Effect of grain moisture content during milling on pasting profile and functional properties of amaranth fractions

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Abstract Evaluation of functional properties of milled fractions of grain amaranth may be useful to decide the end uses of the grain. Hence, pasting profiles of amaranth fractions obtained by milling the grains at different moisture contents were studied in relation with their starch profile and also with their swelling power and solubility indices. It was observed that, for flour fraction, the viscosity parameters were lowest at 14–16 % moisture content. Swelling power and solubility indices of the samples varied as a function of grain moisture content. The middling fraction also showed similar pasting pattern with the variation of grain moisture content. The seed coat fractions showed higher gelatinization temperature compared to that of fine flour and middling fractions. However, starch content of the fine seed coat fraction was comparable with that of the flour and middling fractions. The coarse seed coat fraction showed lower viscosity parameters than the other samples. Viscosity parameters correlated well among themselves while, they did not show significant correlation with the starch content. However, the viscosity parameters showed negative correlation with the soluble amylose content. The study revealed that, the fractions obtained by milling the grains at different moisture content show differential pasting profiles and functional properties.

Keywords Amylose · Milled fractions · Pasting profile · Starch · Swelling power · Solubility index

Introduction

Amaranth (*Amaranthus cruentus*) is one of the important grains and marking a renewed interest because of its excellent nutrient profile. Being a pseudo cereal, amaranth contains good quality proteins, dietary fiber and lipids rich in unsaturated fats (Alvarez-Jubete et al. 2009; Escudero et al. 2006) and used in many traditional food preparations. Amaranth has been cultivated in US (Baker and Rayas-Duarte 1998) and China (Wu and Corke 1999). It is grown in India to some extent, particularly in Maharashtra, Gujarat, and some parts of south India and used for human consumption.

Amaranth is a good source of riboflavin (Berghofer and Schoenlechner 2002) and also minerals such as calcium, magnesium and iron (Alvarez-Jubete et al. 2009). It is also known for its good quality proteins rich in essential amino acid such as lysine, tryptophan and sulphur containing amino acids like methionine (Bressani 1989). Apart from this, the grain proteins also exhibit favourable effects on cholestolemia (Mendonca et al. 2009). Like cereals, amaranth contains starch as one of the major components ranging from 48 to 69 g/100 g, depending on the species (Teutonico and Knorr 1985). The starch granules are polygonal, measuring 1–3 µm and have a high swelling power (Stone and Lorenz 1984). Amaranth exhibits waxy nature, its amylose content is relatively very less compared to other cereals and hence, the functional properties of amaranth starch will be of prominence (Resio and Suarez 2001; Bello-Perez et al. 2006). Amaranth starch has been found to have low viscosity, high solubility, and low gelatinization temperature (Chaturvedi et al. 1997; Resio and Suarez 2001). The rheological properties of amaranth starch indicated that, the paste contains pseudoplastic and thixotropic behaviour and the flow properties were better than that of maize starch (Teli et al. 2007). Kong et al. (2010) reported the pasting behaviour of different varieties of

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amaranth and showed that the viscosity parameters vary to a greater extent among the different varieties.

Amaranth is a small seeded grain with about 1 mm diameter. The embryo of the grain encloses the starch rich perisperm like a ring. The embryo is therefore large and accounts for 25 % of the grain size. The seed coat is very smooth and thin. Due to small grain structure, fractionation of amaranth poses challenge to the millers. Generally, amaranth is milled and the whole flour is used for different products using disc, hammer and pin mills were reported by several researchers (Becker et al. 1981; Berghofer and Schoenlechner 2002). Milling the grain amaranth using roller mill was explored by Nanka (1998), wherein a vario-technical roller mill was used to obtain a protein rich and starch-rich fraction. Schoenlechner (2000) used a technical scale roller mill in combination with a plansifter. However, the focus was limited to use a single break system of roller mill and the seed coat fractions of the grain were not separated. Milling of amaranth using multiple break system of the roller mill and preparation of different grain fractions including the coarse and fine seed coat fractions and also the study of influence of grain moisture content on the milling quality is being published elsewhere by the same group of authors. It has been well reported that the grain moisture content has direct influence on the milling quality of the grain (Sakhare et al. 2014). The distribution of the nutrients in grain varies along with its botanical components. At higher moisture level, the grain may cut open but the bran and the seed coat components may not get powdered easily (Dharmaraj et al. 2015). At lower moisture level, the grains exhibit comparatively fragile nature and the chances of getting admixed with seed coat and bran portions are high. The seed coat and bran fractions contain relatively low starch contents compared to the pure endosperm fractions. Generally, the pasting profile of a particular sample is a relative property of its total starch content in cereals or alike grains. Moreover, amaranth contains relatively low amylose content. Thus, the pasting and some of the functional properties such as swelling power and solubility index of different grain fractions of amaranth is of importance to design the end uses of the products. Hence, the main objective of this study was to evaluate the influence of the grain moisture content on the pasting profile of different milled fractions of amaranth. Swelling power and solubility index, starch, total and soluble amylose contents of the different fractions were also evaluated in relation with the pasting profile.

