Quality Assurance and Safety of Crops & Foods, 2017; 9 (3): 285-293

Wageningen Academic Publishers

Physical characteristics of different oat cultivars: influence on pasting, functional and antioxidant properties

M. Kaur* **and S. Singh**

Department of Food Science and Technology, Guru Nanak Dev University, GT Road, Amritsar 143005, India; mandyvirk@rediffmail.com

Received: 20 August 2016 / Accepted: 27 November 2016

RESEARCH ARTICLE

Abstract

This study examined physical properties of grains from eight oat cultivars in relation to their techno-functional, pasting and antioxidant properties. All the cultivars differed significantly ($P<0.05$) in their physical parameters such as length, width, thickness, seed weight, seed volume, surface area and sphericity. The ash, fat, protein and fibre contents of the flours ranged from 0.84-3.54%, 2.02-7.27%, 6.12-13.33% and 0.21-0.84%, respectively. All the flours exhibited varied functional properties such as water absorption (4.0-7.24 g/g), oil absorption (3.15-6.28 g/g), Bulk density (0.511-0.610 g/ml) and gelation capacity (12-18%). The flours showed low foaming capacity but exhibited highly stable foams. The antioxidant activity of flours varied between 4.94-6.82% whereas the reducing power and total phenolic content was 1,131-1,463 µg AAE/g and 1,688-2,016 µg GAE/g. Pasting temperature, peak, breakdown and final viscosity of the flours ranged between 90.2-93.2 °C, 288-620 mPa, 50-94 mPa and 324-939 mPa, respectively. The results of pasting parameters revealed that PLP-1 exhibited significantly ($P<0.05$) lowest peak, breakdown, trough, setback and final viscosities. Kent and PLP-1 were the most potential cultivars as they varied significantly ($P<0.05$) from other cultivars in their measured properties as shown by principal component analysis (PCA). Several significant correlations between physical, antioxidant and pasting parameters were revealed by PCA.

Keywords: starch, rheology, oats, grains processing, food quality

1. Introduction

Oats (*Avena sativa*) is a minor crop which was earlier commonly used for fodder purpose but owing to its nutritional properties is gaining popularity among humans. Oats are commercially utilised in many forms such as flakes, rolled or as flour. A variety of oat products are becoming popular such as breakfast cereals, oat fermented products, and oat rice, oat milk and other value added products (Choi *et al.*, 2012). Oat and oat products are rich source of functional molecules such as proteins, amino acids, dietary fibre, β-glucan, vitamins and also in phytochemicals such as phytate, polyphenols and phenolic acids (Verardo *et al.*, 2011). Numerous bioactive compounds in oats have been reported such as ferulic acid, caffeic acid, vanillic acid, p-coumaric acid, p-hydroxybenzoic acid, syringic acid, quercetin, kaempferol and avenanthramides which are unique to oats. These compounds have a great potential as powerful antioxidants and as neutraceuticals (Kilci and Gocmen, 2014; Peterson, 2001). Oat contain avenanthramides which are readily bioavailable polyphenols that possess numerous beneficial properties such as anti-inflammatory, anti-cancer and antiproliferative that maybe useful in reducing incidence of various diseases such as coronary heart diseases, skin irritation and colon cancer (Yang *et al.*, 2014). These antioxidants also preserve colour and taste of food and prevent it from rancidity (Alrahmany and Tsopmo, 2012). Oat grains are nutritionally very rich as they contain carbohydrate mainly starch (70-80% of dry matter), protein (11-55%) and lipids (3.1-10.9%). Total dietary fibre in oat grains ranges from 12-38% and about 30-50% of this total fibre is water soluble. Oats are rich in tocopherols and contain about 2.3 mg tocopherols/100 g grain (Lásztity, 1998). Oat grains are commonly processed as whole grain as its groat is softer than other grains and therefore cannot be easily converted into separate germ, endosperm and bran fractions (Decker *et al.*, 2014). Milling and processing of oats depends on oat and groat physical characteristics. The size of groat to the size of grain affects the test weight, hectolitre weight, bulk density and maximum size of flakes that can be generated. Dehulling larger oat grains can be done at slower rotor speed in comparison to smaller oat grains (Doehlert *et al.*, 2006). For designing the equipment for processing, separation, sorting, storing and transportation, knowledge of the physical properties of agricultural foods and products is important (Gharekhani *et al.*, 2013).

