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Quality Changes in Pearl Millet Based Pasta during Storage in Flexible Packaging

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ABSTRACT

Pearl millet based pasta was evaluated for quality changes during 6-month storage in bi-axially oriented polypropylene (BOPP) packaging material of 100 µm thickness and water vapour transmission rate of 7.71 g,m^{-2}.day^{-1} at ambient condition (32.95 ± 8.75 °C (max), 17.6 ± 12.1 °C (min) and 79 ± 19 % RH). The quality parameters of pasta were determined at intervals of 1 month. Moisture content (MC) of pasta varied from 8.87 % to 11.90 %, water activity 0.51 to 0.66, free fatty acids (FFA) 0.48 % to 0.82 %, peroxide value (PV) 2.10 to 5.79 meq.kg^{-1} of oil, fat acidity 20.54 mg.100 g^{-1} to 37.77 mg.100 g^{-1}. Cooking loss (6.22 % to 7.66 %) and variation in textural properties such as hardness (10.75-11.68 N), cohesiveness (0.60-0.64), springiness (1.17-1.26 mm), gumminess (6.01-6.45 N), chewiness (6.15-6.45 N.mm) of pasta were found to be non-significant during storage period. Moisture content, water activity, FFA, PV, fat acidity were found to be positively related to storage period. Microbial counts (total plate count, yeast, mould, *E. Coli*, *Salmonella, Shigella*) were not detected during the entire storage period. With overall acceptability value of 7.67 out of 9, the sensory evaluation revealed very good acceptability of the product even after 6 months of storage. Thus, the overall quality, safety, and acceptability of the product remained acceptable throughout the 6-month storage period.

Key words:
Storage, pearl millet pasta, FFA, PV, fat acidity, sensory evaluation

During recent times, pasta has emerged among the trending foods in India with the consumption rate growing at a rapid pace. There are more than 30 pasta brands available in the country (Anon., 2016), and most of them are made of durum wheat (*Triticum durum*) semolina, which contains gluten protein. The disorders related to gluten namely, celiac disease, wheat allergy, and non-celiac gluten sensitivity are becoming an epidemiological phenomenon with a global prevalence of about 5 % (Elli *et al*., 2015). Also, deficiencies of essential micronutrient ions or excesses of toxic ions are of concern in wheat (Abecassis *et al.,* 2000). And hence, research efforts are continuing on replacing wheat either fully or partially in pasta and similar products.

Pearl millet (*Pennisetum glaucum*) is commonly known as bajra, and has excellent nutritional profile, especially with respect to micronutrients. Pearl millet, being gluten free, was considered as an alternative crop for exploring the possibility of making pasta, either using 100 % of it or substitution of wheat to the maximum possible extent. Jalgaonkar and Jha (2016) developed pasta using a blend of pearl millet flour and wheat semolina in the ratio of 50:50 with acceptable quality. The shelf life of pearl millet flour has been reported to be short, ranging from 5 to 10 days (Kaced *et al*., 1984; Yadav *et al*., 2012; Tiwari *et al*., 2014; Jalgaonkar *et al.,* 2016). Hence, pearl millet-based products need evaluation for its quality and storage stability.

Varying reports have been published on shelf life and quality of similar category of food products. Spaghetti prepared from durum semolina and 10 % bean flour could be stored for six months in plastic bags at room temperature (Duskiewicz-Reinhard *et al*., 1988).

Pangloli *et al*. (2000) suggested that noodles prepared from wheat flour, 10 % de-fatted soy flour and sweet potato as 10 % flour or 15 % puree could be stored under air with greater quality retention at 4.4 °C for 6 months. Pinarli *et al*. (2004) found that macaroni prepared from semolina blended with 15 % wheat germ could be stored up to one year without affecting quality. Kaur *et al*. (2012) reported that pasta prepared from durum wheat semolina enriched with 15 % of wheat, rice, and oat bran and 10 % barley bran packed in high-density polyethylene packs (200 gauge) was acceptable with respect to its quality up to 4 months of storage at the ambient condition. Yadav *et al*. (2014) reported that pasta from a blend of wheat and pearl millet flour in the ratio of 9:1 with vegetable paste (2 % dry solids) was acceptable up to 3 months stored in polyethylene bags (50 μm) without any preservative under ambient conditions.