Materials and methods

Material

Grain amaranth (K432) procured from the University of Agricultural Sciences, Bangalore, Karnataka, India, was

cleaned to remove any foreign particles and stored in polyethylene bags till use. The grains contained 4.37 g/100 g fat, 14.8 g/100 protein, 3.97 g/100 g ash, 13.4 g/100 g dietary fiber and 61.6 g/100 g of carbohydrates. The initial moisture content of the grains was 11 g/100 g. The moisture contents of the samples were determined by air oven method (AACC 2000). The moisture contents of the samples were increased to desired levels (12.5, 14, 16, 17 and 18.5 g/100 g) by adding additional water. The additional water required for each level was calculated using the following formula;

$$Q = \frac{M2-M1}{100-M2} W$$

Where:

Q is the amount of water (L).

W is the weight of seed at initial moisture content (kg).

M2 is the desired moisture content of seed (%).

M1 is the initial moisture content of seed (%)

Samples (2 kg each) were poured in to a rotary drum mixer and total quantity of water for the batch was divided into 2–4 aliquots and sprinkled on the grains. After each sprinkling, the mixture was rotated for about 5 min and about 30 min in the end and rested for 24 h at ambient conditions (28 °C and 64 % RH) in air tight containers (Sakhare et al. 2015). The tempered samples were pulverized in a laboratory scale roller mill (Buhler, MLU-202) to get 4 streams namely flour (FF) (−200 μ), middling (MF) (−400 + 200 μ), fine seed coat (FSC) (−600 + 400 μ) and coarse seed coat (CSC) (+600 μ) fractions. The middling and seed coat fractions were further pulverized to get flour of less than 250 μ particle size. All the samples were equilibrated to 12 % moisture content in a dessicator maintained at 64 % relative humidity and taken for further analysis.

Pasting profile

Twelve percent aqueous slurry (w/v) was transferred to heating bowl of the Brabender visco- amylograph (Model No. 803202, Brabender, Duisburg, Germany) and heated to raise the temperature at the rate of 7.5 °C per min from 30 °C to 92 °C and then maintained for 5 min at 92 °C, followed by cooling at same rate to 50 °C and held for 1 min. The change in the viscosities during the heating, cooking and cooling cycles were recorded and reported.

Swelling power and solubility index

One gram of the meal taken in a graduated centrifuge tube was mixed with 10 ml of water and incubated for 30 min in a water bath maintained at 30 °C followed by centrifugation at 1750×g for 25 min. The supernatant was decanted and the

weight of the residue was noted to calculate the swelling power. The supernatant was transferred into a pre-weighed petriplate and evaporated to dryness on a water bath, dried in an air oven maintained at 105 °C for 5 h. Based on the dry weight and the weight of the residue, the percentage soluble was calculated and denoted as solubility index. The experiment was repeated at 97 °C also (Stone and Lorenz 1984).

Total starch

The total starch contents of the samples were estimated following the enzymatic digestion method. Defatted samples (100 mg) were dispersed in 15 ml of water containing 0.1 ml of heat stable α -amylase. To the mixture, 15 ml of 0.05 M acetate buffer (pH 4.8) containing 10 mg of glucoamylase was added and incubated at 60 °C for 16 h. The contents were made up to 100 ml and the reducing sugars were estimated using dinitrosalicylic reagent (Holm et al. 1986).

Amylose

The total and soluble amylose contents of the samples were determined according to the method of Sowbhagya and Bhattacharya (1971).

Statistical analysis

The entire experiments were performed with three independent trials, and data were calculated on dry weight basis and presented as mean $\pm$ standard deviation (SD). Data were assessed for significant difference by employing DMRT and were considered significant at $p < 0.05$. The correlation coefficients of the data were calculated using Systat-13 software.

Results and discussion

Table 1 presents the pasting parameters, starch and amylose content of fine flour fraction of amaranth. A significant decrease in the gelatinization temperature (GT) of the samples was observed with the increase in the grain moisture content up to 16 % and there after the decrease in GT was not significant. The flour fractions obtained by milling the grains at 14 and 16 % moisture content showed lower values for all the viscosity parameters compared to that obtained at other moisture contents. It was observed that, most of the viscosity parameters were initially high at 11 and 12 % grain moisture contents, marked a decrease at 14 to 16 % moisture contents and showed an increase at elevated moisture contents of 17 and 18.5 %. The samples showed highest the starch content at 12.5 % grain moisture and the lowest value at 18.5 % moisture content. The soluble amylose was high at 14 and 16 %

moisture range and showed low values at all other moisture contents. In contrast to this, the insoluble and total amylose contents were high at 12.5 and 16 % grain moisture contents compared to the other samples. Ikegwu et al. (2009) reported that the peak viscosity varies as a result of the amylose contents of the starches. Oguntunde (1987) reported that the associative bonding of the amylose fraction is responsible for the structure and pasting behaviour of starch granule. Thus, the samples having more apparent amylose contents may exhibit higher peak viscosity, which was true for the sample milled at 12.5 % moisture content wherein the total starch as well as total amylose contents were high. However, samples milled at higher moisture contents did not show any trend for starch and amylose contents with peak viscosity. It was reported that, peak viscosity is also associated with degree of starch damage and high starch damage results in high peak viscosity (Sanni et al. 2001). This may be the reason for the higher peak viscosity values of the samples obtained at 11 and 12.5 % moisture content. The lower moisture content of the sample could be one of the reasons for higher starch damage (Haros et al. 2004).