Pasting properties of oats are affected by interaction between its three major components: β-glucan, starch, and protein (Liu *et al.*, 2010). Because of the problem of separation effects due to other components most of studies reported on pasting properties of cereal starches have been concentrated on isolated starch (Zhou *et al.*, 2000). Pasting properties of oat starch, oatmeal and flour have been reported by various workers (Choi *et al.*, 2012; Doehlert *et al.*, 1997; Zhou *et al.*, 2000).The pasting properties of oat flours have an impact on textural attributes and consumer acceptance of food products. Oat slurries which show short time to peak viscosity and high relative mean values of peak viscosity and final viscosity are easily acceptable by consumers (Hall and Tarr, 2000). There have been some studies on oat breeding, grain qualities and functionalities, but little information on relationships between grain and flour qualities have been reported. Therefore, this study was conducted with the objective to correlate physical properties of grains with techno-functional, antioxidant and pasting properties of flours from different oat cultivars.

2 Material and methods

Materials

Representative samples of eight Indian oat cultivars: PLP-1 (CSK HPKV, Palampur, India), OS-6, OS-7, OS-364, HFO-114 (CCS HAU, Hisar, India) and OL-9, OL-10, Kent (PAU, Ludhiana, India) were procured. Seeds were cleaned for dirt, damaged seeds, foreign material and stored at 20 °C until further use. All the reagents used in the study were of analytical grade

Reagents

2, 2-diphenyl-1-picrylhydrazyl (DPPH), ferrozine and standard ferulic acid were purchased from Sigma-Aldrich (Steinheim, Germany). Folin-Ciocalteu's reagent, trichloroacetic acid (TCA), ferrous chloride, potassium ferricyanide and ferric chloride were obtained from LobaChemie, Mumbai, India. All chemicals and reagents used were of analytical grade.

Physical characteristics of grains

Grains from different oat cultivars were analysed for their physical parameters such as length (L), width (W) and thickness (T) using vernier caliper. Various parameters (Equations 1-4) were calculated from L, W and T such as:

Surface area (S) was calculated by method given by Jain and Bal (1997):

$$S = \pi BL^2 / (2L - B) \quad (1)$$

Where, $B = \sqrt{WT}$.

Aspect ratio (R_a) was calculated by the formula:

$$R_a = W/L \quad (2)$$

Equivalent diameter (D) and sphericity (φ) was calculated by the method given by Mohsenin (1986):

$$D = \{L(W + T)^2/4\}^{1/3} \quad (3)$$

$$\phi = (LWT)^{1/3}/L \quad (4)$$

Bulk density was determined using the mass/volume relationship whereas true density was calculated using toluene displacement method given by Mohsenin (1986).

Chemical composition

Grains were ground to prepare flour which was stored under refrigeration till further used. Flour samples were analysed for their moisture, fat, ash, protein (%N×6.25) and crude fibre content by standard methods of analysis (AOAC, 1990). Colour measurements of flours were carried out using a Hunter colorimeter Model D 25 optical sensor (Hunter Associates Laboratory Inc., Reston, VA, USA) on the basis of L* (lightness), a* (redness and greenness) and b* (yellowness and blueness) values. Each test was performed in triplicates on dry weight basis.

Functional properties

Water absorption of flours was measured by the centrifugation method of Sosulski (1962). Samples (3 g) were dispersed in distilled water (25 ml) in centrifuge tubes, held for 30 min and then centrifuged at 3,000×*g* for 25 min. Supernatants were decanted and the amount of sediments was weighed. For the determination of oil absorption, the method of Lin *et al.* (1974) was used. Samples (0.5 g) were mixed with refined sunflower oil (6 ml) in centrifuge tubes and held for 30 min followed by centrifugation at 3,000 g for 25 min. The oil separated was removed and residue was weighed. Bulk density was measured by method as given by Kaur and Singh (2005). Least gelation concentration (LGC) of the flours was determined by the method of Sathe and Salunkhe (1981). Test tubes containing flour suspensions (2-20% concentration) in 5 ml distilled water were prepared and heated for 1 h in boiling water followed by cooling at 4 °C for 2 h. The tubes were then inverted to see whether the samples fell down on inversion. Emulsifying properties were determined according to the method given by Naczk *et al.* (1985). Flour sample (3 g) was dispersed in 50 ml distilled water and 25 ml sunflower oil in a homogeniser (Yorco, India) for 60 sec. The emulsion was then divided into two centrifuge tubes and centrifuged at 3,000 g for 5 min. The emulsions were then heated at 85 °C for 15 min followed by centrifugation to determine the stability of emulsions. The capacity and stability of foams were determined by the method of Lin *et al.* (1974). 3% dispersion of flour in 50 ml distilled water was homogenised using homogeniser for 3-4 min. The blend was then immediately transferred to a graduated cylinder and percentage of volume increase due to whipping was noted. For the determination of foam stability, foam volume changes in the cylinder were recorded at different time intervals of storage.

