water solubility index (g per 100 g)	Oil absorption capacity (g per 100 g)	Swelling power (g g^{-1})	Optimum cooking time (min)	Water absorption (g per 100 g)	Volume expansion (mL g^{-1})	Gruel solid loss (%)
QPM (50) GG (1.5)	160.82 ± 1.92^{d}	7.39 ± 0.03^{c}	112.56 ± 0.86^{a}	6.51 ± 0.02^{e}	8.10 ± 0.02^{e}	162.79 ± 0.86^{d}	4.15 ± 0.07^{d}	7.69 ± 0.06^{c}
QPM (50) GG (1.5) PG	110.39 ± 1.09^{h}	6.56 ± 0.09^{f}	111.12 ± 0.51^{ab}	6.12 ± 0.12^{f}	7.30 ± 0.03^{g}	118.85 ± 2.01^{g}	3.98 ± 0.11^{e}	6.87 ± 0.02^{e}
QPM (50) GG (3)	164.21 ± 1.18^{c}	6.96 ± 0.15^{e}	109.72 ± 1.28^{b}	7.51 ± 0.04^{c}	8.25 ± 0.03^{d}	167.49 ± 0.90^{c}	4.82 ± 0.11^{b}	6.67 ± 0.01^{ef}
QPM (50) GG (3) PG	116.78 ± 1.74^{g}	6.15 ± 0.05^{g}	106.40 ± 1.25^{c}	7.23 ± 0.1^{d}	7.40 ± 0.05^{f}	120.79 ± 2.24^{g}	4.67 ± 0.13^{c}	5.85 ± 0.21^{g}
QPM (100) GG (1.5)	187.83 ± 1.25^{b}	9.36 ± 0.15^{a}	103.77 ± 0.66^{d}	7.75 ± 0.07^{b}	8.40 ± 0.01^{b}	195.80 ± 1.61^{b}	4.26 ± 0.05^{d}	9.21 ± 0.31^{a}
QPM (100) GG (1.5) PG	124.45 ± 0.36^{f}	7.84 ± 0.18^{b}	104.89 ± 0.58^{cd}	7.18 ± 0.04^{d}	8.15 ± 0.08^{e}	135.42 ± 2.12^{f}	3.91 ± 0.08^{e}	8.10 ± 0.05^{b}
QPM (100) GG (3)	190.24 ± 1.51^{a}	7.17 ± 0.12^{d}	101.41 ± 1.29^{e}	8.18 ± 0.17^{a}	9.30 ± 0.02^{a}	200.17 ± 0.98^{a}	5.44 ± 0.03^{a}	7.40 ± 0.05^{d}
QPM (100) GG (3) PG	128.67 ± 2.48^{e}	6.25 ± 0.06^{g}	100.12 ± 1.62^{e}	7.76 ± 0.14^{b}	8.30 ± 0.04^{d}	140.79 ± 1.08^{e}	4.83 ± 0.05^{b}	6.42 ± 0.22^{f}

Values are expressed as Mean ± standard deviation; Means with different superscripts in a column differ significantly at $P < 0.05$.
GG, guar gum; PG, pre-gelatinized; QPM, quality protein maize; (1.5) and (3): percentages of guar gum; (100) and (50): levels of QPM.

reduction in TPC and TFC when the samples were subjected to pre-gelatinization can be ascribed to the binding of phenolic compounds with other macromolecules and their decomposition at elevated temperatures. However, a significant decline in the antioxidant activity was observed in samples that were exposed to pre-gelatinization prior to drying. A significant positive correlation was obtained between antioxidant activity and TPC ($r = 0.951$, $P < 0.05$), TFC ($r = 0.989$, $P < 0.05$) denoting a significant contribution of total phenols and flavonoids towards antioxidative nature of the samples.