Kinetic modelling is necessary to derive basic information for a system, in order to describe reaction rate as function of storage time and predict specific changes in food during storage (Van Bockel, 1996; Kumar and Mishra, 2004). Deteriorative quality changes (moisture content, total plate count, firmness, cooking loss and colour change) during accelerated storage of millet-pomace based functional pasta followed zero-order kinetics (Gull *et al*., 2016).

This study was aimed to evaluate the qualitative changes in pearl millet-based pasta at ambient condition. Various deterioration indicators of food products as moisture content, water activity, microbial load, free fatty acid, peroxide value, fat acidity, changes in cooking quality, textural properties and sensory quality were determined as a function of storage period.

MATERIALS AND METHODS

Raw Material

Clean dry pearl millet grain was ground into flour using a hammer mill (Sanco, India). Pearl millet flour and semolina having average particle size of 425 μm were used for making pasta.

Preparation of Pasta

Pasta was prepared using 50:50 blend composition of pearl millet flour and wheat semolina (Jalgaonkar and Jha, 2016). The moisture content of flour was determined initially. A calculated amount of water was slowly added and mixed into a homogenous mixture to adjust the moisture content of flour to 30 % (w.b.). It was ensured before extrusion that the flour blend does not contain any lump. The moisture content of the conditioned sample was determined. The difference between targeted and actual conditioned moisture content was found to be approximately 0.5 per cent. Conditioned feed mixture was metered into a twin-screw extruder (BTPL make, Kolkata, India) by a twin-screw feeder equipped with it. The extruder operating condition was set as 70 °C barrel temperature, 12 rpm feeder speed, and 120 rpm screw speed (Jalgaonkar, 2017). The input feed rate was 5.37 $kg.h^{-1}$. A concentric double cylinder type die was used to get a cylindrical hollow product with a wall thickness of 0.91 mm. After the extruder system parameters (product temperature and motor torque) reached a steady state, the samples were collected in open pans and allowed to come to room temperature before being cut with a knife into small pieces of approximately 15 mm in length. Drying of pasta was carried out to attain a moisture content of about 8-9 % (w.b.) in tray dryer (MSW-216, Macro Scientific Works, New Delhi) maintained at 50 °C (Kaur *et al*., 2012) for 2 h. The resultant dried product was cooled and then packed in bi-axially oriented polypropylene (BOPP) packaging material of 100 μm thickness having water vapour transmission rate (WVTR) of 7.71 $g.m^{-2}.day^{-1}$. The water vapour transmission rate was measured by a water vapour transmission tester (Model: PERME® W3/030, China). The WVTRs of the packaging material of major commercial brands of pasta in the market were also evaluated and found to be the same as of BOPP film used in this study.

Packets containing 55±3 g of pasta sample were stored in room under ambient condition (maximum temperature: 32.95±8.75 °C, minimum temperature: 17.6±12.1 °C and relative humidity: 79±19 %) for 6 months. The qualitative changes during the 6-month storage period were evaluated.

Quality Attributes of Extruded Pasta during Storage

Stored pasta was withdrawn at 1-month intervals up to 6 months of storage. Analyses of moisture content, water activity, free fatty acids, peroxide value, fat acidity, microbial analysis, cooking loss, textural properties and sensory evaluation were conducted in each month with new sample packets.

Moisture content

Moisture content of a sample was determined using Eq.

1 by subjecting the material at 105±2 °C for 24 h in an oven to constant mass (AOAC, 1990; Method 925.10).

$$\text{Moisture content} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100 \quad ...(1)$$

Water activity

Water activity was measured using a ROTRONIC (model Hygrolab 3) instrument.