At ambient temperature (30 °C), the highest swelling power was shown by the sample obtained at 18.5 % moisture content and the lowest was for that obtained at 12.5 % moisture content (Table 1). However, the sample obtained at 18.5 % moisture content showed lowest values for solubility (11.81 g/100 g) and that obtained at 16 % moisture content showed highest value (15.31 g/100 g). On cooking, the highest swelling power was exhibited by the flour fraction obtained at 11 % grain moisture content, which decreased as the moisture content increased to 16 % and then afterwards followed an increasing trend. In contrast to this, the solubility was highest for the fraction obtained at 16 % moisture content and lowest for that milled at 11 % moisture content.

Table 2 presents the pasting parameters, starch and amylose contents of middling fractions of amaranth. It was observed that the GT decreased as the moisture content of the sample increased from 11 to 16 %. Further increase in the moisture content did not show any significant change in the GT values. However, the peak, hot paste, cold paste and breakdown viscosities including the setback viscosity values were lowest at 16 % of the grain moisture content. Compared to fine flour fractions, the middling fractions showed lower breakdown viscosity. This may be due to the presence of comparatively small sized starch granules present in the middling fraction which resist high break down (Singh et al. 2014). Similar to fine flour fraction, the starch content was relatively lower at higher moisture contents of 17 and 18.5 % and the soluble amylose contents were higher at 14 and 16 % grain moisture contents. The middling fraction also followed the similar trend like fine flour fractions for insoluble and total amylose contents. The swelling power was highest for the sample milled at 16 % moisture content. On cooking, the sample milled at

Table 1 Pasting parameters, starch, amylose contents, swelling power and solubility index of fine flour fractions of amaranth milled at different moisture contents

Parameters	Moisture content					
	11 %	12.5 %	14 %	16 %	17 %	18.5 %
Gelatinization temperature(°C)	73.9 ± 0.07 ^c	72.9 ± 0.07 ^b	72.8 ± 0.08 ^b	71.5 ± 0.08 ^a	71.7 ± 0.07 ^a	71.8 ± 0.14 ^a
Peak viscosity (BU)	191 ± 2.83 ^c	220 ± 4.24 ^f	96.5 ± 2.12 ^a	103.5 ± 0.70 ^b	129 ± 1.41 ^c	182 ± 5.65 ^d
Hot paste viscosity (BU)	150 ± 1.41 ^c	167 ± 2.83 ^f	70 ± 1.41 ^a	79 ± 1.41 ^b	101 ± 0.07 ^c	138.5 ± 4.95 ^d
Cold paste viscosity (BU)	204 ± 1.41 ^c	226.5 ± 3.53 ^f	108.5 ± 2.12 ^a	120 ± 1.41 ^b	146.5 ± 0.70 ^c	194.5 ± 4.95 ^d
Breakdown (BU)	41 ± 1.41 ^d	53 ± 1.41 ^f	26.5 ± 0.70 ^b	23.5 ± 0.70 ^a	29 ± 1.41 ^c	43.5 ± 0.70 ^c
Setback (BU)	54 ± 0.07 ^d	59.5 ± 0.70 ^f	38.5 ± 0.70 ^a	40.5 ± 0.70 ^b	45.5 ± 0.70 ^c	56 ± 0.70 ^c
Starch content (g/100 g)	65.6 ± 0.04 ^c	68.5 ± 0.08 ^c	61.2 ± 0.01 ^b	67.5 ± 0.83 ^d	60.5 ± 1.67 ^{ab}	59.8 ± 0.33 ^a
Soluble amylose (g/100 g)	1.06 ± 0.02 ^a	1.25 ± 0.02 ^b	1.44 ± 0.09 ^c	1.44 ± 0.09 ^c	1.19 ± 0.06 ^b	1.19 ± 0.01 ^b
Insoluble amylose(g/100 g)	2.91 ± 0.02 ^b	4.38 ± 0.07 ^c	2.50 ± 0.10 ^a	3.25 ± 0.35 ^b	2.56 ± 0.10 ^a	2.50 ± 0.10 ^a
Total amylose (g/100 g)	3.97 ± 0.04 ^b	5.63 ± 0.09 ^d	3.94 ± 0.01 ^b	4.69 ± 0.26 ^b	3.75 ± 0.03 ^a	3.69 ± 0.01 ^a
Swelling Power (g/100 g)						
30 °C	252.5 ± 1.27 ^c	226.7 ± 1.34 ^d	239.0 ± 0.41 ^b	260.0 ± 0.58 ^d	261.4 ± 0.65 ^d	265.3 ± 0.41 ^a
97 °C	869.0 ± 1.05 ^e	785.21 ± 0.65 ^e	700.82 ± 1.6 ^b	613.42 ± 1.05 ^a	736.97 ± 1.27 ^c	752.80 ± 1.6 ^d
Solubility Index (g/100 g)						
30 °C	13.77 ± 0.35 ^b	14.03 ± 0.01 ^c	11.75 ± 0.04 ^a	15.31 ± 0.07 ^d	13.75 ± 0.11 ^b	11.81 ± 0.07 ^a
97 °C	25.22 ± 0.44 ^a	26.80 ± 0.28 ^b	29.23 ± 0.44 ^d	33.24 ± 0.38 ^c	27.12 ± 0.10 ^c	27.12 ± 0.07 ^c