In vitro starch digestibility

The sample with 100% QPM flour had lower starch digestibility than that with 50% QPM flour owing to the high fibre, protein and flavonoid content of QPM than semolina. Also, a negative relation between starch breakdown with the protein content of pasta was observed. It can be ascribed to the formation of a protein barrier surrounding starch granules, thereby limiting the availability of substrate for enzymatic action. The starch digestibility declined profoundly in the presence of flavonoids due to their ability to bind at active sites of the enzyme, inhibiting alpha-amylase activity. Starch digestibility declined with an increase in guar gum level from 1.5% to 3%. Guar gum increases the viscosity of the food system, altering the enzyme-substrate reactions, mass transfer of the molecules (enzymes and sugars) and hydrolysis kinetics. A similar trend on guar gum addition was reported for corn starch where a significant decline in both extent of starch digestibility and rate of reaction was noted (Sasaki & Kohyama, 2012). However, a significant improvement in the starch digestibility was observed in the pre-gelatinized pasta which could be correlated to the partial gelatinization of the maize starch exposing the sites and thus higher rate of enzymatic action.

In vitro protein digestibility

The IVPD of pasta samples with 1.5% guar gum was significantly higher than those incorporated with 3% guar gum. 100% QPM pasta had higher protein digestibility followed by 50% QPM pasta. A significant decline in the protein digestibility was observed when the guar gum level was increased from 1.5% to 3% attributing to the coating effect of the gum on the protein molecules that tends to curtail the proteolytic action, thereby causing a decline in the protein digestibility. Pre-gelatinized samples had significantly higher protein digestibility than their raw counterparts since cooking exposed the peptide bond them as a result of thermal denaturation of proteins instigating conformational changes in the secondary structure and subsequent water loss.

Table 2 Bioactive composition and *in vitro* nutrient digestibility of quality protein maize pasta as affected by pre-gelatinization and guar gum addition

Samples	Total phenolic content (mg GAE g^{-1})	Total flavonoid content (mg quercetin per 100 g)	Antioxidant activity (% DPPH radical scavenging activity)	Starch digestibility (g maltose per 100 g pasta)		Protein digestibility (g per 100 g pasta)	
				Uncooked	Cooked	Uncooked	Cooked
QPM (50) GG (1.5)	2.33 ± 0.05^{d}	29.45 ± 0.9^{e}	30.45 ± 0.45^{c}	23.34 ± 0.25^{d}	55.23 ± 1.04^{e}	54.05 ± 0.88^{a}	56.80 ± 0.24^{d}
QPM (50) GG (1.5) PG	2.15 ± 0.02^{e}	30.36 ± 0.66^{e}	28.31 ± 1.14^{d}	30.8 ± 0.31^{a}	72.56 ± 0.22^{a}	57.12 ± 1.03^{bc}	60.12 ± 0.25^{b}
QPM (50) GG (3)	2.28 ± 0.03^{d}	32.56 ± 0.73^{d}	30.22 ± 0.76^{c}	21.42 ± 0.29^{e}	51.47 ± 1.25^{g}	51.01 ± 1.15^{e}	53.43 ± 0.21^{g}
QPM (50) GG (3) PG	2.17 ± 0.03^{e}	30.67 ± 1.87^{e}	29.97 ± 0.37^{c}	28.81 ± 0.28^{b}	69.78 ± 0.60^{b}	53.87 ± 1.21^{d}	55.75 ± 0.19^{e}
QPM (100) GG (1.5)	3.31 ± 0.01^{a}	$50. 63 \pm 1.83^{b}$	44.17 ± 0.34^{a}	19.09 ± 0.34^{g}	51.41 ± 0.79^{f}	57.43 ± 1.19^{b}	59.79 ± 0.28^{b}
QPM (100) GG (1.5) PG	2.89 ± 0.04^{b}	47.76 ± 1.72^{c}	42.21 ± 0.81^{b}	25.12 ± 0.44^{c}	65.11 ± 1.29^{c}	60.86 ± 0.22^{a}	63.87 ± 0.50^{a}
QPM (100) GG (3)	3.29 ± 0.03^{a}	53.14 ± 0.48^{a}	44.02 ± 0.68^{a}	17.87 ± 0.11^{h}	44.25 ± 0.47^{g}	53.28 ± 0.22^{d}	55.98 ± 0.20^{e}
QPM (100) GG (3) PG	2.67 ± 0.07^{c}	48.51 ± 0.39^{c}	41.12 ± 0.62^{b}	21.44 ± 0.49^{e}	61.78 ± 0.80^{d}	55.87 ± 0.81^{c}	58.34 ± 0.11^{c}

Values are expressed as Mean ± standard deviation; Means with different superscripts in a column differ significantly at $P < 0.05$.
DPPH, 2,2-diphenyl-1-picrylhydrazyl; GAE, gallic acid equivalent; GG, guar gum; PG, pre-gelatinized; QPM, quality protein maize; (1.5) and (3): percentage of guar gum; (100) and (50): level of QPM.