Antioxidant properties

For the determination of antioxidant properties, flour samples were extracted with 80% methanol (except for total phenolic content where acidified methanol was used) on a metabolic shaker for 2 h. Antioxidant activity (AOA) was measured using a modified version of the method explained by Brand-Williams *et al.* (1995). For the measurement of AOA, extracts were reacted with 3.9 ml of DPPH solution and the absorbance was read at 515 nm at 0 and 30 min using spectrophotometer (Shimadzu-1800; Shimadzu, Tokyo, Japan). The total phenolic content (TPC) was determined according to method explained by Gao *et al.* (2002). TPC of the extract was measured by adding 1.5 ml of freshly diluted Folin-Ciocalteu's reagent and 1.5 ml of sodium carbonate followed by incubation for 90 min at room temperature. The absorbance was measured at 725 nm. The reducing power was measured as described by Zhao *et al.* (2008). To the extract, 2.5 ml of potassium ferricyanide and phosphate buffer was added followed by incubation at 50 °C and addition of 10% TCA to the mixture and then centrifugation at 10,000 g for 10 min. The absorbance was measured at 700 nm. Metal chelating activity of extract was measured as reported by Dinis *et al.* (1994).The metal chelating activity of extract was determined by addition of 50 µl of ferrous chloride and 1.6 ml of 80% methanol and then addition of ferrozine. After incubation for 10 min absorbance was measured at 526 nm.

Pasting properties

The pasting properties of flours were evaluated by a Modular Compact Rheometer (model 52; Anton Paar Co. Ltd, Graz, Austria). Viscosity profiles of flours were recorded using flour suspensions (8%, w/w). The suspensions were held at 50 °C for 1 min, heated to 95 °C at the rate of 6 °C/min and held at 95 °C for 2.7 min. These were then cooled from 95 to 50 °C at the rate of 6 °C/min and held at 50 °C for 2 min. Various pasting parameters, such as peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown viscosity (BV), setback viscosity (SV), and pasting temperature (PT), were recorded.

Statistical analysis

The data reported in all tables are average of triplicate observations. The data were subjected to statistical analysis using Minitab Statistical Software version. 14 (Minitab Inc., State College, PA, USA) and Pearson correlation coefficient between the properties were established. Principal component analysis of measured properties was carried out to provide difference and similarities among different oat cultivars.

3. Result and discussion

Physical characteristics of grain

The grains from different oat cultivars were analysed for their various physical characteristics (Table 1). Oat kernel shape and size are influenced by genetic and environmental factors (Pietrzak and Fulcher, 1994). Raw material to be used for milling purposes is usually selected on the basis of absence of foreign grain and material, husk content, test weight, moisture content, grain weight, sound appearance and odour (Ganssmann and Vorwerck, 1995). The value of length and width of the grains from different oat cultivars ranged from 6.78-9.65 mm and 2.36-2.88 mm, respectively. These values were lower than earlier reported values for length (9.26-11.11 mm) and width (2.81-3.03 mm) for oat cultivars (Doelhert *et al.*, 2006). The grains from HFO-114 cv. were found to be longest in size whereas thickness of OL-9 cv. was found to be lowest as compared to other cultivars. L/W ratio is a useful guide to the nature of data relating to endosperm, and more significantly the starch (Evers and Millar, 2002). L/W ratio was observed to be highest for PLP-1 cv. and lowest for Kent cv. whereas the reverse was true for aspect ratio (Table 1). Amongst all cultivars equivalent diameter was observed to be largest for OS-346 cv. (3.96 mm) and smallest for OL-9 cv. (3.14 mm). Sphericity is defined as the ratio of the surface area of the sphere having the same volume as that of the grain to the surface area (Mohensin, 1986). Grain sphericity from different oat cultivars was in the range of 0.36-0.47. OL-9 cv. was significantly (P<0.05) different from all cultivars in exhibiting lowest values for equivalent diameter, surface area and sphericity (Table 1). OS-346 cv. showed lowest values both for true density as well as bulk density. All the cultivars differed significantly (P<0.05) in their 100 seed weight and seed volume. Kent cv. showed the lowest value

