Rheological quality of pearl millet porridge as affected by grits size

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Abstract Study was conducted to optimize pearl millet grits size for the preparation of acceptable porridge with skimmed milk powder (SMP). Pearl millet porridge was prepared with different grits size (1.410, 0.841, 0.595, and 0.420 mm). A positive ($r=0.904$) correlation was observed between water absorption index and grits size. Porridge showed shear thinning behavior as, initially shear stress increased with increase in shear rate and later on decreased. Porridge prepared with larger grits (1.410 mm) exhibited higher firmness (38.4 ± 1.27 N) and viscosity (446 ± 3.9 cP), whereas smaller grits (0.420 mm) resulted in less viscous (118.8 ± 1.74 cP) and firm (20.4 ± 1.85 N) porridge. The medium grits (0.841 mm) produced porridge with acceptable firmness (30.7 ± 1.56 N) and viscosity (298.1 ± 8.81 cP) with moderate (6.0 ± 0.10) acceptability. To improve sensory quality of porridge (grits size 0.841 mm); skimmed milk powder at different levels (0, 5, 10 and 15 %) was added and its effect on various quality parameters was studied. SMP addition significantly ($P \leq 0.05$) modified the gelatinization and gelling behavior of grits and decreased ($P \leq 0.05$) all the pasting characteristics except pasting temperature, which increased from 77.1 ± 1.85 to 85.9 ± 3.46 °C. The peak (499 ± 6.6 cP) and final viscosity (450 ± 11.9 cP) of porridge (0.841 mm) prepared with 15 % SMP are quite similar. Hence, it maintains viscosity on cooling, similar to maximum viscosity attained during cooking. Keeping in view the rheological, firmness and sensory quality, 0.841 mm

grits of pearl millet with 15 % SMP was found optimum for preparation of acceptable porridge.

Keywords Pearl millet · Rheology · Skimmed milk powder · Firmness · Viscosity · Porridge

Introduction

Pearl millet (*Pennisetum typhoides*) is predominately grown in arid and semi arid regions of India under rainfed conditions and plays an important role in the dry land economy. It possesses more energy (1,517 kJ/100 g), protein (11.8 %) and fat (4.8 %) than sorghum (1,382 kJ energy, 10.4 % protein and 3.1 % fat) and maize (1,504 kJ energy, 9.2 % protein and 4.6 % fat) (FAO 1995). Besides high nutritional value, the protein efficiency ratio is also higher than that reported for wheat and sorghum. Pearl millet is also rich source of minerals especially iron, calcium and zinc and can provide these at lower cost as compared to wheat and rice (Parthasarathy et al. 2006). It is processed traditionally and consumed by economically weaker sections of the population throughout Asia and Africa (Jain and Bal 1997). However, its consumption both in rural and urban areas is declined due to increase in per capita income, growing urbanization, changes in taste and preference (Radhakrishnan 2005). Therefore, challenge to improve pearl millet utilization as food lead to preparation of diversified food items with improved taste and acceptability. Earlier various food products i.e. pearl millet based *halwa* mix (Yadav et al. 2011), weaning mix (Balasubramanian et al. 2011), *upma* mix (Balasubramanian et al. 2012), composite pasta (Yadav et al. 2012) have been developed successfully in our institute. Among the breakfast food, porridge is widely consumed often with the addition of salt, butter, sugar, milk or cream, depending on regional preferences. It is

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prepared by heating flour-water mixture resulting in starch gelatinization and in general, consumed warm (Rooney et al. 1986). In many African and Asian countries, porridge prepared from sorghum, pearl millet, rice and corn are quite popular. Porridge is a continuous matrix of starch molecules; hence viscosity is considered an important indicator of its quality. Variation in viscosity of porridge may be attributed to the variation in starch gelatinization with differences in grit size. Skimmed milk powder (SMP) is a good source of protein and essential amino acids and can be used to enhance the nutritional quality and sensory acceptability of composite foods. Cereal grits supplemented with SMP can be a good approach to develop nutritious and acceptable food product to combat protein energy malnutrition. Therefore, an attempt was made to standardize pearl millet grits size for porridge preparation and to enhance its acceptability with SMP with respect to rheological oscillatory measurements, viscosity, textural and sensory attributes.