Free fatty acids (FFA)

FFA content (% oleic acid) of a sample was determined using AOAC, 1990 (Method 940.28). About one gram of ground pasta sample was taken in a 100 ml conical flask. Neutral ethanol (50 ml) was added in the flask, and the mix was titrated against 0.1 normality solution of NaOH with phenolphthalein as an indicator. FFA value was calculated using equation 2 as:

$$FFA\text{ (as \% oleic acid)} = \frac{\text{Titre value} \times 0.1\text{ N NaOH} \times 0.282 \times 100}{\text{Weight of sample}} \quad ...(2)$$

Peroxide value (PV)

One gram of ground pasta sample was taken in a conical flask, and 15 ml of solvent (acetic acid and chloroform 2:1) was added in it. Then 1 ml of freshly prepared saturated potassium iodide solution was added, and allowed to stand for 5 min in dark. This was followed by addition of 30 ml of distilled water, and the liberated iodine was titrated with 0.1 N $Na_2S_2O_3$ (sodium thiosulphate solution) using 0.01 % starch solution as an indicator (AOAC, 1990; Method 965.33). PV ((meq/kg fat)) was calculated using Eq. 3 as:

$$PV = \frac{(\text{Titre value} - \text{Blank value}) \times 0.1\text{ N sodium thiosulphate} \times 1000}{\text{Weight of sample}} \quad ...(3)$$

Fat acidity

Fat acidity (mg.100g^{-1}) was determined by AOAC (1990) method 14.067, rapid method for corn, and using Eq. 4. Approximately 20 g of finely ground sample was weighed and poured into a 100 ml conical flask. Exactly 50 ml toluene alcohol phenolphthalein solution (0.02 %) was added into it. Sample was shaken in a mechanical shaker for 30 min. The liquid was carefully decanted to maximum possible extent onto a filter paper inserted in a glass funnel. The funnel was covered with petri plate to reduce evaporation. Out of decanted liquid, 25 ml of filtrate was taken in a conical flask. Then, 25 ml alcohol phenolphthalein solution (0.04 %) was added in the same flask. The extract was titrated against 0.0178 normality of KOH solution. End point of original solution being titrated should match the colour of solution made by adding 2.5 ml 0.01 % $KMnO_4$ solution to 50 ml 0.5 % $K_2Cr_2O_7$ solution.

Fat acidity = 10 x (Titre value - Blank value) ...(4)

Microbial analysis

Freshly prepared pasta samples were subjected to microbiological analysis, and the evaluation was carried out at monthly intervals up to 6 months of storage. The samples were analysed for the population of total plate count, yeast, mould, and presence of *E. Coli*, *Salmonella* and *Shigella* in standard plate count agar (Harrigan and McCance, 1996), Malt glucose yeast peptone agar (Anon., 1960), Martin Rose Bengal Agar (Martin, 1950) and BCP broth media (Seeley and Van Denmark, 1970), respectively.

One gram of pasta sample was used to make serial dilutions in 0.8 % saline blanks. Appropriate dilutions were plated in triplicates on respective media and incubated at 30 °C for 24-48 h. After incubation, the counting of colonies was manually done, and the results were expressed in terms of colony forming unit (cfu) per gram of sample. Dilutions were initially plated on XLD agar (Hi Media) for detection of *E. Coli./Salmonella/ Shigella*. For *E. Coli*, 10^{-1} and 10^{-2} dilutions were incubated at 37 °C for 48 hours and observations were taken for acid and gas production. If tubes recorded for acid and gas, then it was considered positive for the presence of coliforms/soil borne bacteria.

Cooking loss

Cooking loss was measured according to the BIS method (IS 1485 2010).

Textural properties

Textural properties of cooked pasta were measured using the Texture Analyser (Model: *TA+HDi*®, Stable Micro Systems, UK) equipped with a cylindrical probe (p/75 mm). Texture analyser settings used were: Mode: Texture Profile Analysis 2 (return to start); pre-test speed: 3 mm.s^{-1}; test speed: 1 mm.s^{-1}; post-test speed: 10 mm.s^{-1}; distance: 50 % in compression mode; time: 1 s; data acquisition rate: 200 pps.

From the TPA curve, hardness (maximum peak force during the first compression), cohesiveness (ratio of the area under the second peak of compression to the area under the first peak of compression), springiness (distance at which a deformed sample went back to its non-deformed condition after the deforming force is removed during the second compression), gumminess (product of hardness and cohesiveness) and chewiness (product of hardness, cohesiveness and springiness) were calculated as followed by Limroongreungrat and Huang (2007).