Table 1. Physical characteristics of grains from different oat cultivars.[1,2]

Cultivar	Length (mm)	Width (mm)	Thickness (mm)	L/W ratio	Aspect ratio	Equi. dia. (mm)	Surface area $(mm)^2$	Sphericity	True density (g/ml)	Bulk density (g/ml)	100 grain weight (g)	100 seed volume (ml)
OL-9	8.45 ± 0.01^{c}	2.4 ± 0.03^{a}	1.5 ± 0.11^{a}	3.52^{d}	0.28^{a}	3.14^{a}	28.36^{a}	0.36^{a}	1.42^{c}	0.69 ± 0.21^{c}	1.80 ± 0.05^{b}	2.33 ± 0.57^{ab}
OL-10	$8.18\pm.0.21^{b}$	2.45 ± 0.01^{a}	1.8 ± 0.02^{a}	3.33^{c}	0.30^{ab}	3.29^{bc}	30.95^{b}	0.39^{b}	1.89^{e}	0.58 ± 0.31^{a}	1.19 ± 0.01^{a}	2.66 ± 0.01^{b}
KENT	6.78 ± 0.07^{a}	2.36 ± 0.14^{a}	2.2 ± 0.23^{b}	2.87^{a}	0.34^{b}	3.23^{b}	29.18^{b}	0.47^{d}	1.62^{d}	0.61 ± 0.04^{a}	1.17 ± 0.28^{a}	1.33 ± 0.02^{a}
OL-6	9.22 ± 0.08^{e}	2.62 ± 0.08^{b}	2.5 ± 0.15^{d}	3.51^{d}	0.28^{a}	3.87^{de}	43.03^{de}	0.41^{cd}	1.90^{e}	0.80 ± 0.01^{d}	2.20 ± 0.05^{c}	1.66 ± 0.14^{a}
OS-7	8.85 ± 0.03^{d}	2.66 ± 0.3^{c}	2.3 ± 0.09^{c}	3.32^{c}	0.30^{ab}	3.73^{d}	39.96^{d}	0.42^{c}	1.18^{ab}	0.89 ± 0.06^{e}	2.28 ± 0.01^{c}	2.66 ± 0.30^{b}
OS-346	8.95 ± 0.4^{d}	2.88 ± 0.05^{d}	2.5 ± 0.16^{d}	3.10^{b}	0.32^{b}	3.96^{e}	44.36^{e}	0.44^{cd}	1.01^{a}	0.57 ± 0.01^{a}	2.58 ± 0.14^{d}	5.33 ± 0.02^{c}
HFO-114	9.65 ± 0.08^{f}	2.71 ± 0.14^{c}	2.4 ± 0.01^{c}	3.56^{e}	0.28^{a}	3.92^{ef}	44.53^{e}	0.40^{b}	2.56^{f}	0.61 ± 0.1^{a}	2.60 ± 0.01^{d}	2.00 ± 0.11^{ab}
PLP-1	9.01 ± 0.12^{d}	2.51 ± 0.15^{a}	2.1 ± 0.39^{b}	3.58^{e}	0.27^{a}	3.58^{c}	37.22^{c}	0.39^{b}	1.29^{b}	0.68 ± 0.11^{b}	2.23 ± 0.02^{c}	1.66 ± 0.02^{a}

[1] Length (L), width (W), and thickness values are an average of 10 readings. True density, bulk density, 100 grain weigh, and 100 seed volume values are an average of triplicate readings (± standard deviation). Values followed by similar letters in a column do not differ significantly ($P<0.05$).
[2] Aspect ratio $R_a = W/L$; Equi. dia. $D = \{L(W + T)^2/4\}^{1/3}$; surface area $S = \pi BL^2/(2L - B)$ where $B = \sqrt{WT}$; sphericity $\varphi = (LWT)^{1/3}/L$.

both for seed weight as well as seed volume whereas HFO-114 cv. exhibited the highest seed weight.