Materials and methods

Raw materials

Pearl millet grains (var. PHB-2168), grown in the year 2012 were obtained from Punjab Agricultural University, Ludhiana, India. The grains were cleaned using cleaner cum grader (Indosaw, Ambala, India) and stored in gunny bags at $10 \pm 2^\circ\text{C}$ till further use. Grains (15.0 kg) were decorticated for 30 min in millet pearler (Carborundum disc mill, Mathesis Engineers, Hyderabad, India) with constant shaft speed of 800 rpm. This results in 20 % decortication. The decorticated grains were pulverized (Lakshmi Industries, Ludhiana) and sieved using sieve shaker (Model 7290; Indosaw, Ambala, India) to obtain different sized grits viz., 1.410, 0.841, 0.595 and 0.420 mm.

Fig. 1 Water absorption index (WAI) and water solubility index (WSI) of pearl millet grits

Table 1 Effect of pearl millet grits size on firmness and viscosity of porridge

Grits size, mm	Viscosity, cP	Firmness, N
1.410	446±3.9 ^a	38.4±1.27 ^a
0.841	298±8.8 ^b	30.7±1.56 ^b
0.595	212±3.2 ^c	24.6±2.24 ^c
0.420	118±1.7 ^d	20.4±1.85 ^d
LSD ($P < 0.05$)	11.8	4.1

Values followed by the same letter within a column are not significantly different ($P \leq 0.05$)

Skimmed milk powder (SMP) was procured from local market.

Chemical analysis

The moisture (method 44–19), protein (method 46–12), fat (method 30–25) and ash (method 8–01) content were determined using AACC (2000) standard methods. Carbohydrate was calculated by subtracting the sum of moisture, protein, fat and ash from 100 (Merrill and Watt 1973). Minerals (calcium, iron and phosphorus) were determined using AOAC (1995) methods. All the reagents used for chemical analysis were of analytical grade.

Porridge preparation

Pearl millet porridge was prepared (grits: water, 1:5) following Gomez et al. (1997) method. Initially, the grits were cooked with half amount of water (2.5 out of 5 parts) until slurry was formed. Later, the remaining (2.5 parts) water (boiling) was added in the slurry and stirred continuously. The gas burner was turned off, when the entire mixture reaches to boil, and stirred gently to avoid lump formation and sticking of porridge at the bottom of pan.

Fig. 2 Shear stress–strain relationship of pearl millet porridge of different grits size (mm)

Fig. 3 Storage modulus dependency on stress of different grits size (mm) pearl millet porridge

Water absorption (WAI) and water solubility (WSI) index

WAI and WSI were determined as per the method described by Qing-Bo et al. (2005). Each sample (3.0 g) was dispersed in 30 ml of distilled water and stirred gently. The dispersion was allowed to stand for 30 min in a water bath at 30 ± 2 °C. Subsequently, the dispersion was centrifuged at 3,000 rpm for 15 min. The supernatants were decanted into an evaporating dish of known weight, dried at 110 °C and weighed. The WAI was considered as the weight of sediment obtained after removal of the supernatant. The WSI was considered as the weight of dry solids in the supernatant expressed as percentage of the original weight of sample. The WAI and WSI were calculated using following equations:

$$WAI(g/g) = \frac{\text{Weight gain by gel}}{\text{Dry weight of sample}} \quad (1)$$

$$WSI(\%) = \frac{\text{Weight of dry solids in supernatant}}{\text{Dry weight of sample}} \times 100 \quad (2)$$

Rheological measurements

The rheological measurements were performed on Physica MCR 301 Rheometer (Anton Paar, Osterreich, Austria), using parallel plate configuration (PP5) of 5 mm diameter at 30 °C. The freshly prepared sample was loaded onto the measuring plate of the rheometer immediately without any coating to prevent dehydration. The sample was allowed to rest for 10 min on the plate to prevent the influence of structural modification during sample handling and loading. The dynamic modulli were performed, in a shear rate range of $0.01\text{--}500\text{ s}^{-1}$. Each test was carried out in triplicate.