Colour analysis

L^* and ΔE values denoting brightness and colour difference, a^* and b^* values depicting yellow-blue and red green components are most important in assessing the colour attributes of pasta. 50% QPM pasta showed higher L^* values in comparison to 100% QPM pasta as indicated in Table 3. Steam treatment led to a significant reduction in L^* values. An increase in the redness was observed in pre-gelatinized pasta in comparison to raw pasta in case of both 50% and 100% QPM pasta. The yellowness (b^*) enhanced with the increasing level of QPM flour. The yellowness index can be linked with the presence of high carotenoids, phenols and flavonoids pigments and enzymatic reactions as justified by the positive correlation between TFC ($r = 0.883$, $P < 0.05$), TPC ($r = 0.747$, $P < 0.05$) and b^* values. Significant differences in the ΔE values of QPM pasta were visible denoting the colour difference between samples. The increase in brightness may be ascribed to complete starch gelatinization in pasta establishing a positive relationship between the degree of gelatinization of starch during processing and clarity of pasta.

Texture analysis

The firmness of the pasta denotes the arrangement of the protein matrix in the cooked pasta samples and their bond strength. Both pre-gelatinization treatment and rise in the gum level led to an increase in the firmness of pasta as indicated in Table 3. Gum addition increased the firmness attributing to dense and firm network development due to the interaction of various biopolymers and hydrocolloids. A strong negative correlation ($r = 0.968$, $P < 0.05$) was found between GSL and pasta's firmness ascribing to the loosening of the matrix due to leaching of the soluble portions in the cooking water.

Sensory evaluation

The significant difference in the overall acceptability of the different pasta samples was observed (Table 3). QPM pasta (100% QPM) supplemented with 3% guar and further pre-gelatinized were found most acceptable. Yellow-golden hue was clearly visible in all pasta samples. However, when pregelatinized, the samples became less opaque and developed a brighter yellow-colour. Enhancing the guar gum level from 1.5% to 3% led to a significant improvement in the texture of pasta. Similar results pertaining to the addition of guar gum were reported by (Shere *et al.*, 2020) where mouthfeel, texture and overall acceptability of noodles improved significantly.

Microstructure studies using SEM

Distinct polyhedral-shaped corn starch granules were prominently visible in 100% QPM pasta whereas in case of pasta with 50% of QPM flour, flat lens-shaped wheat starch granules in addition to polyhedral and angular corn starch granules were observed. The addition of binders/gums forms a protective layer that envelops the swollen and gelatinized starch granules. Also, increasing the amount of guar gum in 50% QPM pasta and 100% QPM pasta led to a uniform and dense and internal structure as denoted by the arrows in Fig. 1. A compact continuous sheet-like structure was obtained at 3% guar gum incorporation that provides evidence for lower cooking loss and

Table 3 Colour analysis, overall acceptability and texture of quality protein maize pasta as affected by pregelatinisation and guar gum levels