Sensory evaluation

Sensory evaluations of developed pasta along with one commercial pasta were carried out as per BIS method [BIS: 6273-(1971)]. A panel consisting of ten people (age group 20 to 30 years) evaluated the product for individual characters as appearance, texture, taste, colour and overall acceptability using a 9-point hedonic scale, where 9=Like extremely, 8=Like very much, 7=Like moderately, 6=Like slightly, 5=Neither like nor dislike, 4=Dislike slightly, 3=Dislike moderately, 2=Dislike very much, 1=Dislike extremely (Ranganna, 1986; Rathi *et al*., 2004).

Model for Computation of Changes in Quality Attributes of Pasta

To predict changes in a particular food during storage, various studies (Labuza *et al*., 1982; Van Bockel, 1996; Kumar and Mishra, 2004; Dak *et al.,* 2014; Gull *et al*., 2016) have been reported. These studies have indicated the suitability of zero-order reaction. Hence, in the present study, the zero-order kinetics (Eq. 5) was used to predict the changes in quality parameters during storage of pasta.

$$B = Bo + k\theta \qquad ...(5)$$

Where,

B = Value of quality attributes (Moisture content, water activity, free fatty acids, peroxide value, fat acidity) at time θ,

Bo = Initial value of quality parameters,

k = Rate constant for quality attributes per unit storage days, and

θ = Storage period, days.

Statistical Analysis

The experiment was carried out using completely randomized design. Results are expressed as a mean ± standard error of triplicate analyses for all measurement, except the textural determination and sensory evaluation of the samples. Analysis of variance (ANOVA) and least significant differences was calculated using SAS version 9.3. Significance was accepted at P ≤ 0.05.

RESULTS AND DISCUSSION

Nutritional Composition

Nutritional composition of the developed pearl millet pasta was determined as protein (12.34 %), fat (1.43 %), ash (0.82 %), iron (8.91 mg.100 g^{-1}), zinc (2.93 mg.100 g^{-1}), calcium (21.66 mg.100 g^{-1}).

Moisture Content

Moisture content has an important role in determining the storage life of food products. As per the Indian standard [BIS: 1485-(2010)], the moisture content of pasta should not be more than 12 per cent. During the storage period, a consistent increase in moisture content of pasta was recorded (Fig. 1), but was limited within 12 per cent. It increased from 8.87 % to 11.90 % at the end of 6 months of storage period. Analysis of variance (Table 1) revealed that the storage period had significant (P≤ 0.05) effect on the moisture content of pasta. The gain in moisture content was due to hygroscopic nature of the product, the permeability of the packaging material and storage environment (changes in temperature and relative humidity), as also reported by Nagi *et al.* (2012) for an increase in moisture content of cereal bran enriched biscuit in flexible packaging. The results showed that moisture content (<12%) of pasta packed in BOPP packaging material was within the permissible limit throughout the storage period.

Water Activity

Water activity is an important means of predicting and controlling the shelf-life of food products. The water activity of pasta increased significantly (P≤ 0.05) from

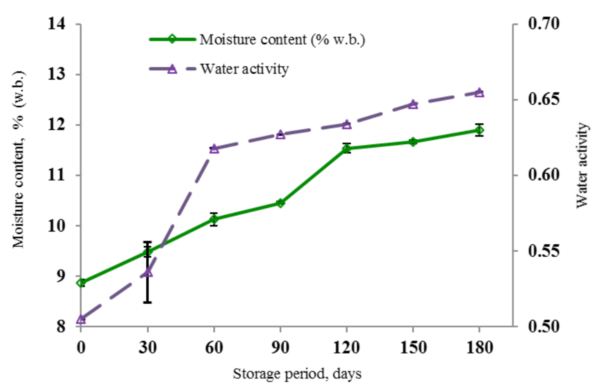

Fig. 1: Effect of storage period on moisture content and water activity of dry pasta

Table 1. ANOVA for moisture content, water activity, FFA, PV and fat acidity of pasta

Source	Moisture content, % (w.b.)	Water activity	FFA, %	PV, meq.kg^{-1} of oil	Fat acidity, mg.100g^{-1}
F value	207.05^{S}	86.22^{S}	115.50^{S}	36.09^{S}	147.37^{S}
Error df	12	12	12	12	12
Error MS	0.01975	0.000119	1.13587	0.001386	0.043544
LSD	0.25	0.0194	1.896	0.0662	0.3712
Pr>f	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note: d.f. refers to degrees of freedom; MS refers to mean sum of square; LSD refers to least significant difference; ^{S}significant at P≤0.05.