Pasting characteristics

Pasting properties were determined using rapid viscosity analyser (Model 3-D, Series 4, Newport Scientific Pvt. Ltd, Australia) with thermocline software version 3.0. The paste consistency profile for each sample (2.5 g dry basis) was determined with distilled water at final weight of 25 ± 0.01 g. Each sample was held at 50 °C for 1 min and stirred at 960 rev/min followed by constant stirring at 160 rev/min while heating from 50 °C to 95 °C @ 12 °C/min, holding at 95 °C for 2.5 min followed by cooling to 50 °C @ 12 °C/min and holding at 50 °C for 2 min. The rapid viscosity analyzer (RVA) indicates starch viscosity by measuring the resistance of flour and water slurry to the stirring action of paddle. RVA plot of viscosity (cP) versus time (s) was used to determine peak viscosity (PV), breakdown viscosity (BD), final viscosity (FV) and set back (SB) viscosity (AACC 2000).

Firmness

Firmness of the porridge samples was measured using TA-XT₂ texture analyzer (version 07.15H, TA-HDi; Stable Micro Systems Ltd., Surrey, UK). The firmness was determined using perspex (SMS P/25) probe at 30 ± 2 °C. The test conditions were: pre test speed 2.0 mm/s, test speed 2.0 mm/s, post test speed 2.0 mm/s, distance—8 mm, load cell—5 kg. The

Table 2 Effect of pearl millet grits size on sensory quality of pearl millet porridge

Grits size, mm	Color	Aroma	Taste	Appearance	Mouth feel	OAA
1.410	4.2 ± 0.14^a	5.8 ± 0.10^a	4.1 ± 0.16^a	3.8 ± 0.10^a	3.4 ± 0.10^a	4.5 ± 0.10^a
0.841	5.4 ± 0.14^b	6.1 ± 0.16^a	5.5 ± 0.10^b	5.2 ± 0.10^b	5.8 ± 0.14^b	6.0 ± 0.21^b
0.595	4.1 ± 0.28^c	5.8 ± 0.22^a	4.8 ± 0.10^c	4.9 ± 0.10^c	4.5 ± 0.10^c	5.4 ± 0.16^c
0.420	3.3 ± 0.10^d	5.2 ± 0.22^b	4.2 ± 0.14^d	4.0 ± 0.14^d	4.1 ± 0.22^d	4.3 ± 0.14^d
LSD ($P \leq 0.05$)	0.41	0.41	0.28	0.23	0.33	0.33

Values followed by the same letter within a column are not significantly different ($P \leq 0.05$)

OAA overall acceptability score

Table 3 Correlation between physical, rheological and sensory characteristics of porridge prepared with different grits size

	Mouth feel	OAA	Storage modulus	Loss modulus	Firmness	WSI	WAI
Storage modulus	0.960 ^a	0.989 ^b	1.000	–	–	–	–
Loss modulus	0.905 ^a	0.828 ^a	0.821 ^a	1.000	–	–	–
Firmness	0.258	0.315	0.452	0.359	1.000	–	–
WSI	0.254	0.215	0.069	0.043	–0.857 ^a	1.000	–
WAI	–0.028	–0.143	–0.287	–0.016	–0.921 ^a	0.846 ^a	1.000

WAI water absorption index, WSI water solubility index, OAA overall acceptability score

^a Significant at 0.05 level

^b Significant at 0.01 level

compression force at which product offers maximum resistance at the highest peak of graph was taken as the firmness value for the particular sample. Average of ten replications was taken for each individual sample.

Viscosity

The viscosity of porridge samples was measured by viscometer (Visco Star H, J.P. selectors, Spain) fitted with disc spindles at 30 °C. All measurements were carried out immediately after cooking the porridge samples.

Sensory analysis

Semi-trained panel of judges (ten) selected from the staff of central institute of post-harvest engineering and technology evaluated the porridge samples (50.0 g) in terms of colour, aroma, taste, appearance, mouth feel and overall acceptability (OAA) using nine point hedonic scale (Larmond 1977) from liked extremely (9) to disliked extremely (1).