Sample	*L**		*a**		*b**		Δ*E*		Overall acceptability	Firmness (N)
	Un-cooked	Cooked	Un-cooked	Cooked	Un-cooked	Cooked	Un-cooked	Cooked		
QPM (50) GG (1.5)	50.96 ± 0.92^{a}	54.56 ± 1.43^{a}	1.59 ± 0.01^{f}	1.08 ± 0.01^{f}	17.01 ± 0.36^{e}	12.4 ± 0.37^{e}	11.56 ± 0.39^{f}	9.61 ± 0.06^{g}	7.5 ± 0.26^{d}	0.44 ± 0.02^{d}
QPM (50) GG (1.5) PG	48.34 ± 0.50^{b}	44.01 ± 0.40^{e}	1.67 ± 0.02^{ef}	1.24 ± 0.02^{de}	15.32 ± 0.17^{g}	11.04 ± 0.19^{f}	12.58 ± 0.06^{e}	18.83 ± 0.78^{a}	8.4 ± 0.08^{ab}	0.51 ± 0.02^{c}
QPM (50) GG (3)	50.01 ± 0.24^{a}	54.98 ± 0.59^{a}	1.64 ± 0.01^{ef}	1.20 ± 0.03^{e}	17.78 ± 0.22^{d}	13.45 ± 0.50^{d}	12.77 ± 0.12^{e}	9.96 ± 0.41^{g}	8.2 ± 0.33^{bc}	0.62 ± 0.02^{b}
QPM (50) GG (3) PG	48.67 ± 1.05^{b}	52.68 ± 0.14^{b}	1.72 ± 0.07^{e}	1.32 ± 0.01^{d}	15.95 ± 0.67^{f}	11.89 ± 0.31^{e}	12.65 ± 0.18^{e}	10.96 ± 0.01^{f}	8.5 ± 0.05^{ab}	0.74 ± 0.01^{a}
QPM (100) GG (1.5)	47.84 ± 0.69^{bc}	50.98 ± 0.51^{c}	1.91 ± 0.02^{d}	1.49 ± 0.03^{c}	18.67 ± 0.23^{c}	14.12 ± 0.05^{c}	14.98 ± 0.66^{d}	13.56 ± 0.09^{e}	7.8 ± 0.34^{cd}	0.35 ± 0.01^{e}
QPM (100) GG (1.5) PG	44.52 ± 1.00^{d}	47.69 ± 0.69^{d}	3.73 ± 0.12^{b}	2.98 ± 0.13^{a}	20.07 ± 0.08^{b}	16.92 ± 0.43^{ab}	18.63 ± 0.08^{b}	17.98 ± 0.44^{b}	8.5 ± 0.22^{ab}	0.42 ± 0.01^{d}
QPM (100) GG (3)	47.01 ± 0.25^{d}	50.67 ± 1.42^{c}	2.11 ± 0.04^{c}	1.54 ± 0.03^{c}	22.02 ± 0.20^{a}	17.15 ± 0.25^{a}	17.93 ± 0.23^{c}	15.64 ± 0.37^{d}	8.3 ± 0.06^{b}	0.49 ± 0.02^{c}
QPM (100) GG (3) PG	44.12 ± 0.99^{e}	48.98 ± 0.09^{d}	3.89 ± 0.02^{a}	1.86 ± 0.05^{b}	21.76 ± 0.04^{a}	16.43 ± 0.22^{b}	20.02 ± 0.14^{a}	16.53 ± 0.51^{c}	8.8 ± 0.33^{a}	0.63 ± 0.02^{b}

Values are expressed as Mean ± standard deviation; Means with different superscripts in a column differ significantly at $P < 0.05$.
GG, guar gum; PG, pre-gelatinized; QPM, quality protein maize; (1.5) and (3): percentages of guar gum; (100) and (50): levels of QPM.