Mean values with different superscripts were significantly different within row at $p < 0.05$

Results are expressed on dry weight basis

12.5 % moisture content showed highest swelling power of 786.2 g/100 g. Similarly, the solubility index was highest for

the sample milled at 16 % moisture content at room temperature. The same trend was observed on cooking.

Table 2 Pasting parameters, starch and amylose contents of middling fractions of amaranth milled at different moisture contents

Parameters	Moisture content					
	11 %	12.5 %	14 %	16 %	17 %	18.5 %
Gelatinization temperature (°C)	73.20 ± 0.28 ^d	72.10 ± 0.07 ^c	70.40 ± 0.49 ^b	68.20 ± 0.42 ^a	68.70 ± 0.50 ^a	68.90 ± 0.07 ^a
Peak viscosity (BU)	98.00 ± 1.41 ^b	128.50 ± 0.53 ^d	53.50 ± 0.70 ^a	52.00 ± 1.41 ^a	98.50 ± 0.70 ^b	123.50 ± 1.41 ^c
Hot Paste viscosity(BU)	87.00 ± 1.41 ^b	113.50 ± 2.12 ^d	45.50 ± 2.12 ^a	45.50 ± 2.12 ^a	86.50 ± 0.70 ^b	107.50 ± 2.12 ^c
Cold paste viscosity(BU)	133.00 ± 1.41 ^d	164.50 ± 2.12 ^f	89.00 ± 1.41 ^b	78.50 ± 2.12 ^a	129.50 ± 0.70 ^c	157.50 ± 1.41 ^e
Breakdown (BU)	11.00 ± 0.7 ^c	15.00 ± 1.41 ^d	8.00 ± 1.41 ^b	6.50 ± 0.7 ^a	12.00 ± 0.70 ^c	16.00 ± 2.12 ^d
Setback (BU)	46.00 ± 0.05 ^c	51.00 ± 0.07 ^d	33.50 ± 0.70 ^a	33.00 ± 0.7 ^a	43.50 ± 0.70 ^b	50.00 ± 0.70 ^d
Starch content(g/100 g)	66.29 ± 0.05 ^d	63.31 ± 0.08 ^c	61.70 ± 0.83 ^b	66.61 ± 0.75 ^d	61.11 ± 1.0 ^b	59.74 ± 0.08 ^a
Soluble amylose(g/100 g)	1.19 ± 0.06 ^a	1.38 ± 0.03 ^b	1.56 ± 0.09 ^d	1.56 ± 0.07 ^d	1.44 ± 0.03 ^c	1.31 ± 0.03 ^b
Insoluble amylose(g/100 g)	2.62 ± 0.23 ^b	3.85 ± 0.07 ^d	2.63 ± 0.10 ^b	2.82 ± 0.17 ^c	2.50 ± 0.88 ^a	2.50 ± 0.01 ^a
Total amylose(g/100 g)	3.81 ± 0.17 ^a	5.22 ± 0.04 ^c	4.19 ± 0.01 ^b	4.38 ± 0.17 ^b	3.94 ± 0.02 ^a	3.81 ± 0.04 ^a
Swelling Power (g/100 g)						
30 °C	263.0 ± 0.65 ^b	221.1 ± 1.27 ^a	266.9 ± 1.27 ^b	296.2 ± 1.05 ^d	269.8 ± 1.34 ^b	279.5 ± 0.21 ^c
97 °C	790.1 ± 1.6 ^d	786.2 ± 0.42 ^d	784.9 ± 1.6 ^d	663.2 ± 0.58 ^a	711.4 ± 0.41 ^b	741 ± 1.05 ^c
Solubility Index (g/100 g)						
30 °C	16.68 ± 0.28 ^c	12.78 ± 0.35 ^a	11.02 ± 0.04 ^a	18.21 ± 0.01 ^d	16.64 ± 0.10 ^c	14.29 ± 0.07 ^b
97 °C	27.90 ± 0.38 ^a	28.31 ± 0.01 ^{ab}	32.80 ± 0.13 ^c	36.61 ± 0.27 ^d	27.87 ± 0.44 ^a	29.59 ± 0.17 ^b