Proximate composition

Proximate composition varied significantly ($P<0.05$) among flours from different oat cultivars (Table 2).The moisture and ash contents of the flours ranged between 6.97-8.55% and 0.84-3.54%, respectively. Moisture content of the flour in the present study was in close agreement to that reported earlier for different oat varieties by Ozcan *et al.* (2009) (7.90-8.60%) and Huttner *et al.* (2010) (10.63-14.06%). Ash content of oat flours was in the range as observed earlier (1.58-1.89%) by Choi *et al.* (2012) and (1.45-1.91%) by Ozcan *et al.* (2009). Highest fat and protein content was observed in OL-9 cv. with the values of 7.27 and 13.33%, respectively (Table 2). The fat content in the range of 7.39-10.01% has been observed (Choi *et al.*, 2012) which was higher than that observed in the present study (2.01-7.27%). Protein content in the present study (6.12-13.33%) was in the range (11.13-14.37%) reported earlier by Choi *et al.* (2012) whereas fibre content was lower than reported by Ozcan *et al.* (2009) (1.40-2.10%). These variations are attributed to the effect of environmental and varietal differences. OL-9 was significantly ($P<0.05$) different from all the other cultivars in exhibiting significantly ($P<0.05$) lower moisture and ash contents and higher fat, fibre and protein contents. Hunter colour values (L*, a*, and b*) of flours from different

Table 2. Proximate composition and colour characteristics of flours from different oat cultivars.[1,2]

Cultivar	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Fibre (%)	L*	a*	b*
OL-9	6.97 ± 0.01^{a}	1.87 ± 0.06^{b}	7.27 ± 0.05^{f}	13.33 ± 0.37^{f}	0.82 ± 0.002^{e}	87.04 ± 0.32^{b}	1.28 ± 0.07^{b}	11.37 ± 0.17^{a}
OL-10	7.82 ± 0.01^{c}	2.16 ± 0.13^{c}	6.18 ± 0.01^{ef}	11.28 ± 0.04^{e}	0.79 ± 0.005^{d}	84.22 ± 2.42^{ab}	1.30 ± 0.01^{b}	11.84 ± 0.60^{ab}
KENT	7.82 ± 0.02^{c}	1.74 ± 0.11^{b}	4.35 ± 0.04^{c}	8.74 ± 0.05^{b}	0.84 ± 0.002^{e}	87.81 ± 0.18^{b}	1.21 ± 0.05^{a}	11.70 ± 0.08^{ab}
OS-6	8.51 ± 0.03^{e}	3.54 ± 0.04^{e}	2.02 ± 0.01^{a}	9.63 ± 0.04^{c}	0.62 ± 0.003^{c}	84.79 ± 1.91^{b}	1.46 ± 0.05^{d}	12.49 ± 0.28^{b}
OS-7	8.23 ± 0.03^{d}	2.00 ± 0.08^{c}	5.93 ± 0.03^{e}	$10.50\pm.02^{d}$	0.21 ± 0.007^{a}	86.44 ± 0.22^{b}	1.37 ± 0.04^{c}	12.25 ± 0.09^{ab}
OS-346	8.55 ± 0.04^{e}	2.42 ± 0.08^{d}	3.70 ± 0.02^{b}	11.38 ± 0.04^{e}	0.37 ± 0.005^{b}	85.58 ± 0.10^{b}	1.40 ± 0.01^{c}	12.59 ± 0.06^{b}
HFO-114	8.31 ± 0.04^{de}	0.84 ± 0.06^{a}	6.00 ± 0.08^{e}	6.12 ± 0.02^{a}	0.79 ± 0.002^{d}	83.78 ± 2.93^{ab}	1.11 ± 0.32^{a}	11.28 ± 0.42^{a}
PLP-1	7.37 ± 0.02^{b}	2.31 ± 0.12^{d}	4.81 ± 0.06^{d}	10.98 ± 0.01^{de}	0.21 ± 0.003^{a}	79.72 ± 2.23^{a}	2.12 ± 0.05^{e}	15.92 ± 0.66^{c}

[1] Values are an average of triplicate observations (± standard deviation). Values followed by similar superscript letters in a column do not differ significantly ($P<0.05$).
[2] L* = lightness; a* = redness and greenness; b* = yellowness and blueness.

oat cultivars are presented in Table 2. L* (lightness) values of the flours varied from 79.72-87.81, with Kent cv. showing the highest values. Colour scale value of a* and b* varied from 1.11-2.12 and 11.28-15.92, respectively. PLP-1 cv. was significantly (P<0.05) different from other cultivars in its lowest L* and highest a* and b* values.