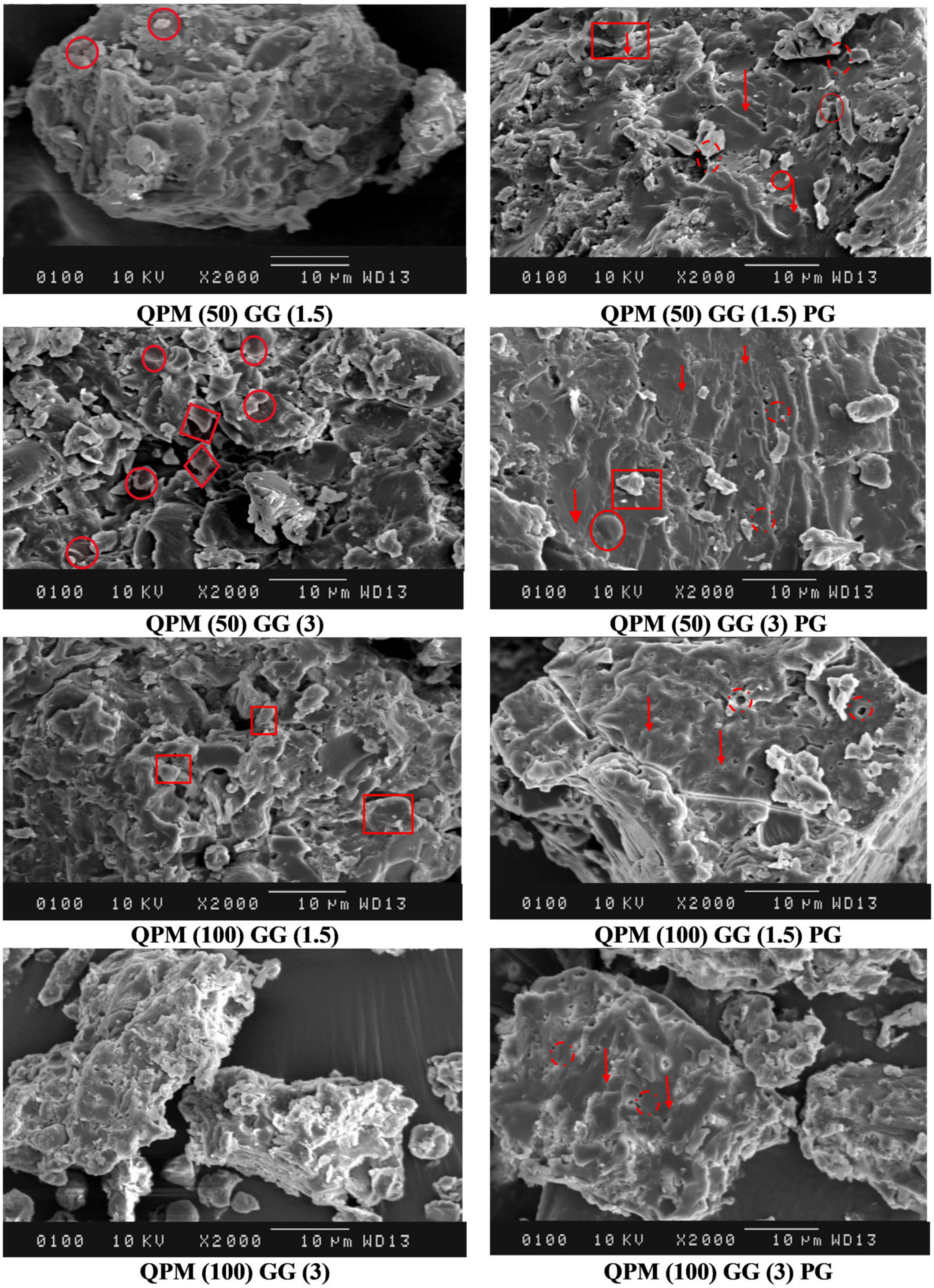

Figure 1 Morphology of quality protein maize pasta as affected by guar gum levels and pre-gelatinization treatment; circle, square, arrows and dashed circles represent wheat starch, maize starch, uniform protein matrix with embedded swollen starch molecules and air spaces in the matrix, respectively; GG, guar gum; PG, pre-gelatinized; QPM, quality protein maize; (1.5) and (3): percentages of guar gum; (100) and (50): levels of QPM.

longer cooking time of pasta incorporated with 3% guar gum. Similar results were reported by microstructure studies of spinach-semolina noodles incorporated with guar gum (Shere *et al.*, 2020).

A continuous sheet with intermittent air spaces that may be the result of fragmentation of starch particles due to partial gelatinization and further fusion to form agglomerates were observed in pregelatinized samples as indicated by arrow and dashed circles. A similar effect of pre-gelatinization was revealed by (Gandhi *et al.*, 2021) and (Khatkar & Kaur, 2018). An agglomerated, smooth and compact surface in the pregelatinized samples was observed. This was supported by the findings of Luo *et al.* (2015) where steamed white noodles showed a more compact, soft and dense internal structure with a significant loss in protein and starch individuality.

