Effect of pregelatination on rheology, cooking and antioxidant activity of pasta

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Abstract The present study explores the possibility of using twin screw extruder for preparation of pregelatinized pasta. The effects of extrusion parameters feed moisture (28 and 32%), barrel temperature (60–105 °C) and screw speed (100–200 rpm) on pregelatinized pasta were investigated. Prepared pasta was analysed for quality characteristics in terms of cooking quality, degree of gelatinization, color, texture, pasting properties, bioactive composition. Results indicated that higher screw speed improved the cooking quality of pasta and decreased gruel solid loss. Degree of gelatinization revealed positive relation with temperature and feed moisture. Extrusion conditions, altered the color of pasta, a decrease in L*, increase in a* and b* values was observed. Higher peak viscosity was observed at lower barrel temperature and feed moisture. A significant retention in total phenolic content and flavonoid content was observed with higher feed moisture. Extrusion leads to increase in antioxidant activity and firmness upon increasing screw speed and feed moisture.

Keywords Gelatinization · Cooking · Color · Total phenolic content · Total flavanoid content · Antioxidant activity

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Introduction

In recent years, pasta has turned into a noteworthy development portion of cereal industry. Pasta products are becoming popular in the current lifestyle due to its convenience, cost and palatability. The dynamic development of small catering services and the expanding prominence of fast food have stimulated the improvement of such kind of cereal foods. (Kaur et al. 2012).

Pasta is a food that displays a distinctive structure; the ingredient (semolina) utilized as a part of its readiness increase the multifaceted nature of the food matrix (protein, starch, non-starch polysaccharides). Likewise, the method used to make pasta assumes a vital part in the improvement of the nourishment framework. In extruders, food ingredients is being cooked under baro warm conditions, shear energy employed by the turning screw, and extra heating of the barrel, warms the nourishment material to its liquefying point or plasticating point (Van Zuilichem 1992; Moscicki et al. 2007). Thus the effect of the processing methods on the making of pasta, their influence on pasta quality (cooking, color, texture etc.) and their impact on the bioavailability of phytochemicals is matter of concern. During pasta cooking, if starch swelling with exudates loss persists, that will promote firmness of cooked pasta by entrapping starch particles in continuous network alveoli. In the meantime, if protein coagulates in discrete masses without a consistent structure wins; subsequently pasta will indicate non-abrasiveness and normally stickiness (Cunin et al. 1995; Del Nobile et al. 2005; Grzybowski and Donnelly 1979).

Bioactive components occurring in cereal products influence human wellbeing through scavenging free radicals, chelating the metal particles that catalyze oxidation responses, hindering the movement of oxidant catalysts,

and actuating cancer prevention agent chemicals (Heimler et al. 2005; Lambert et al. 2005; Kaur and Kapoor 2001; Vita 2005).

Phenolics comprise the largest group among natural antioxidants. Phenolics contain a few gatherings of mixes contrasting in structure: phenolic acids (benzoic acids and hydroxycinnamic acids), flavonoids (flavonols, flavones, flavanols, isoflavones), stilbenes and tannins (Kaur and Kapoor 2001; Cheynier 2005; Rice-Evans et al. 1997; Wiczowski and Piskula 2004). The study was used to investigate the effect of extrusion on bioactive compounds (phenolic compounds, flavonoids and their antioxidant activity), cooking and rheological characteristics of pregelatinized pasta prepared using twin screw extruder.

Materials and methods

Raw material used in pasta production

Commercial semolina obtained from local food store was used in this study.

Proximate analysis of raw material

AACC (2000) methods were used for determination of proximate analysis of semolina.

Extrusion

Extrusion experiments were performed on a co-rotating intermeshing twin screw extruder model BCH (Clextral, Firminy, France).

Experimental design

A randomized experimental design was carried out to optimize the processing conditions for pregelatinized pasta. Feed moisture (28 and 32%), barrel temperature (60–105 °C) and screw speed (100–200 rpm) being the extrusion variables (Tables 1, 2, 3). The influence of these variables was assessed.

Degree of starch gelatinization (DSG)

Amylose/iodine blue method was used for determination of degree of gelatinization (Birch and Priestley 1973).