Functional properties

Functional properties of flours from different oat cultivars were determined and are shown in Table 3. The application of flours from different plant or animal sources in food systems depends greatly on information about the physiochemical and functional properties of such food materials. All the flours differed significantly (P<0.05) in their LGC ranging between 12-18%. PLP-1 cv. showed lowest LGC value making it a good gel-forming or firming agent and can be useful for food systems such as pudding and snacks which require thickening and gelling. In addition, flour from PLP-1 cv. also exhibited highest dispersibility (337 sec) and lowest bulk density (0.511 g/ml). Bulk density of flours in the present study was lower than reported values of 0.73-0.77 g/ml for oat flours (Sandhu *et al.*, 2017). Particle size differences may be the cause of variations in bulk density of the flours.

Emulsion activity (EA) of the flours varied between 7.49-15.70%. Kent cv. was significantly (P<0.05) different from other cultivars in its lowest EA (7.5%) but exhibited highest emulsion stability (ES) of 40.77%. Emulsion properties are useful in food systems such as mayonnaise, salad dressing, cakes, frozen desserts and coffee whiteners (Elkhalifa and Bernhardt, 2010). Water absorption capacity (WAC) is an important processing parameter and has implications for viscosity. It is also important for consistency of products and baking properties (Niba *et al.*, 2001). WAC of the flours was in the range of 4.00-7.24 g/g with the highest value being observed in OL-10 cv. The major chemical affecting oil absorption index is protein, which is composed of both hydrophilic and hydrophobic parts. HFO-114 cv. was significantly (P<0.05) different from other cultivars both with respect to its lowest oil absorption capacity (OAC) as well as water absorption capacity. OAC is important as oil not only acts as a flavour retainer but also improves palatability, increases the mouth feel of foods and extends the shelf life especially in bakery or meat products where fat absorption is desired (Aremu *et al.*, 2007).

Foaming capacity (FC) is the ability of substance in a solution to produce foam after shaking vigorously. The foaming properties of flour from different oat cultivars were studied at different flour concentrations (1-10%) (Figure 1). The decrease in foam volume with the passage of time (5-90 min) to determine foam stability (FS) was also studied (Figure 2). FC of all the flours increased with the increase in concentration of flours. At 1% flour concentration FC was in the range of 10-13% which increased to 16-19% at 10% flour concentration. Highest FC of 19% was observed for OS-346 cv. (10% flour concentration). FC and FS are generally determined by the loss of liquid which results in destabilisation 'leakage' and is measured as a volume decrease (Elkhalifa and Bernhardt, 2010). A decrease in FS with the increase in storage time was observed in all the flours. After 90 min of storage FS ranged between 92.03-94.99% with the lowest FS being exhibited by OL-10 cv.

Antioxidant properties

Oats have been recognised as a good source of phytochemicals, and their antioxidant properties have been determined by using DPPH (Gujral *et al.*, 2011; Sandhu *et al.*, 2017). The antioxidant activity of oat flour using DPPH assay, reducing power, metal chelating and total phenolic content are represented in Table 4. AOA of the

Table 3. Functional properties of flours from different oat cultivars.[1,2]

Cultivar	LGC (%)	Dispersability (sec)	Bulk density (g/ml)	Emulsion activity (%)	Emulsion stability (%)	WAC (g/g)	OAC (g/g)
OL-9	16^{c}	281 ± 2.5^{c}	0.531 ± 0.003^{b}	10.47 ± 0.74^{b}	24.89 ± 1.24^{a}	6.04 ± 0.18^{c}	5.28 ± 0.03^{c}
OL-10	14^{b}	188 ± 1.5^{a}	0.597 ± 0.003^{cd}	11.70 ± 0.50^{bc}	26.50 ± 0.81^{a}	7.24 ± 0.07^{e}	5.97 ± 0.08^{d}
KENT	16^{c}	245 ± 4.7^{b}	0.548 ± 0.002^{b}	7.49 ± 1.0^{a}	38.44 ± 1.98^{c}	6.95 ± 0.08^{de}	6.28 ± 0.03^{e}
OS-6	18^{d}	325 ± 4.1^{cd}	0.53 ± 0.004^{b}	14.19 ± 2.1^{cd}	37.31 ± 1.2^{c}	5.10 ± 0.05^{b}	5.48 ± 0.03^{cd}
OS-7	16^{c}	277 ± 2.08^{bc}	0.601 ± 0.002^{d}	15.70 ± 0.69^{d}	28.04 ± 1.17^{b}	6.49 ± 0.01^{d}	5.32 ± 0.01^{c}
OS-346	14^{b}	195 ± 2.64^{a}	0.546 ± 0.005^{b}	12.52 ± 0.53^{c}	40.77 ± 1.14^{d}	6.46 ± 0.06^{d}	4.28 ± 0.02^{b}
HFO-114	18^{d}	291 ± 0.57^{c}	0.610 ± 0.006^{d}	9.33 ± 0.32^{ab}	25.71 ± 0.44^{a}	4.00 ± 0.04^{a}	3.15 ± 0.04^{a}
PLP-1	12^{a}	337 ± 0.57^{d}	0.511 ± 0.003^{a}	13.99 ± 1.28^{cd}	30.76 ± 0.61^{b}	5.12 ± 0.04^{b}	4.34 ± 0.05^{b}