FTIR spectra of pasta

Representative spectra of pasta samples over the wavelength of 4000 to 650 cm^{-1} have been illustrated in Fig. 2 a and b for 50% and 100% QPM pasta, respectively. The absorbance ratio (1047/1022 cm^{-1}) was found lower in case of pregelatinized samples than their raw counterparts. The ratio declined from 0.6640 to 0.6131 for sample with 50% QPM (1.5% GG), 0.6103 to 0.5946 for sample with 100% QPM (3% GG), 0.6278 to 0.5984 for sample with 100% QPM (1.5% GG) and 0.5277 to 0.4957 for sample with 100% QPM (3% GG) on partial gelatinization (Figure 3S) in the supplementary file. This strongly supports a shift of starch granules from crystalline towards amorphous state as a consequence of partial gelatinization. Modifications in the secondary structure of protein in the amide I band

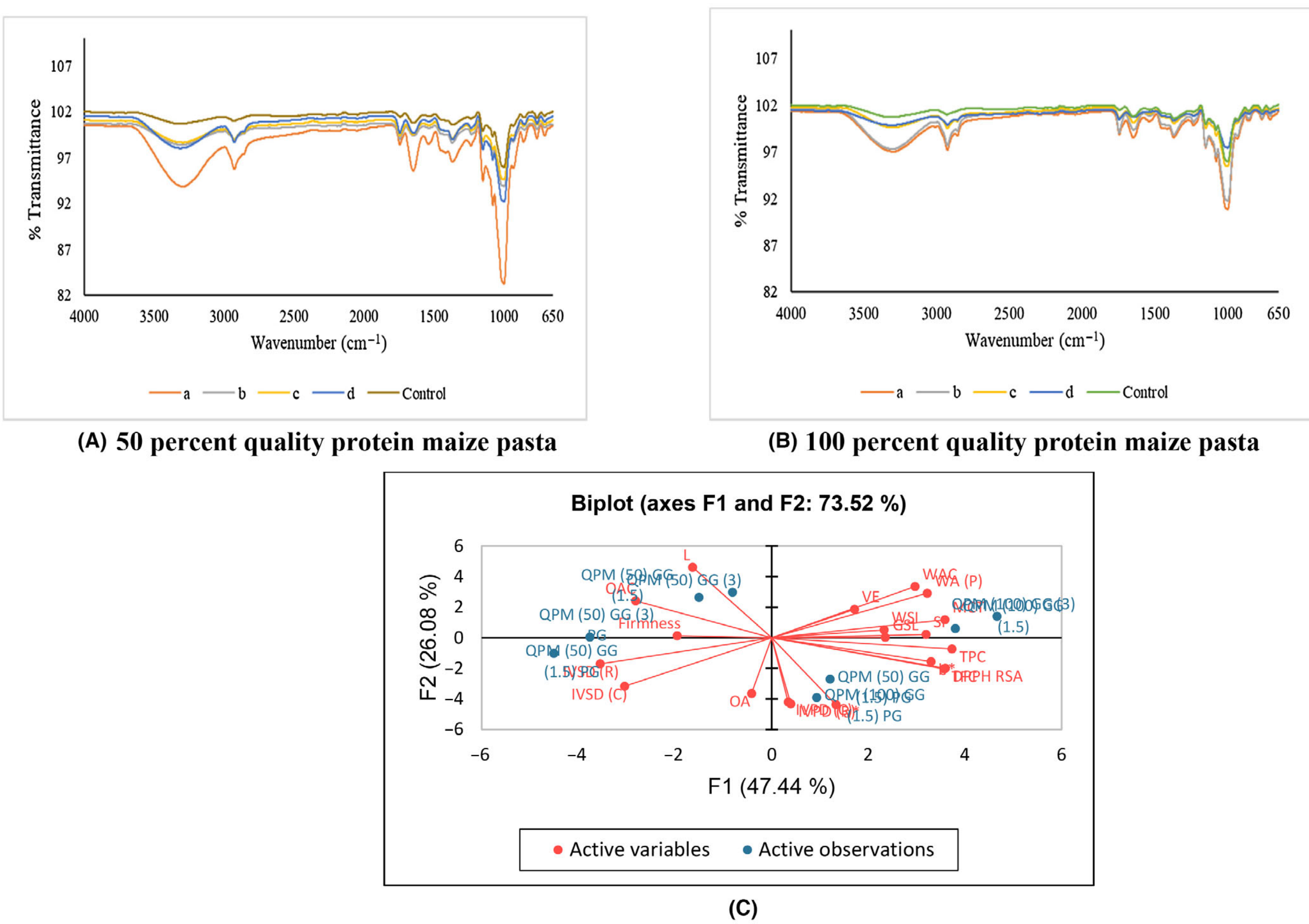

Figure 2 FTIR spectra of raw and pre-gelatinized pasta: (A) and (B) refer to 50 percent quality protein maize pasta 100 percent quality protein maize pasta respectively; a—1.5% guar gum, raw; b—1.5% guar gum, pregelatinized; c—3% guar gum, raw; d—3% guar gum, pregelatinized. (C) Multivariate analysis (PCA) plot defined by F1 and F2 with data variance of 73.52%. Active variables correspond to different functional and physico-chemical properties, whereas active observations represent different levels of gums and pre-gelatinization treatment.

(1600–1700 cm^{-1}) were studied using second derivative gaussian deconvolution. The secondary structure of the protein fractions was mainly composed of β-sheet and β-turn (accounting about 86–99%) followed by random coils and α-helix. The absence or minor proportions of α-helix and higher percentage of β-sheet indicated unfolding of the native protein and formation of protein aggregates that may be attributed to the heat denaturation of proteins during mixing, pre-gelatinization and drying of pasta. The results revealed that the β-turns, α-helix structures and random coils in the native protein got transformed into β-sheets and were in accordance with the findings of Zhang *et al.* (2019) where steam explosion increased the percentage of β-sheet structure in camellia seed protein. Low α-helix proportion has been found strongly related with better protein digestibility (Yasar *et al.*, 2020).

Principal component analysis

Data variance (73.52%) from multivariate PCA was expressed majorly in terms of two-dimensional factors, F1 (47.44%) and F2 (26.08%) as depicted in PCA plot (Fig. 2, d). Raw samples with 50% QPM (both 1.5% and 3% guar gum) were characterised by F2, while the rest of samples were defined by F1 factor. The observations lying opposite to each other showed strong negative correlation whereas the ones in close proximity exhibited a positive correlation. The WAC, VE, GSL, SP and OCT had strong correlation supported by the raw pasta with 100% QPM (1.5% and 3% guar gum). Also, WSI and GSL were closely associated with raw samples with 100% QPM and lied exactly opposite to firmness linked with pregelatinized pasta with 50% QPM and 3% guar gum.