Mean values with different superscripts were significantly different within row at $p < 0.05$

Results are expressed on dry weight basis

The GT was highest for the fine seed coat fraction obtained at 11 % grain moisture content which decreased with increase in moisture contents (Table 3). Highest peak viscosity was showed by the fraction obtained at 18.5 % grain moisture content while the lowest was showed by the fraction at 11 % grain moisture content. The fine seed coat fractions contained part of the endosperm portions and hence showed relatively equal amount of starch content compared to that of flour and middling fractions. The starch content was lowest for the sample milled at 18.5 % grain moisture content followed by the sample milled at 16 % grain moisture content. The soluble amylose fraction was highest and the insoluble amylose was lowest for the sample milled at 16 % moisture content. The swelling power of the fine seed coat was highest for the fraction milled at 18.5 % moisture content, both at ambient (30 °C) and boiling temperature (97 °C) and the lowest value was recorded for the sample milled at 16 % moisture content. The solubility index was high for the sample milled at 16 % grain moisture content both at ambient and boiling temperature.

The coarse seed coat fractions exhibited comparatively high GT than all other streams. It is generally known that, presence of seed coat increases the GT (Dharmaraj et al. 2015). The samples milled at 14 and 16 % grain moisture content showed highest GT than other samples. This indicates that, seed coat can be efficiently removed at these moisture range (Table 4). The peak, hot paste, cold paste and breakdown viscosities were comparatively low at 14 to 16 % moisture

range. Compared to the other fractions, the coarse seed coat samples showed lower peak viscosity. Presence of comparatively lower starch content and higher fat content in these fractions may be the reason for this, as it was reported that, higher fat content may attribute to lower peak viscosity due its lubricating effect (Shevkani et al. 2014). Total starch content of all the samples was relatively low and soluble, insoluble and total amylose contents also followed the same trend. The swelling power of the coarse seed coat fraction was highest for the sample milled at 16 % moisture content at ambient conditions and on cooking the sample at 17 % moisture content showed highest swelling values (Table 4). However, for the solubility index, the fraction obtained at 16 % moisture content showed the highest values for both the temperatures.

Adebawale et al. (2005) reported that the higher the breakdown in viscosity, the lower the ability of the sample to withstand heating and shear stress during cooking. For fine flour fractions, highest break down viscosity was recorded for the sample milled at 12.5 % grains moisture content, while for that of the middling fraction it was at 18.5 % grain moisture content. Compared to the flour and middling fractions, the breakdown viscosity values were significantly low for the fine and coarse seed coat fractions. For fine seed coat fraction, the paste stability decreased as the moisture content of the grains increased. Shimelis et al. (2006) reported that final viscosity is used to indicate the ability of starch to form paste or gel after cooling and that less stability of starch paste is commonly accompanied with high value of breakdown. It

Table 3 Pasting parameters, starch and amylose contents of fine seed coat fractions of amaranth milled at different moisture contents

Parameters	Moisture content					
	11 %	12.5 %	14 %	16 %	17 %	18.5 %
Gelatinization temperature (°C)	75.50 ± 0.07 ^d	70.50 ± 0.07 ^c	70.20 ± 0.07 ^c	59.70 ± 1.7 ^a	63.50 ± 0.07 ^b	63.90 ± 0.28 ^b
Peak viscosity (BU)	43.50 ± 0.71 ^a	74.00 ± 2.83 ^c	57.00 ± 1.41 ^b	58.50 ± 1.41 ^b	97.50 ± 0.70 ^c	110.50 ± 1.41 ^d
Hot paste viscosity (BU)	40.00 ± 1.41 ^b	68.50 ± 2.12 ^d	35.50 ± 0.7 ^a	46.50 ± 2.12 ^c	84.00 ± 1.41 ^e	95.00 ± 2.83 ^f
Cold paste viscosity (BU)	70.00 ± 0.7 ^b	107.00 ± 2.83 ^d	66.00 ± 1.41 ^a	79.00 ± 1.41 ^c	130.00 ± 1.4 ^e	143.00 ± 4.24 ^f
Breakdown (BU)	4.50 ± 0.7 ^{ab}	5.50 ± 0.7 ^b	4.00 ± 1.41 ^a	12.00 ± 0.7 ^c	14.50 ± 0.7 ^d	15.50 ± 0.7 ^d
Setback (BU)	31.50 ± 0.7 ^b	38.50 ± 0.7 ^c	29.00 ± 1.41 ^a	32.50 ± 0.7 ^b	46.00 ± 0.7 ^d	48.00 ± 1.41 ^e
Starch content(g/100 g)	66.41 ± 0.03 ^c	62.10 ± 0.06 ^d	61.82 ± 0.67 ^{cd}	58.10 ± 0.67 ^b	61.11 ± 0.06 ^c	57.02 ± 0.06 ^a
Soluble amylose(g/100 g)	1.25 ± 0.01 ^a	1.44 ± 0.03 ^c	1.72 ± 0.04 ^d	1.75 ± 0.04 ^d	1.38 ± 0.04 ^b	1.38 ± 0.01 ^b
Insoluble amylose(g/100 g)	2.22 ± 0.24 ^{ab}	3.36 ± 0.06 ^d	2.37 ± 0.01 ^c	2.03 ± 0.01 ^a	2.56 ± 0.01 ^c	2.38 ± 0.01 ^b
Total amylose(g/100 g)	3.47 ± 0.22 ^a	4.81 ± 0.09 ^d	4.09 ± 0.04 ^c	3.78 ± .04 ^b	3.94 ± 0.03 ^c	3.75 ± 0.01 ^b
Swelling Power (g/100 g)						
30 °C	302.5 ± 0.65 ^a	301.7 ± 1.05 ^a	300.3 ± 0.41 ^a	303.4 ± 0.42 ^a	327.9 ± 0.65 ^b	332.8 ± 0.41 ^b
97 °C	712.9 ± 1.27 ^c	686.9 ± 1.34 ^c	636.7 ± 1.60 ^b	589.4 ± 1.05 ^a	733.3 ± 0.58 ^d	739.1 ± 1.6 ^d
Solubility Index (g/100 g)						
30 °C	16.9 ± 0.28 ^{bc}	17.96 ± 0.07 ^{cd}	17.3 ± 0.01 ^c	18.04 ± 0.01 ^d	16.08 ± 0.10 ^b	14.67 ± 0.35 ^a
97 °C	29.23 ± 0.44 ^a	31.25 ± 0.17 ^b	33.24 ± 0.38 ^c	35.32 ± 0.38 ^d	31.49 ± 0.11 ^b	31.49 ± 0.38 ^b