[1] Values are an average of triplicate observations (± standard deviation). Values followed by similar superscript letters in a column do not differ significantly (P<0.05).
[2] OAC = oil absorption capacity; WAC = water absorption capacity.

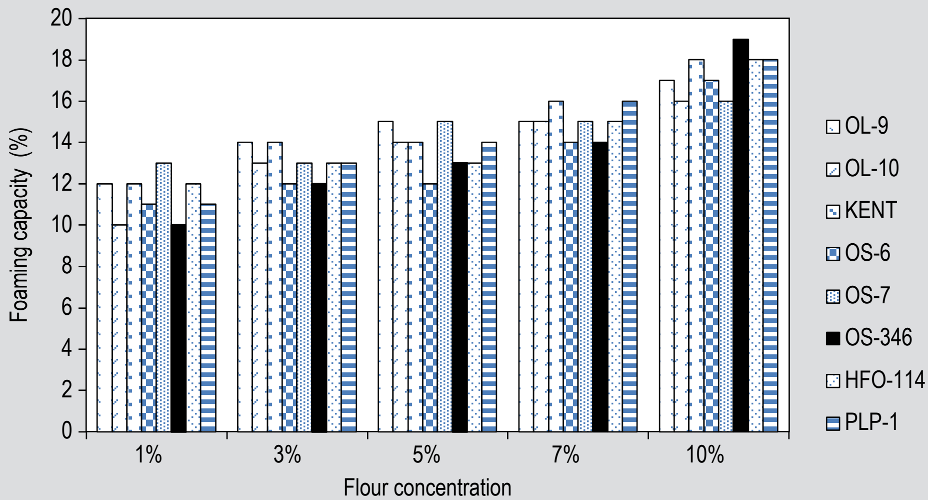

Figure 1. Effect of flour concentration on foaming capacity of flours from different oat cultivars.

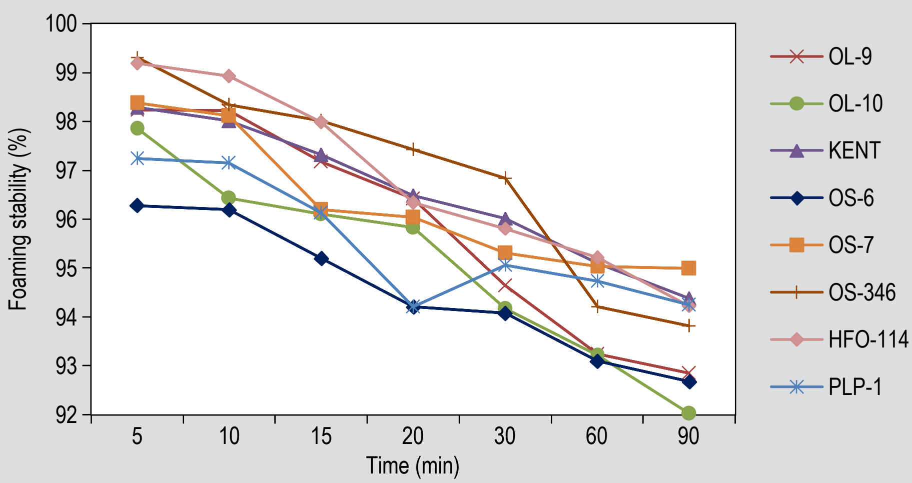

Figure 2. Effect of time on foam stability of flours from different oat cultivars.