Conclusion

Since maize lacks gluten functionality, the development of pasta with 100% maize flour presents challenges in obtaining pasta with desired textural properties. Replacement of network forming wheat gluten presents the need to use gums and treatments like pre-gelatinization, where the hydrocolloids shielded the starch granules against shear forces and provided desirable product texture due to the ionic interaction between starch and guar gum. Considering the consumer acceptability based on sensory scores, 100% QPM pasta supplemented with 3% guar gum and further pregelatinized was found most acceptable. The product has higher protein, excellent antioxidative properties, *in vitro* digestibility of protein and carbohydrates and a great overall acceptance among consumers. In addition, the pasta prepared with 100% QPM flour exhibited an additional advantage of being gluten-free. The synergistic effect of guar gum and pre-gelatinization positively influenced cooking quality and *in vitro* digestibility. This study could serve as a relevant source for future investigations dealing with the novel combinations of processing aids for the development of enriched, fabricated and convenient food products.

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Author contributions

Swati Joshi: Conceptualization (equal); formal analysis (equal); investigation (equal); writing – original draft (equal). **Savita Sharma:** Conceptualization (equal); supervision (equal); visualization (equal). **Rajan Sharma:** Conceptualization (equal); investigation (equal); software (equal); writing – original draft (equal). **Antima Gupta:** Methodology (equal); validation (equal); writing – review and editing (equal). **Ramesh Kumar:** Resources (equal); writing – review and editing (equal).

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

Ethical approval was not required as the study did not involve any human or animal testing.

Peer review

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Data availability statement

The authors elect not to share data.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure 3S. FTIR spectra of Quality Protein Maize pasta denoting (a) changes in the carbohydrate profile as studied by second derivative and Gaussian deconvolution and (b) changes in the secondary structure of protein.