Cooking characteristics of pasta

AACC (2000) methods were used for determination of cooking characteristics viz. water absorption (%), volume expansion (mL/g) and gruel solid loss (%).

Color

Color meter, CR-300 (Minolta Camera Co. Ltd., Japan) was used for measuring the color of the dried pasta. Results were expressed in the CIE $L^*a^*b^*$ space as L^* (lightness; 0 = black, 100 = white), a^* (+ a^* = redness, – a^* = greenness) and b^* (+ b^* = yellowness, – b^* = blueness) values (CIE 1986). The value of hue angle for each sample was calculated using following equation.

$$h^* = \arctan\left(\frac{b^*}{a^*}\right)$$

Pasting properties of pasta

Rapid visco analyser (RVA) model starch Master (Newport Scientific, Warriewood, Australia) was used to determine the pasting properties of pregelatinized processed pasta.

Textural attributes of pasta

Texture of cooked pasta was measured using TA-XT2 texture analyzer with a 50 kg load cell. HDP/BSK metal blade probe was used to shear cooked pasta strands with pre-test speed 5 mm/s, test-speed 1 mm/s, post test-speed 0.5 mm/s, distance 2 mm and force of 0.5 N. Texture Exponent software (v. 4.0.8.0) has been employed to calculate, firmness, cohesiveness, springiness, stickiness, gumminess (hardness x cohesiveness) and chewiness (gumminess x springiness).

Total phenolic content (TPC)

Extraction was made according to the method proposed by Sharma and Gujral (2010) with slight modifications. Briefly, finely ground samples (1 g) were extracted twice with acidified methanol:water (80:20 v/v) solution acidified with 0.1% HCl, for 2 h. After centrifugation the supernatants were pooled and transferred to 50 mL volumetric flask and volume was made with the aqueous methanol. Total phenolic contents in the extracts were estimated using Folin–Ciocalteu reagent (Sharma and Gujral 2010). In brief, the reaction mixture contained equal volumes of extract and aqueous methanol and 5 mL freshly diluted (1:10) Folin–Ciocalteu reagent. After 4 min, 4 mL sodium bicarbonate was added. The contents were shaken and incubated for 2 h at 25 °C. The absorbance at 725 nm was measured using Spectronic-200 and was used to calculate the phenolic contents using gallic acid as a standard. The total phenolic contents were expressed as mg gallic acid equivalent (GAE)/100 g dry weight.

Table 1 Effect of extrusion processing variables on cooking characteristics and color of pregelatinized pasta (100 rpm screw speed)

Moisture content (%)	Temperature (°C)	Minimum cooking time (min)	Water absorption (%)	Volume expansion (mL/gm)	Gruel solid loss (%)	L*	a*	b*	Hue angle
28	60	11:04 ± 0.29	119.43 ± 1.37	2.19 ± 0.11	9.32 ± 0.06	56.6 ± 0.674	-1.67 ± 0.06	8.37 ± 1.153	78.72 ± 0.652
	75	12:12 ± 0.22	118.95 ± 1.27	2.02 ± 0.06	8.61 ± 0.1	50.64 ± 0.923	-2.1 ± 1.1	9.17 ± 1.271	77.77 ± 0.2713
	90	12:43 ± 0.45	122 ± 1.15	2.34 ± 0.05	8.01 ± 0.09	45.76 ± 0.839	-2.4 ± 1.5	10.74 ± 0.839	77.41 ± 0.835
	105	14:02 ± 0.22	120.75 ± 1.22	1.82 ± 0.08	6.70 ± 0.10	42.6 ± 0.679	-2.7 ± 1.0	11.67 ± 0.679	76.98 ± 0.771
32	60	9:02 ± 0.10	122.41 ± 1.41	2.40 ± 0.10	7.11 ± 0.08	65.6 ± 0.454	-0.5 ± 0.03	8.05 ± 0.900	86.45 ± 896
	75	9:32 ± 0.24	125.17 ± 1.30	2.45 ± 0.13	7.42 ± 0.07	54.04 ± 0.721	-0.8 ± 0.01	10.74 ± 1.271	85.75 ± 1.290
	90	9:43 ± 0.40	129.58 ± 1.28	2.51 ± 0.08	7.41 ± 0.08	51.1 ± 0.393	-1.3 ± 0.96	14.67 ± 1.290	84.94 ± 0.848
	105	10:39 ± 0.23	140.49 ± 1.22	2.62 ± 0.07	4.91 ± 0.04	50 ± 0.254	-1.5 ± 0.06	16.8 ± 1.220	84.9 ± 0.656
LSD ($p < 0.05$)		0.511	2.169	0.137	0.128	1.413	0.521	1.904	1.480