0.51 to 0.66 (approximately 30 % increase) during the storage period of 6 months (Fig. 1). The increase in the water activity might be due to hygroscopic nature of the product, the permeability of packaging material and changing outside environmental conditions (temperature and relative humidity).

As per California Food Safety Law (2012), rice noodles are not acceptable when the water activity is above 0.85. Kaur *et al*. (2012) reported water activity values from 0.35 to 0.75 of bran enriched pasta, which was influenced by storage period and found the product acceptable up to 4-month of storage (corresponding to water activity range of 0.6 to 0.7). Manthey *et al*. (2008) reported no change in water activity of pasta prepared from semolina as well as semolina enriched with 15 % flaxseed flour during 7 weeks of storage at 4 °C.

Microbial Analyses

Despite the increase in moisture content and water activity in pasta, no microbial growth was detected. Total plate count, yeast, mould, *E. Coli*, *Salmonella,* and *Shigella* were not detected during the entire storage period of 6 months. This showed that pearl millet pasta remained microbiologically safe. The water activity of pasta was in the range 0.51 to 0.66 throughout the whole storage period, and was not favourable for microbial growth. That could be the probable reason for the absence of microorganisms.

Similarly, Yadav *et al*. (2014) reported that yeast and mould count was not found during 90 days of storage of pasta prepared from a blend of wheat and PMF (9:1) with vegetable paste (2 % dry solids) stored in polyethylene bags (50 μm) under ambient conditions.

FFA, PV and Fat Acidity

Storage period had a noticeable effect on free fatty acid, peroxide value and fat acidity of pasta samples (Table 1). A significant increase in the FFA, PV and fat acidity was observed with storage period (Fig. 2 and Fig. 3). At the end of 6 months of the storage period, FFA and PV in pasta increased from 0.48 % to 0.82 % and from 2.10 meq.kg^{-1} to 5.79 meq.kg^{-1} of oil, respectively.

A gradual increase in fatty acids and peroxide value of pasta, caused by enzymatic hydrolysis of the lipids had also been reported by Chaiyasit *et al*. (2007) with an increase in the storage period. Yadav *et al.* (2014) had also reported that FFA of pasta (wheat and PMF

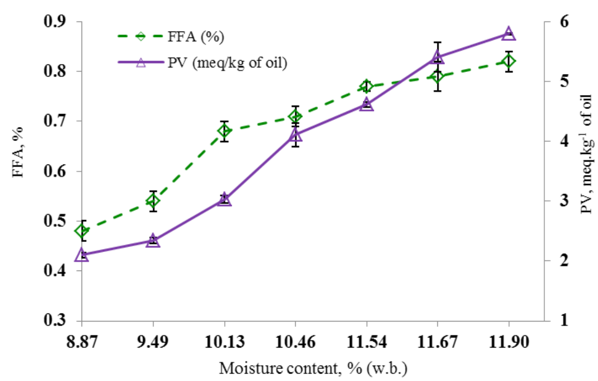

Fig. 2: Effect of storage period on free fatty acid and peroxide value of dry pasta