Statistical analysis

All experiments were conducted using completely randomized factorial design and analysis of variance (Snedecor and Cochran 1994) was carried out using AGRES statistical software (Ver 3.01, Pascal International Software Solutions, Atlanta, GA, USA).

Results and discussion

Water absorption index (WAI) and water solubility index (WSI) of pearl millet grits of different size

Decorticated pearl millet grains were analyzed for protein, fat, ash and carbohydrate and the corresponding values were 10.5 ± 0.12 , 4.7 ± 0.13 , 1.7 ± 0.05 and 61.5 ± 0.21 %, respectively. Water absorption index (WAI) and water solubility index (WSI) for grits of different size were determined. WAI of grits decreased from 7.6 ± 0.22 to 6.7 ± 0.29 g/g and WSI increased from 13.1 ± 0.99 to 16.8 ± 1.35 % as the size reduced from 1.410 to 0.420 mm (Fig. 1). Water solubility of larger particles was low due to lesser surface area. It can be depicted from the figure that grits size had significant ($P \leq 0.05$) effect on WAI and WSI. WAI of grits was positively ($r = 0.904$) and WSI was negatively correlated ($r = -0.997$) with size.

Firmness and viscosity of porridge with different grits size

The porridge prepared from various grits size i.e. 1.410, 0.841, 0.595, and 0.420 mm was subjected to quality evaluation. The firmness of porridge prepared with largest grits (1.410 mm) was 38.4 ± 1.27 N and of lowest grits (0.420 mm) was 20.4 ± 1.85 N (Table 1). It showed decreasing trend as grits size reduced. The viscosity also decreased from 446 ± 3.9 to 119 ± 1.7 cP as the grits size reduced from 1.410 to 0.420 mm. Porridge of lower grits size had lower viscosity and more flowy

Table 4 Pasting characteristics of pearl millet grits (0.841 mm) incorporated with different levels of SMP

SMP, %	Peak viscosity, cP	Break down, cP	Set back, cP	Final viscosity, cP	Pasting temperature, °C
0	840 ± 6.1^a	477 ± 7.1^a	749 ± 13.9^a	$1,213 \pm 8.2^a$	77.1 ± 1.85^a
5	686 ± 7.8^b	396 ± 9.5^b	457 ± 14.8^b	747 ± 3.9^b	77.9 ± 3.63^a
10	516 ± 6.1^c	308 ± 5.3^c	337 ± 4.8^c	545 ± 1.7^c	78.8 ± 2.50^a
15	499 ± 6.6^d	258 ± 4.4^d	250 ± 3.3^d	450 ± 11.9^d	85.9 ± 3.46^b
LSD ($P \leq 0.05$)	15.4	15.9	24.4	17.3	6.8

Values followed by the same letter within a column are not significantly different ($P \leq 0.05$)

SMP skimmed milk powder

Fig. 4 Effect of skimmed milk powder (SMP) on viscosity and firmness of porridge prepared from 0.841 mm grits

appearance which is an undesirable characteristic. The smaller grits showed lower water holding ability resulting in poor quality (less viscous) porridge. Due to higher WAI, larger grits produced porridge with higher firmness and viscosity.

Rheological quality

The shear stress and shear rate relationship of pearl millet porridge as influenced by grits size are shown in Fig. 2. Shear stress increased with increase in shear rate up to 300 s^{-1} , thereafter decreased for the porridge prepared with grits size of 0.841 and 0.595 mm. It may be due to breakage of swelled starch granules at higher shear rate, indicating shear thinning behavior. However, for larger grits (1.410 mm) porridge, shear stress was almost constant with respect to increase in shear rate. This is attributed to higher hardness and viscosity of porridge with larger grits size. Lesser increase in shear stress was observed for porridge prepared with lowest grits size (0.420 mm) as compared to porridge of larger (0.841 and 0.595 mm) grits. This might be attributed to larger surface area and more shear thinning behavior of lower grits size. Various researchers reported shear thinning behavior of similar kind of food products like wheat porridge (Manohar et al. 1998), semi-liquid foods (Sopade and Kassam 1992), wheat, corn and tapioca starch (Christianson and Bagley 1983; Gujral and