Values are mean ± SD

Table 2 Effect of extrusion processing variables on cooking characteristics and color of pregelatinized pasta (150 rpm screw speed)

Moisture content (%)	Temperature (°C)	Minimum cooking time (min)	Water absorption (%)	Volume expansion (mL/gm)	Gruel solid loss (%)	L*	a*	b*	Hue angle
28	60	9:33 ± 0.45	118.10 ± 1.15	1.82 ± 0.05	8.72 ± 0.08	58.4 ± 1.153	-1.12 ± 0.06	9.97 ± 0.759	83.6 ± 0.775
	75	10:32 ± 0.22	118.75 ± 1.27	1.90 ± 0.10	7.33 ± 0.05	57.34 ± 1.271	-1.4 ± 0.95	10.74 ± 0.801	82.58 ± 0.746
	90	10:50 ± 0.10	119.0 ± 1.21	2.32 ± 0.07	7.62 ± 0.06	53.37 ± 1.206	-1.98 ± 1.31	13.84 ± 0.817	81.86 ± 0.832
	105	14:17 ± 0.22	120.41 ± 1.17	1.61 ± 0.08	5.91 ± 0.1	50.2 ± 1.169	-2.1 ± 0.96	14 ± 0.679	81.47 ± 0.812
32	60	8:93 ± 0.41	121.33 ± 1.37	2.22 ± 0.06	6.71 ± 0.09	67.74 ± 1.365	-0.5 ± 0.03	10 ± 0.900	87.14 ± 0.866
	75	9:99 ± 0.19	123.55 ± 1.27	2.20 ± 0.04	6.81 ± 0.13	55.6 ± 1.271	-1.04 ± 0.53	12 ± 0.870	85.05 ± 0.976
	90	10:11 ± 0.39	121.47 ± 1.29	2.31 ± 0.1	6.38 ± 0.14	55.8 ± 1.290	-1.64 ± 2.76	13.94 ± 0.588	83.3 ± 0.713
	105	11:16 ± 0.25	130 ± 1.22	2.22 ± 0.06	3.21 ± 0.15	54 ± 1.218	-1.9 ± 0.05	15 ± 1.660	82.79 ± 0.694
LSD ($p < 0.05$)		0.537	2.156	0.130	0.125	2.154	0.390	1.387	1.412

Values are mean ± SD

Table 3 Effect of extrusion processing variables on cooking characteristics and color of pregelatinized pasta (200 rpm screw speed)

Moisture Content (%)	Temperature (°C)	Minimum cooking time (min)	Water absorption (%)	Volume expansion (mL/gm)	Gruel solid loss (%)	L*	a*	b*	Hue angle
28	60	9:42 ± 0.45	117.65 ± 1.24	1.82 ± 0.06	6.35 ± 0.74	64.9 ± 0.759	− 0.7 ± 0.02	11 ± 0.832	86.36 ± 0.694
	75	11:19 ± 0.2	118.45 ± 1.27	1.91 ± 0.08	6.19 ± 0.05	62.62 ± 0.801	− 1.3 ± 0.37	12.7 ± 0.976	84.16 ± 0.656
	90	11:26 ± 0.40	114.10 ± 1.16	2.20 ± 0.1	7.20 ± 0.1	54.67 ± 0.786	− 1.7 ± 0.58	14.14 ± 1.552	83.15 ± 0.281
	105	15:16 ± 0.25	117.40 ± 1.20	1.42 ± 0.07	5.21 ± 0.75	54.1 ± 0.616	− 2.3 ± 0.05	16.8 ± 0.743	82.21 ± 0.866
32	60	10:35 ± 0.35	120 ± 1.22	2.20 ± 0.05	6.32 ± 0.08	70.6 ± 0.454	− 0.4 ± 0.01	12.24 ± 0.834	88.13 ± 1.01
	75	10:35 ± 0.23	121.3 ± 1.27	2.20 ± 0.10	6.11 ± 0.2	60.89 ± 0.590	− 0.56 ± 0.05	13.04 ± 0.757	87.55 ± 0.762
	90	10:92 ± 0.44	120.4 ± 1.37	1.92 ± 0.09	5.21 ± 0.76	57.1 ± 0.393	− 0.9 ± 0.59	14.47 ± 1.290	86.45 ± 0.874
	105	11:46 ± 0.26	123.2 ± 1.17	1.80 ± 0.11	2.21 ± 0.07	55.3 ± 0.654	− 1.3 ± 0.09	16 ± 0.656	85.36 ± 0.225
LSD ($p < 0.05$)		0.584	2.150	0.132	0.468	1.395	0.293	1.758	2.081