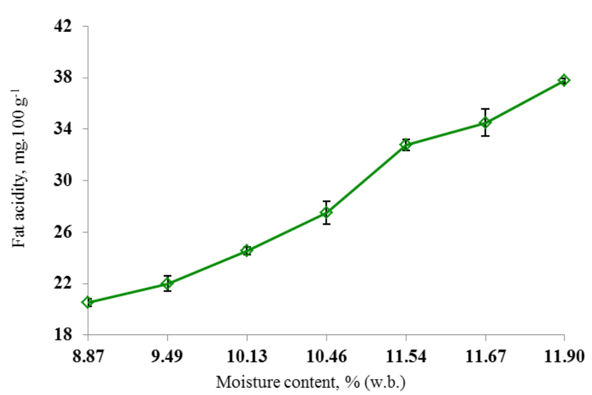

Fig. 3: Effect of storage period on fat acidity of dry pasta

in the ratio of 9:1) incorporated with 2 % vegetable paste (carrot, tomato, turnip, and spinach) increased approximately from 0.2-0.5 % to 0.7-0.9 % during 3 months of storage. However, it was in an acceptable range. Similarly, Kaur *et al.* (2012) reported that FFA of pasta enriched with cereal bran increased with increase in storage period, but the values remained within acceptable range. Thus, the flavour, taste and overall acceptability of pasta were not much affected. Manthey *et al.* (2008) reported that the FFA content of pasta increased from 1.90 % to 2.36 % during refrigerated storage.

Although peroxide value of pasta increased with increase in storage period, it remained below 10 meq.kg^{-1} of oil and acceptable for consumption of the product (Anon., 2015). This indicated that no significant oxidative rancidity took place during storage. This presumably occurred because of both lipase and lipoxygenase enzymes had been largely inactivated during the extrusion cooking, and that the water activity of the pasta was also low. Yadav *et al.* (2014) revealed that peroxide value of pasta incorporated with 2 % vegetable paste increased from 7-9 meq.kg^{-1} to 9-12 meq.kg^{-1} of oil (approximately), but remained under acceptable range. In a previous study, Verardo *et al.* (2009) reported that PV in spaghetti prepared from durum wheat semolina increased from 8.2 meq O_2.kg^{-1} to 38.8 meq O_2.kg^{-1} of fat under light exposure with day light lamp over 12 months of storage and from 8.2 meq O_2.kg^{-1} to 17.2 meq O_2.kg^{-1} of fat under accelerated ageing at 55 °C for 27 days of storage. It was suggested that light exposure caused a fast propagation of oxidation regardless of the fat content. Kaced *et al.* (1984) too suggested that hydrolytic action of lipases appeared to increase with an increase in flour moisture during storage of pearl millet.

Fat acidity has been reported to be related with bitter taste development in pearl millet flour (Nantanga *et al.,* 2008). In the present study, it was observed that an increase in the storage period caused a significant (*P≤0.05)* increase in fat acidity (Table 1) of pasta. During 6-month storage, fat acidity increased from 20.54 mg.100g^{-1} to 37.77 mg.100g^{-1}. The increase in fat acidity during the storage of PMF has been suggested to be due to increase in de-esterified fatty acids through lipolysis (Nantanga *et al*., 2008). Typically, the increase in fat acidity was found to be positively related to moisture content of pasta (Fig. 3). Likewise, Kaced *et al.* (1984) reported that fat acidity increased more rapidly in the PMF sample stored in cotton bags, presumably because of its higher moisture content. The hydrolytic action of lipases, as measured by fat acidity, was also suggested to be more rapid at higher moisture content.

Although, there was an increase in FFA, PV and fat acidity value during the storage period, but the occurrence of rancidity or bitter taste in the product was not noticed as observed by sensory evaluation report of the product.

Cooking Quality

Cooking quality was evaluated in terms of cooking loss, which is related to solid leaching during cooking and is widely used as an indicator of the overall cooking performance (D'Egidio *et al.,* 1982).

Cooking loss varied from 6.22 % to 7.66 %, and remained below 8 % throughout the storage period of 6 months. The upper limit has been prescribed by the Indian Standard [BIS: 1485-(2010)] for products like macaroni, spaghetti, vermicelli and egg noodles. The variation in the cooking loss was found to be non-significant (Table 2**).** This indicated that the pasta retained its cooking quality even after 6 months of storage. Yadav *et al.* (2014) had also reported non-significant increase in gruel loss of pasta with different composition during storage up to 90 days under ambient condition. Pinarli *et al*. (2004) too reported the non-significant effect of storage period on cooking loss of macaroni after one year of storage. Kaur *et al*. (2012) also did not find much increase in the leaching of solids from cereal bran enriched pasta water during storage period of 4 months.