Sodhi 2002). Extent of particle crowding in the dispersed phase and the gelatinous characteristics of the dispersing phase in the three-dimensional network influence the shear stress and viscosity curves of porridges. Figure 3 represents the dependency of storage modulus on shear stress of porridge prepared with different grits size. It is depicted from the figure that storage modulus of porridge increased with increase in grits size. This might be due to formation of more viscous and compact textured porridge. Keawkaika et al. (2010) also observed higher viscosity and storage modulus for larger grain size rice as compared to smaller one. The storage modulus of all porridge samples were higher than loss modulus (data for loss modulus is not given) suggesting, solid like elastic behaviour of porridge. In general, as grits size reduced, the storage modulus decreased with increase in shear stress. However, highest reduction in storage modulus of porridge prepared with largest grits size (1.410 mm) was observed. It might be due to higher firmness (38.4 N) and viscous mass (446.7 cP), which indicates that porridge with higher grits size behave like solids. In contrast, smaller grits uniformly disperse in continuous phase and provides elastic network with higher stability. It can be observed from Fig. 3 that porridge prepared from 0.841 mm grits was more stable as compared to other grits under study. Keeping in view, the porridge stability (as indicated by storage modulus), firmness, viscosity and overall acceptability, grits of 0.841 mm size was considered best among the tested grits for porridge preparation.

Sensory quality of porridge of different grits size

The sensory scores for color, aroma, taste, appearance, mouth feel and overall acceptability (OAA) of porridge prepared from different grits size ranged from 5.4 ± 0.14 to 3.3 ± 0.10 , 6.1 ± 0.16 to 5.2 ± 0.22 , 5.5 ± 0.10 to 4.1 ± 0.16 , 5.2 ± 0.10 to 3.8 ± 0.10 , 5.8 ± 0.14 to 3.4 ± 0.10 and 6.0 ± 0.21 to 4.3 ± 0.14 , respectively (Table 2). Kokini et al. (1977) correlated rheological parameters with sensory quality and reported that sensory parameters depend on product internal viscoelastic

Table 5 Effect of SMP on sensory profile of pearl millet porridge prepared from 0.841 mm grits

SMP, %	Color	Aroma	Taste	Appearance	Mouth feel	OAA
0	5.4 ± 0.24^a	6.1 ± 0.22^a	5.5 ± 0.29^a	5.2 ± 0.21^a	5.8 ± 0.08^a	6 ± 0.08^a
5	5.8 ± 0.43^a	6.9 ± 0.16^b	6.2 ± 0.11^b	6.0 ± 0.15^b	6.4 ± 0.22^b	6.5 ± 0.18^b
10	7.2 ± 0.29^b	7.5 ± 0.29^c	6.9 ± 0.16^c	7.2 ± 0.29^c	7.3 ± 0.16^c	7.4 ± 0.22^c
15	8.4 ± 0.22^c	8.7 ± 0.16^d	8.5 ± 0.22^d	8.8 ± 0.10^d	8.9 ± 0.14^d	8.9 ± 0.11^d
LSD ($P \leq 0.05$)	0.71	0.50	0.48	0.46	0.37	0.36

Values followed by the same letter within a column are not significantly different ($P \leq 0.05$)

SMP skimmed milk powder, OAA overall acceptability score

behaviour. The storage modulus is positively correlated ($P \leq 0.05$) with mouthfeel ($r=0.960$) and overall acceptability ($r=0.989$) of the porridge (Table 3). The sensory data for all the parameters are below the acceptable range, though the porridge prepared with 0.841 mm grits scored higher sensory scores (Table 2) as compared to other porridge samples under study. This reconfirms the results of firmness and rheological values for porridge prepared with 0.841 mm grits. To improve the sensory quality of porridge (grits size 0.841 mm), skimmed milk powder (SMP) was incorporated at different levels i.e. 5, 10, and 15 %. The effect of SMP on rheological and sensory quality of porridge is discussed below.