Mean values with different superscripts were significantly different within row at $p < 0.05$

Results are expressed on dry weight basis

Table 4 Pasting parameters, starch and amylose contents of coarse seed coat fractions of amaranth milled at different moisture contents

Parameters	Moisture content					
	11 %	12.5 %	14 %	16 %	17 %	18.5 %
Gelatinization temperature (°C)	77.20 ± 0.49 ^a	78.60 ± 0.2 ^{bc}	79.40 ± 0.07 ^c	79.20 ± 0.07 ^c	78.10 ± 0.42 ^b	78.20 ± 0.7 ^b
Peak viscosity (BU)	38.00 ± 1.41 ^d	33.50 ± 0.7 ^c	28.50 ± 0.70 ^b	20.00 ± 0.7 ^a	41.50 ± 0.7 ^e	38.50 ± 0.7 ^d
Hot paste viscosity(BU)	28.50 ± 0.7 ^c	27.50 ± 0.7 ^c	23.00 ± 0.70 ^b	17.50 ± 0.7 ^a	37.50 ± 0.7 ^e	34.50 ± 0.7 ^d
Cold paste viscosity(BU)	51.00 ± 0.7 ^c	50.00 ± 1.41 ^c	47.50 ± 0.70 ^b	38.00 ± 0.7 ^a	65.50 ± 0.7 ^e	60.00 ± 0.7 ^d
Breakdown (BU)	9.50 ± 0.7 ^c	6.00 ± 0.7 ^d	5.00 ± 0.70 ^c	2.5.00 ± 0.7 ^a	4.00 ± 0.7 ^b	4.00 ± 0.7 ^b
Setback (BU)	22.50 ± 0.7 ^b	22.50 ± 0.7 ^b	24.50 ± 0.70 ^c	20.50 ± 0.7 ^a	28.00 ± 0.7 ^e	25.50 ± 0.7 ^d
Starch content(g/100 g)	39.38 ± 0.03 ^c	38.55 ± 0.05 ^c	36.89 ± 0.75 ^b	35.59 ± 0.75 ^a	46.66 ± 1.34 ^e	43.22 ± 0.83 ^d
Soluble amylose(g/100 g)	0.75 ± 0.03 ^a	0.88 ± 0.14 ^b	1.00 ± 0.09 ^c	1.09 ± 0.09 ^c	1.06 ± 0.03 ^c	0.94 ± 0.01 ^{bc}
Insoluble amylose(g/100 g)	1.25 ± 0.11 ^a	2.07 ± 0.10 ^f	1.72 ± 0.12 ^e	1.66 ± 0.12 ^d	1.57 ± 0.15 ^c	1.37 ± 0.17 ^b
Total amylose(g/100 g)	2.00 ± 0.09 ^a	2.94 ± 0.09 ^e	2.72 ± 0.04 ^d	2.75 ± 0.04 ^d	2.63 ± 0.17 ^c	2.31 ± 0.17 ^b
Swelling Power (g/100 g)						
30 °C	357.6 ± 0.58 ^b	397.9 ± 0.21 ^d	364.1 ± 0.42 ^b	372.4 ± 0.41 ^c	339.2 ± 0.21 ^a	360.5 ± 0.65 ^b
97 °C	382.5 ± 1.60 ^a	381.8 ± 1.34 ^a	396.7 ± 1.05 ^b	398.0 ± 0.65 ^b	521.4 ± 1.27 ^c	496.8 ± 1.27 ^b
Solubility Index (g/100 g)						
30 °C	15.72 ± 0.28 ^b	10.30 ± 0.07 ^a	11.94 ± 0.01 ^a	17.93 ± 0.04 ^c	16.61 ± 0.11 ^b	15.00.07 ± ^b
97 °C	25.73 ± 0.38 ^a	27.06 ± 0.17 ^b	27.60 ± 0.04 ^b	30.82 ± 0.10 ^c	29.59 ± 0.04 ^c	27.87 ± 0.35 ^b