Textural Quality

Objective measurements of textural qualities of cooked pasta viz. hardness, cohesiveness, springiness, gumminess, and chewiness were not significantly affected during the storage period (Table 2). Hardness of pasta varied from 10.75-11.08 N, cohesiveness 0.60-0.64, springiness 1.17-1.26 mm, gumminess 6.01-6.45 N, and chewiness 6.15-6.45 N.mm during the entire storage period. Duszkiewicz-Reinhard *et al.* (1988) too reported that firmness of spaghetti prepared from durum semolina, durum semolina blended with navy or pinto bean flour and its concentrate showed non-significant difference between themselves over time of 6 months of storage at room temperature (23 °C).

Sensory evaluation

Colour, aroma, texture and taste are the important characteristics for acceptability of a food item, and these are also good indicators of the physicochemical changes during storage (Rao *et al*., 1995).

Sensory evaluation of the prepared pasta revealed non-significant effect of storage period on the liking of pasta by the panelists in terms of appearance, texture, taste, colour and overall acceptability (Table 3). At the end of 6-month storage, the sensory score for appearance, texture, taste, colour and overall acceptability of pasta was rated as 7.00, 7.00, 8.00, 6.80 and 7.70, respectively, indicating a well acceptable product. Yadav *et al*. (2014) too reported that though the overall acceptability (OAA) scores of pasta prepared from wheat and PMF (9:1) incorporated with 2 % vegetable paste decreased a little during 90-day storage under ambient condition, but non-significant effect on sensory quality (colour, aroma, texture, taste, mouth feel and OAA) was observed. Kaur *et al.* (2012) reported cereal bran enriched pasta (15 % level of wheat, rice and oat

Table 2. Effect of storage period on cooking and textural properties of cooked pasta

Storage period, days	Cooking loss, %	Hardness, N	Cohesiveness	Springiness, mm	Gumminess, N	Chewiness, N.mm
0	6.22±0.08[c]	10.95±0.26[a]	0.61±0.02[a]	1.21±0.01[a]	6.11±0.37[a]	6.15±0.38[a]
30	6.56±0.13[bc]	10.94±0.46[a]	0.62±0.01[a]	1.17±0.06[a]	6.27±0.27[a]	6.17±0.05[a]
60	7.04±0.77[bac]	10.83±0.22[a]	0.63±0.01[a]	1.21±0.02[a]	6.40±0.13[a]	6.45±0.21[a]
90	7.27±0.02[bac]	11.08±0.37[a]	0.60±0.02[a]	1.23±0.02[a]	6.01±0.46[a]	6.27±0.59[a]
120	7.49±0.02[ba]	10.75±0.31[a]	0.64±0.03[a]	1.21±0.01[a]	6.45±0.57[a]	6.36±0.45[a]
150	7.56±0.03[ba]	11.14±0.51[a]	0.60±0.00[a]	1.17±0.01[a]	5.95±0.28[a]	6.27±0.12[a]
180	7.66±0.45[a]	10.96±1.17[a]	0.61±0.02[a]	1.26±0.05[a]	5.98±0.39[a]	6.45±0.66[a]
ANOVA						
F value	2.47[NS]	0.05[NS]	0.79[NS]	1.85[NS]	0.33[NS]	0.12[NS]
Error df	12	18	18	18	18	18
Error MS	0.358	1.386	0.001	0.004	0.513	0.514
LSD	1.06	1.75	0.05	0.09	1.06	1.06

Note: Values are mean ± standard error of four replications except cooking loss; mean in the same columns followed by same superscript letter are not differed significantly at P≤0.05; d.f. refers to degrees of freedom; MS refers to mean sum of square; LSD refers to least significant difference.