Values are mean ± SD

DPPH radical scavenging activity assay

Antioxidant activity was measured using 1,1-Diphenyl-2-picrylhydrazyl (DPPH) radical scavenging method (Brand-Williams et al. 1995). The scavenging capacities of extracts were estimated by the reduction of the reaction color between DPPH solution and sample extracts. Freshly prepared DPPH solution (0.2 mM) was mixed with sample extracts. The mixture was kept in dark for 30 min and absorbance was recorded at 515 nm using Spectronic-200. The control was made without sample and its absorbance was measured at $t = 0$. The results were presented as percent radical scavenging activity calculated by following formula.

$$\% \text{ Radical scavenging activity} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

Total flavonoid content

Aluminium chloride colorimetric method was used for determining total flavonoid content (Woisky and Salatino 1998). Two mL of the extract was mixed with 100 μL of 10% AlCl_3 , 100 μL of 1 mol per litre potassium acetate and 2.8 mL water and allowed to incubate at room temperature for 30 min. Thereafter, the absorbance of the reaction mixture was subsequently measured at 415 nm on spectrophotometer (Make: CECIL and MODEL: CE7400).

Overall acceptability

Overall acceptability of the semolina was assessed by using semi-trained panel members on 9-point hedonic scale as described in previous section (Larmond 1977).

Statistical analyses

The data obtained in this study were expressed as the mean of triplicate determinations. The means of all the parameters were examined for significance by analysis of variance (ANOVA) and in case of significance, mean separation was accomplished by Duncan's test which was analyzed with SPSS (SPSS, [PASW version 18.0] Inc., USA) p values < 0.05 were considered to be significant.

Results and discussion

Proximate analysis of raw material

The semolina used was found to contain 14% moisture, 10.08% protein, 1.79% fat, 0.54% ash, 1.02% crude fibre, 72.57% carbohydrate.

Effect of extrusion process variables on degree of starch gelatinization (DSG)

Starch gelatinization is the interruption of molecular order within the starch granule which causes irreversible changes in properties, for example, granular swelling, local crystalline liquefying, loss of birefringence and starch solubilization. Degree of gelatinized (DSG) starch gives the extent of modification that occurred in the starch granules during extrusion and extent of DSG depends upon feed moisture, barrel temperature and shear during extrusion processing. The DSG varied significantly for different extrusion variables. At 28% feed moisture the DSG of pasta ranged between 33.4 and 115.15% whereas at 32% feed moisture, the DSG of pasta was found in the range of 53.1–131.57% (Fig. 1). Feed moisture and barrel temperature demonstrated a positive connection with DSG. Expanding the moisture in the batter would increment both granule swelling and amylose draining and, thus, DSG.

Fig. 1 Effect of screw speed and barrel temperature on degree of starch gelatinization **a** 28% feed moisture **b** 32% feed moisture

Effect of extrusion process variables on cooking characteristics

Processing variables influence was observed on various cooking parameters viz. minimum cooking time, water absorption, volume expansion and gruel solid loss of pasta. Cooking time of pasta varied from 9 to 15 min. An expansion in cooking time was seen with an expansion in barrel temperature and screw speed. Wang et al. (1999) reported that cooking time extended with increasing dough moisture, barrel temperature or screw speed in pasta produced by twin screw extruder. Water absorption and volume expansion of pasta showed a positive co-relation with feed moisture. Water absorption ranged in between 114.8 and 140.8% where as volume expansion ranged between 1.4 and 2.6 mL/g. Screw speed showed a little negative effect on water absorption whereas barrel temperature had a little effect on water absorption. This increase in water absorption by pasta may be attributed to the increased water binding ability and increased water absorption capacity of the pregelatinized flour. Anderson et al. (1969) revealed that extruded grain items prepared from high dampness batters demonstrated higher water absorption. Comparative investigations directed by Diosady et al. (1985) observed that the lower water retention for extruded starch created at higher screw speed may be identified with expanded shear, bringing about structural modification of the starch.