Mean values with different superscripts were significantly different within row at $p < 0.05$

Results are expressed on dry weight basis

was observed that the final or cold paste viscosity of the fine flour fractions were comparatively higher than the other streams and the sample obtained at 12.5 % grain moisture content showed highest paste stability. However, in contradiction to Kaur et al. (2010), who reported a lower final viscosity than the peak viscosity for different amaranth germplasms, all the fractions in this study showed a higher final viscosity compare to the peak viscosity.

The milling characteristics vary as a function of grain moisture content. The amount of seed coat removed from the fine flour fraction varies as the grain moisture content varies. Moreover, the distribution of protein, fat and carbohydrate contents varies in grains. This may be the main reason for the variations in the pasting as well as in starch profiles.

The correlation coefficients of the viscosity parameters with starch, amylose, swelling power and solubility index

Table 5 Correlation coefficients of starch, amylose, swelling power, solubility index and the viscosity parameters of fine flour fractions of amaranth milled at different moisture contents

	Starch	MV	CPV	HPV	BD	SB	GT	SA	ISA	TA	Swelling power	Solubility index
Starch	1											
MV	0.313	1										
CPV	0.303	0.998*	1									
HPV	0.316	0.998*	0.999*	1								
BD	0.271	0.975*	0.963*	0.960*	1							
SB	0.225	0.989*	0.991*	0.986*	0.969*	1						
GT	−0.268	0.542*	0.527*	0.535*	0.575*	0.499	1					
SA	0.105	−0.721*	−0.749*	−0.754*	−0.591*	−0.724*	−0.597*	1				
ISA	0.859*	0.541*	0.518*	0.523*	0.569*	0.478	−0.047	0.045	1			
TA	0.855*	0.380	0.352	0.356	0.433	0.319	−0.166	0.245	0.980*	1		
Swelling	0.021	0.776*	0.781*	0.793*	0.708*	0.729*	0.849*	−0.880*	0.107	−0.073	1	
Solubility	0.224	−0.728*	−0.732*	−0.737*	−0.690*	−0.710*	−0.905*	0.870*	0.010	0.185	−0.946*	1

MV Maximum viscosity, CPV cold paste viscosity, HPV hot paste viscosity, BD break down viscosity, SB set back viscosity, GT gelatinization temperature, SA soluble amylose, ISA insoluble amylose, TA total amylose

*Indicates significant correlation

Table 6 Correlation coefficients of starch, amylose, swelling power, solubility index and the viscosity parameters of middling fractions of amaranth milled at different moisture contents

	Starch	MV	CPV	HPV	SB	BD	GT	SA	ISA	TA	Swelling power	Solubility index
Starch	1											
MV	−0.383	1										
CPV	−0.348	0.999	1									
HPV	−0.348	0.999	1	1								
SB	−0.315	0.993	0.997	0.997	1							
BD	−0.561	0.974	0.966	0.966	0.955	1						
GT	0.403	0.296	0.328	0.328	0.380	0.173	1					
SA	−0.056	−0.714	−0.736	−0.738	−0.788	−0.628	−0.605	1				
ISA	0.214	0.366	0.371	0.371	0.343	0.284	0.429	0.019	1			
TA	0.194	0.154	0.152	0.152	0.112	0.097	0.249	0.290	0.962	1		
Swelling	−0.153	0.372	0.385	0.385	0.424	0.371	0.818	−0.484	0.284	0.141	1	
Solubility	0.361	−0.812	−0.818	−0.818	−0.832	−0.763	−0.482	0.748	−0.112	0.096	−0.583	1

MV Maximum viscosity, CPV cold paste viscosity, HPV hot paste viscosity, BD break down viscosity, SB set back viscosity, GT gelatinization temperature, SA soluble amylose, ISA insoluble amylose, TA total amylose

*Indicates significant correlation

for flour fractions of grain amaranth is presented in Table 5. Interestingly, the starch content of the flour fractions did not correlate with any of the viscosity parameters. However, a negative correlation (−0.721) was observed between the maximum viscosity and soluble amylose contents of the samples obtained at different moisture conditions. The correlation coefficient of swelling power with maximum viscosity was positive, while that with the solubility index was negative and the trend remained the same for hot paste, breakdown and setback viscosities including the gelatinization temperature. However, the viscosity parameters correlated well among themselves (Table 5).