Table 3. Effect of storage period on sensory evaluation of cooked pasta

Storage period, days	Appearance	Texture	Taste	Colour	Overall acceptability
0	7.00±0.14[a]	7.00±0.14[a]	8.00±0.14[a]	6.80±0.13[a]	7.60±0.15[a]
30	7.10±0.09[a]	7.10±0.09[a]	8.10±0.22[a]	6.80±0.13[a]	7.80±0.19[a]
60	7.00±0.14[a]	6.90±0.22[a]	8.00±0.14[a]	6.50±0.16[a]	7.50±0.16[a]
90	7.10±0.17[a]	7.00±0.14[a]	7.90±0.17[a]	6.90±0.39[a]	7.70±0.28[a]
120	7.00±0.14[a]	7.10±0.17[a]	7.90±0.17[a]	6.80±0.28[a]	7.60±0.15[a]
150	6.90±0.17[a]	7.10±0.33[a]	8.10±0.09[a]	6.80±0.19[a]	7.90±0.09[a]
180	7.00±0.14[a]	7.00±0.28[a]	8.00±0.14[a]	6.80±0.24[a]	7.70±0.14[a]
ANOVA					
F value	0.19[NS]	0.13[NS]	0.22[NS]	0.30[NS]	0.50[NS]
Error df	54	54	54	54	54
Error MS	0.25	0.44	0.30	0.52	0.36
LSD	0.45	0.60	0.50	0.64	0.54

Note: Values are mean ± standard error of ten replications; mean in the same columns followed by same superscript letter are not differed significantly at P≤0.05; d.f. refers to degrees of freedom; MS refers to mean sum of square; LSD refers to least significant difference bran and 10 % barley bran) had acceptability up to 4 months of storage with respect to overall acceptability. Pinarli *et al.* (2004) reported that storage of 15 % raw and microwaved wheat germ enriched macaroni samples up to one year did not make a difference in the result of taste panel evaluation in terms of appearance, flavour, texture and overall score. Noodles prepared from wheat flour, 10 % defatted soy-flour and 10 % sweet potato flour or 15 % sweet potato puree could be stored under air with greater quality retention at 4.4 °C for 6 months (Pangloli *et al*., 2000). Duszkiewicz-Reinhard *et al.* (1988) found no significant differences in spaghetti for six months of storage. Payumo *et al.* (1969) studied the organoleptic test for the coco noodles prepared from wheat, coco and *mung bean* flour (50:30:10), and reported acceptable over a storage period of 6 months.

Kinetics of quality changes in pasta during storage

Kinetics of changes in quality of the pasta during storage was studied using zero-order reaction. The estimates of the parameters of zero-order reaction (Eq. 5) along with the coefficient of determination and standard error are presented in Table 4. Higher correlation coefficient and lower standard error values were used as the basis to judge the adequacy of the reaction. It was observed that all deteriorative changes (moisture content, water activity, FFA, PV, fat acidity) in pasta during storage followed the zero-order reaction kinetics with high coefficients of determination (> 0.79) and low standard errors.

Gull *et al*. (2016) had also compared the deteriorative changes like microbial load and colour change in the pasta (blend of finger millet flour (20 g) and pearl millet flour (12 g) to 100 g composite flour containing durum wheat semolina: carrot pomace as 96:4 stored in BOPP pouch at accelerated condition (40±1 °C and 90±1 % RH) from zero- and first-order kinetics. It was observed that deteriorative changes follows zero order kinetics based on the correlation coefficient (R> 0.98).

CONCLUSIONS

The study illustrated the storage stability and safety of pearl millet-based pasta at ambient storage in BOPP pouches throughout 6-month storage period. Consistent increase in deteriorative quality parameters (moisture content, water activity, FFA, PV, fat acidity) was observed during the storage period. However, no significant difference on cooking quality, textural properties as well as sensory evaluation of pasta was observed during the storage period. Although there were increases in deteriorative parameters, but none of the parameters suggested initiation of spoilage in the product. The total plate count, yeast, mould, *E. Coli*, *Salmonella, Shigella* was not detected during the storage period, which indicated the safety of the product for consumption. The changes in deteriorative quality parameters followed zero-order reaction kinetics.

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Table 4. Estimated kinetic constants for quality parameters of pasta

Parameter	K, per day	R^2	Standard error	Coefficient of variation	Pr> │t│
Moisture content	0.01770	0.951	0.000898	2.335	<0.0001
Water activity	0.00082	0.794	9.27E-05	4.228	<0.0001
FFA	0.00192	0.870	0.000165	6.640	<0.0001
PV	0.02238	0.965	0.000946	6.646	<0.0001
Fat acidity	0.10111	0.961	0.004580	4.412	<0.0001

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