Gruel solid loss was observed to be less for pasta produced at elevated barrel temperature, moisture content and screw speed. Gruel solid loss of pasta ranged from 2.2 to 9.3%. Colonna and Mercier 1983 observed that degradation of starch is more noteworthy at lower moisture of feed prompting lower sub-atomic weight material, that outcomes in expanded water dissolvability of the extrudate. This can be due to better relationship of segments under escalated extrusion cooking treatment which can frame starch–protein complex matrix amid preparing at a temperature higher than starch gelatinization of wheat semolina and within the sight of high dampness. Moreover, as reported by Sharma et al. (2016) noodles made with substitution of flour with gelatinized-retrogradated starch (GRS) or extruded starch (ES) showed higher reduced gruel solid loss.

Effect of extrusion process variables on color

The impact of processing factors was determined on luminosity (L^*), redness (a^*) and yellowness (b^*) of pasta-like products prepared from semolina. The L^* value of the pasta increased gradually with screw speed and feed moisture but diminished with elevated barrel temperature. Similar results were coated down by Kaur et al. (2014)

while studying the effect of screw speed on extrusion behaviour banana flour and corn. The higher feed moisture and barrel temperature influenced redness and yellowness of pasta. Extrusion at lowest temperature (60 °C) and screw speed (220 rpm) produced pasta with lowest a^* value while extrusion at highest temperature (110 °C) and 120 screw speed produced pasta with highest a^* value. Overall, an decrease in redness (a^*) and yellowness (b^*) of pasta was observed with an increase in barrel temperature. The results were in verdict with Ghumman et al. (2016) during their study on effect of high extrusion temperature on extrusion behavior of lentil and horsegram.

Hue angle improved with expanded screw speed and encouraged feed moisture however diminished with an expansion in barrel temperature. The beneficial outcome of barrel temperature on a^* and b^* qualities could be because of heat induced degradation of feed which may likewise have brought down the L^* estimation of tests after extrusion. These outcomes are validated by the decisions of Fratianni et al. (2005), Lamberts et al. (2007) and Singh-Sandhu et al. (2007). In general, various treatments affected the color of pasta and an overall increase in luminosity, redness and yellowness was observed. The negative correlation was obtained between between hue angle and degree of gelatinization presented graphically in Fig. 3. The high value of correlation coefficient demonstrates that there exists strong negative correlation between hue angle and degree of gelatinization of pasta.

Effect of extrusion process variables on texture profile analysis of pasta

Textural characteristics of pregelatinized processed pasta at different extrusion conditions are represented in Fig. 2. Hardness corresponds to the force required to cause deformation of a sample and is associated with firmness of pasta. Hardness/firmness of cooked pasta was found to elevate with increased feed moisture and barrel temperature. Pasta produced at lower feed moisture (28%) and barrel temperature (60 °C) exhibited less firmness than pasta produced at higher feed moisture (32%) and barrel temperature (105 °C). Both gumminess and chewiness showed an increase with an increase in feed moisture and barrel temperature. Adhesiveness of prepared pasta assessed was very low, accordingly the product were characterized by low stickiness and their surface was resilient. Sharma et al. (2016) observed that noodles prepared by addition of gelatinized-retrogradated starch (GRS) or extruded starch (ES) showed higher reduced adhesiveness. However the samples produced at 32% feed moisture and 90 °C barrel temperature showed best texture.