Effect of SMP on pasting characteristics

The pasting characteristics of control and SMP incorporated porridge are shown in Table 4. SMP significantly ($P \leq 0.05$) decreased the peak, breakdown, setback and final viscosity of pear millet porridge. The reduction in pasting parameters was due to dilution of starch in the dispersion, which results by incorporation of SMP. The pasting temperature of porridge increased from 77.1 ± 1.85 to 85.9 ± 3.45 °C at 15 % level of SMP. Pasting temperature gives an indication of the minimum temperature required to cook the porridge. Noisuwan et al. (2007, 2008) also reported that SMP addition increases pasting temperature and decreases viscosity of rice starch gels. Peak viscosity, (an indicator of water-binding capacity of the mixture) decreased from 840 ± 6.1 to 499 ± 6.6 cP with the addition of SMP at 15 % level. Breakdown viscosity decreased from 477 ± 7.1 to 258 ± 4.4 cP at same level of SMP. Lower breakdown value for starchy food is a good indicator of cooking quality (Manohar et al. 2011). The peak (499 ± 6.6 cP) and final viscosity (450 ± 11.9 cP) of porridge prepared with 15 % SMP are similar. This indicates that on cooling, porridge maintains its viscosity similar to maximum viscosity attained during cooking. Effect of SMP on firmness of porridge (grits size 0.841 mm) is shown in Fig. 4. SMP significantly ($P \leq 0.05$) decreased the firmness from 30.7 to 21.8 N at 15 % level.

Effect of SMP on sensory quality

The color of the finished product changes from grayish to whitish when SMP was incorporated, which is desirable for pearl millet porridge. The significant ($P \leq 0.05$) increase in color (5.4 ± 0.25 to 8.4 ± 0.22) and appearance (5.2 ± 0.22 to 8.8 ± 0.10) was observed on increasing the level of SMP (Table 5). The sensory score for aroma was also increased from 6.1 ± 0.22 to 8.7 ± 0.16 at 15 % level of SMP. Typical pearl millet aroma was masked with milk protein aroma. SMP incorporation also improved taste (5.5 ± 0.29 to 8.5 ± 0.22) and mouth feel (5.8 ± 0.10 to 8.9 ± 0.14) of porridge. The sensory evaluation results revealed that overall acceptability score of

porridge prepared with 15 % SMP increased significantly ($P \leq 0.05$) from 6.0 ± 0.10 to 8.9 ± 0.11 .

Nutritional value

Pearl millet porridge of 0.841 mm grits size with and without 15 % SMP was analyzed for its nutritional composition. The protein and ash content of porridge with 15 % SMP were 11.3 ± 0.20 and 1.05 ± 0.100 %, respectively. Calcium and phosphorus content were 240.9 ± 5.54 and 238 ± 1.37 mg/100 g, respectively. The fat and carbohydrate content were in the range of 1.81 ± 0.10 to 1.83 ± 0.10 and 65.7 ± 1.77 to 63.1 ± 3.92 %, while iron content (5.6 ± 0.05 mg/100 g) was similar in both the samples and did not differ significantly ($P \leq 0.05$).

Conclusion

The study indicated that pearl millet porridge exhibits pseudo elastic behavior. The grits size had significant effect on rheological properties i.e. shear stress, storage modulus, firmness and viscosity of porridge. Larger grits produce too firm and viscous porridge, whereas smaller grits produce too soft and low viscous porridge. Too high or low firmness as well as viscosity is not a desirable quality of porridge. Medium size grits (0.841 mm) produce porridge with acceptable firmness and viscosity but with moderate acceptability. Further, sensory as well as nutritional quality can be improved with addition of skimmed milk powder at 15 % level. Thus prepared porridge had high protein (11.3 ± 0.20 %), calcium (240.9 ± 5.58 mg/100 g), and phosphorous (238.1 ± 1.37 mg/100 g) and is suitable for undernourished population. Such value added product would be helpful in promoting utilization of underutilized grain i.e. pearl millet. However, intensive market survey is required before commercialization.

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