The correlation coefficients did not show high value for starch content of middling fractions as a function of viscosity parameters (Table 6). Even swelling power did not correlate with any of the viscosity parameters except for GT (0.818), while the solubility index correlated negatively with all the viscosity parameters similar to flour fractions. The soluble amylose contents were also negatively correlated with the viscosity parameters.

A strong negative correlation was observed between the starch and viscosity parameters for the fine seed coat samples (Table 7). But, the gelatinization temperature showed a positive correlation with the starch contents ($r = 0.88$). Solubility

Table 7 Correlation coefficients of starch, amylose, swelling power, solubility index and the viscosity parameters of fine seed coat fractions of amaranth milled at different moisture contents

	Starch	MV	CPV	HPV	SB	BD	GT	SA	ISA	TA	Swelling power	Solubility index
Starch	1											
MV	−0.646*	1										
CPV	−0.537*	0.973*	1									
HPV	−0.760*	0.799*	0.776*	1								
SB	−0.492	0.961*	0.995*	0.792*	1							
BD	−0.760*	0.799*	0.776*	1	0.792*	1						
GT	0.880*	−0.525*	−0.447	−0.837*	−0.434	−0.837*	1					
SA	−0.438	−0.277	−0.438	−0.088	−0.491	−0.088	−0.445	1				
ISA	0.155	0.244	0.329	−0.246	0.279	−0.246	0.284	−0.239	1			
TA	−0.036	0.125	0.140	−0.286	0.066	−0.287	0.092	0.199	0.904*	1		
Swelling	0.181	0.596*	0.685*	0.285	0.723*	0.285	0.263	−0.905*	0.297	−0.098	1	
Solubility	−0.650*	−0.070	−0.212	0.234	−0.255	0.234	−0.716*	0.938*	−0.325	0.084	−0.832*	1

MV Maximum viscosity, CPV cold paste viscosity, HPV hot paste viscosity, BD break down viscosity, SB set back viscosity, GT gelatinization temperature, SA soluble amylose, ISA insoluble amylose, TA total amylose

*Indicates significant correlation

Table 8 Correlation coefficients of starch, amylose, swelling power, solubility index and the viscosity parameters of coarse seed coat fractions of amaranth milled at different moisture contents

	Starch	MV	CPV	HPV	SB	BD	GT	SA	ISA	TA	Swelling power	Solubility index
Starch	1											
MV	0.856*	1										
CPV	0.970*	0.923*	1									
HPV	−0.063	0.427	0.06	1								
SB	0.879*	0.734*	0.914*	−0.153	1							
BD	−0.063	0.427	0.06	1	−0.153	1						
GT	−0.512*	−0.765*	−0.517*	−0.717*	−0.202	−0.717*	1					
SA	0.058	−0.441	−0.072	−0.934*	0.220	−0.934*	0.724*	1				
ISA	−0.343	−0.386	−0.305	−0.293	−0.206	−0.293	0.629*	0.285	1			
TA	−0.264	−0.483	−0.280	−0.586*	−0.090	−0.586*	0.789*	0.604*	0.936*	1		
Swelling	0.903*	0.587*	0.831*	−0.445	0.841*	−0.445	−0.195	0.402	−0.335	−0.131	1	
Solubility	0.045	−0.470	−0.149	−0.896*	0.04	−0.896*	0.558*	0.932*	0.178	0.490	0.375	1

MV Maximum viscosity, CPV cold paste viscosity, HPV hot paste viscosity, BD break down viscosity, SB set back viscosity, GT gelatinization temperature, SA soluble amylose, ISA insoluble amylose, TA total amylose

*Indicates significant correlation

index did not correlate with the viscosity parameters, while the swelling power showed positive correlation with maximum, cold paste and set back viscosities.

The starch content of the coarse seed coat sample positively correlated with the maximum, cold paste and set back viscosities (Table 8) and showed a negative correlation with the gelatinization temperature. Most of the viscosity parameters showed a positive correlation with the swelling power and a negative relationship with the solubility index.

Leach et al. (1959) reported that the amylose acts both as diluents and inhibitor of swelling and therefore the relationship with the viscosity parameters were negative. Lower peak viscosity indicates more resistance to swelling by the starch granules due to less amylose leaching and lower extent of granule swelling. This indicates that the samples contained a high level of amylose or long amylopectin side chains that resisted shear.

Conclusions

The flour and middling fractions obtained by milling the grains at different moisture contents showed comparatively lower values for the viscosity parameters between 14 and 16 % grain moisture contents. The starch content of the samples did not correlate with the viscosity parameters for flour and middling fractions. A negative correlation (−0.492 to −0.76) was observed between the starch and viscosity parameters for the fine seed coat fraction while, the correlation coefficient was positive (0.856 and 0.879) for the coarse seed coat fraction. The study indicated that, the seed coat may be efficiently removed at 14–16 % grain moisture content. Even

though, grain amaranth contained very low amount of amylose contents, it showed a direct effect on the viscosity parameters of all the fractions. Not only the starch content, the other grain components may also play major role in deciding the functional properties of the flour fractions.

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