Fig. 2 Effect of temperature on textural characteristics of pasta
a 28% feed moisture **b** 32% feed moisture

Effect of extrusion process variables on pasting properties of pasta

The pasting properties of pasta were measured by rapid visco analyzer and are presented in Table 4. Significant ($p < 0.05$) differences were observed in the pasting properties of pasta. At 28% moisture content the peak viscosity of pasta ranged from 298.5 to 667 cP whereas at 32% moisture, the peak viscosity of pasta was found in the range of 220–291 cP.

The highest peak viscosity was observed at lower barrel temperature and lowest peak viscosity was observed at higher barrel temperature for both feed moistures (28 and 32%). The peak viscosity occurs at equilibrium point between swelling and polymer leaching which causes an increase in viscosity. The highest values of viscosity in the product may be associated with a high proportion of ungelatinized starch, whereas the lowest values of viscosity might reflect greater degradation that is attributed to depolymerization and molecular entanglement resulting from the processing conditions (Hagenimana et al. 2006). Carvalho et al. (2002) also reported that the high barrel temperature resulted in increased mechanical effort during the

extrusion process, hence greater starch degradation and low viscosity.

The highest peak viscosity was seen at lower barrel temperature and least peak viscosity was seen at higher barrel temperature for both feed moistures (28 and 32%). The peak viscosity occurs at equilibrium point amongst swelling and polymer leaching which causes an expansion in viscosity. The most elevated estimations of viscosity in the product might be related with a high extent of ungelatinized starch, though the least estimations of viscosity may reflect more noteworthy corruption that is credited to de-polymerization and sub-atomic trap coming about because of the processing conditions (Hagenimana et al. 2006). Carvalho et al. (2002) likewise detailed that the high barrel temperature brought about expanded mechanical exertion amid the extrusion process, thus more noteworthy starch degradation and low viscosity.

Effect of extrusion process variables on total phenolic content

Polyphenolic compounds are effective in preventing the oxidative stress, thus they have a protective and beneficial role for the human body (Mandic et al. 2008). Table 5

Table 4 Rheological properties of pregelatinized pasta

Treatments	Rheological properties					
	Temperature (°C)	Peak viscosity (cP)	Hold viscosity (cP)	Final viscosity (cP)	Breakdown viscosity (cP)	Setback viscosity (cP)
28	60	667 ^c	553 ^d	1547 ^d	99 ^c	1002 ^d
	75	450 ^b	379 ^c	1220.5 ^c	65 ^b	850 ^c
	90	315 ^a	330 ^b	1090.5 ^b	56.5 ^b	779 ^b
	105	298.5 ^a	281.5 ^a	1053 ^a	24.5 ^a	738.5 ^a
32	60	291 ^b	283.5 ^d	1007.5 ^c	38 ^d	839 ^c
	75	275 ^b	278 ^c	987.5 ^c	24.5 ^c	699.5 ^b
	90	225.5 ^a	227.5 ^b	906 ^b	16.5 ^b	687.5 ^b
	105	220 ^a	216 ^a	845 ^a	8.5 ^a	596.5 ^a

Means followed by different superscript letter in the column differ significantly ($p < 0.05$) for a given feed moisture

Table 5 Effect of extrusion processing variables on bioactive compounds of pregelatinized pasta

Treatments	Bioactive compounds			
Moisture (%)	Temperature (°C)	TPC (mg GAE/100 g)	% RSA	TFC (µg Quercetin/mg)
28	60	2.5 ± 0.15 ^c	35.46 ± 0.91 ^d	489.56 ± 6.63 ^a
	75	1.98 ± 0.26 ^{bc}	31.82 ± 0.92 ^c	402.06 ± 2.21 ^b
	90	1.62 ± 0.29 ^{ab}	26.68 ± 1.06 ^b	272.38 ± 1.10 ^c
	105	1.32 ± 0.15 ^a	22.43 ± 0.53 ^a	160.19 ± 0.88 ^d
32	60	3.42 ± 0.29 ^b	40.01 ± 0.91 ^d	505.81 ± 1.77 ^a
	75	2.92 ± 0.15 ^b	36.82 ± 0.92 ^c	464.00 ± 3.31 ^b
	90	1.82 ± 0.29 ^a	30.25 ± 0.53 ^b	352.00 ± 1.55 ^c
	105	1.52 ± 0.15 ^a	22.73 ± 0.92 ^a	229.25 ± 0.66 ^d

Values are mean ± SD

TPC Total phenolic content, RSA radical scavenging effect

presents bioactive composition of prepared pasta. The total phenolics content of the pasta was found in between 1.32 and 3.42 mg GAE/100 g. Amongst all the samples, the highest amount of total phenolics content was observed in the pasta prepared at 32% feed moisture and 60 °C barrel temperature while the lowest content of total phenolics were observed in the samples processed at 28% feed moisture, 105 °C barrel temperature. This indicates that the barrel temperature had significant ($p < 0.05$) negative effect on the total phenolics content of the pasta. This observation is consistent with the study of Viscidi et al. (2004) who stated that extrusion caused a reduction in total phenolics of extruded oat cereals by 24–46%. Zhang et al. (2010) reported that the extrusion is a thermal cooking process and it may destroy or remove the phenolic compounds and affect the antioxidant activity. However, Thakur et al. (2017) observed a higher amount of acid-hydrolyzed bound gallic acid in corn extrudates than base hydrolyzed.

Effect of extrusion process variables on DPPH radical scavenging activity assay

The antioxidant activity expressed as percent radical scavenging activity of prepared pasta is displayed in the Table 5. The antioxidant activity of pasta ranged in between 22.43 and 40.01%. The highest mean antioxidant activity was observed at 32% feed moisture and 60 °C barrel temperature where as lowest antioxidant activity was found at 28% feed moisture and 105 °C barrel temperature. A decrease in feed moisture leads lowering of antioxidant activity. Similar results were noticed by Ozer et al. (2006) during extrusion of nutritious snack foods. The correlation between total phenolic content and antioxidant activity is presented graphically in Fig. 3. The high value of correlation coefficient demonstrates that there exists strong correlation between total phenolic content and antioxidant

activity of pasta. The linear correlation between total phenolic content and antioxidant activity signifies that the phenolic compounds present in pasta have strong in vitro antioxidant activity.

Effect of extrusion process variables on total flavanoid content

Flavonoids have created intrigue due to their wide human well being advancing impacts, the vast majority of which are identified with their antioxidant properties and to synergistic impacts with other antioxidant. Flavonoids have a common structure of diphenylpropanes (C6–C3–C6) consisting of two aromatic rings linked through three carbons and are considered to be largest group of polyphenols. The flavonol quercetin is the most frequently occurring compound in foods. Another antioxidant mechanism of flavonoids may result from the interactions between flavonoids and metal ions especially iron and copper (Sharma and Gujral 2011). Total flavanoid content of pregelatinized pasta ranged between 160.19 and 505.81 µg Quercetin/mg (Table 5). A significant diminishing effect was observed in the total flavanoid content (TFC) with extrusion cooking at higher barrel temperature. The decrease in TFC may be attributed to the thermal destruction of flavonoids, as the flavonoids are reported to be heat sensitive (Sharma and Gujral 2011; Xu and Chang 2008). These results are in good agreement with those previously reported by Im et al. (2003) and Huang et al. (2006) for buckwheat and sweet potato, respectively, upon thermal processing.

Effect of extrusion process variables on overall acceptability

The result of overall acceptability depicted that pasta produced from semolina at higher feed moisture (32%), intermediate barrel temperature (90 °C) and at higher

Fig. 3 The correlation between **a** total phenolics content and antioxidant activity. **b** Hue angle and degree of gelatinization of pasta

screw speed (200 rpm) was found “liked” (sensory score of 7 out of 9) by the panel members.

Conclusion

Overall higher screw speed improved the cooking quality of pasta which may be attributed to better association of components under intensive extrusion cooking treatment which was able to form starch–protein complex matrix during processing at a temperature higher than starch gelatinization and in the presence of high moisture. Various treatments affecting the color of pasta and an overall decrease in luminosity increase in redness and yellowness was observed. As obvious, degree of gelatinization increased with increase in barrel temperature and feed moisture but decreased with increase in screw speed. The highest peak viscosity was obtained at low moisture and temperature. Also, the pasta produced at higher feed moisture and barrel temperature was found to be firmer. Total phenol content and antioxidant properties showed an increase with an increase in feed moisture. The overall acceptability of pasta was found to be 7 on 9-point hedonic score.

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