flours ranged between 4.94-6.82% with highest value being observed for Kent cv. The value of AOA in the present study were in agreement with those reported earlier (6.3-10.2%) by Gujral *et al.* (2011) but lower (11.9-15.5%) than that observed by Sandhu *et al.* (2017). Reducing power is also an indicator of antioxidant activity. The reducing power of oat flour varied significantly (P<0.05) among the cultivars with the highest value being observed for OS-7 cv. (1,463 µg AAE/g). These values are lower (15.9-25.5 µmol AAE/g) than those observed by Gujral *et al.* (2011) for different oat cultivars. Metal chelating activity of the flour was found to be 21.27-33.93% varying significantly (P<0.05) among the cultivars. Metal chelating is another method to evaluate the antioxidant activity. The reaction of Fe^{2+} with ferrozine produces dark colour complex and on the action of metal chelating compound its concentration decreases (Gujral *et al.*, 2011). Metal chelating activity of OS-7 cv. was found to be highest whereas OL-10 cv. had the lowest value. Total phenolic content of flour from different oat cultivars varied significantly (P<0.05) from 1,688 to 2,016 µg GAE/g, lowest for OS-346 cv. and highest for Kent cv.

Pasting properties

Pasting characteristics plays an important role in the selection of a variety useful in industry as a thickener, binder or for any other use (Kaushal *et al.*, 2012). The results of pasting properties of flours from different oat cultivars are summarised in Table 4. The temperature at which viscosity begins to increase, PT provides an indication of the minimum temperature required to cook the flour was observed to vary significantly (P<0.05) among different oat cultivars. OL-9 cv. flour showed the highest PT of 93.2 °C in comparison to other cultivars which indicates the presence

Table 4. Antioxidant and pasting properties of flours from different oat cultivars.[1,2]

Cultivar	Antioxidant activity (%)	Reducing power (µg AAE/g)	Total phenolic content (µg GAE/g)	Metal chelating (%)	Peak viscosity (mPa)	Breakdown viscosity (mPa)	Trough viscosity (mPa)	Setback viscosity (mPa)	Final viscosity (mPa)	Pasting temperature (°C)
OL-9	6.35±0.06^{d}	1,422±3.21^{e}	1,964±5.13^{g}	29.27±0.04^{c}	561±11^{c}	60±5^{b}	501±28^{cd}	327±10^{d}	828±16^{d}	93.2±0.10^{c}
OL-10	6.11±0.03^{bc}	1,131±2.64^{a}	1,835±3.78^{e}	21.27±0.02^{a}	518±15^{b}	78±3^{c}	440±34^{bc}	251±9^{bc}	691±20^{b}	91.4±0.11^{b}
KENT	6.82±0.03^{e}	1,378±2.08^{d}	2,016±3.78^{h}	31.14±0.04^{d}	524±10^{bc}	61±2^{b}	463±33^{c}	281±11^{c}	744±22^{c}	90.8±0.14^{ab}
OS-6	5.91±0.03^{b}	1,275±4.58^{c}	1,863±3.21^{f}	25.01±0.02^{b}	517±12^{b}	63±2^{b}	454±16^{c}	236±14^{b}	690±13^{b}	90.2±0.13^{a}
OS-7	6.71±0.04^{de}	1,463±3.60^{f}	1,752±4.72^{b}	33.93±0.02^{f}	532±18^{bc}	94±3^{d}	438±19^{bc}	276±10^{c}	714±17^{bc}	92.6±0.11^{bc}
OS-346	4.94±0.03^{a}	1,298±2.64^{c}	1,688±4.04^{a}	32.17±0.02^{e}	510±14^{b}	80±4^{c}	430±30^{b}	257±8^{bc}	687±21^{b}	91.4±0.12^{b}
HFO-114	6.2±0.02^{c}	1,187±2.64^{b}	1,701±2.64^{ab}	30.84±0.02^{cd}	620±11^{d}	54±3^{ab}	566±32^{a}	373±13^{e}	939±29^{e}	92±0.10^{bc}
PLP-1	6.01±0.04^{b}	1,390±1.52^{de}	1,811±3.78^{d}	29.44±0.03^{c}	288±10^{a}	50±2^{a}	238±11^{a}	86±5^{a}	324±11^{a}	91.4±0.13^{b}

[1] Values are an average of triplicate observations (± standard deviation). Values followed by similar superscript letters in a column do not differ significantly (P<0.05).
[2] AAE = ascorbic acid equivalent; GAE = gallic acid equivalent.

of starch in it that is highly resistant to swelling and rupturing. Peak viscosity of the flours varied significantly (P<0.05) with highest value being shown by HFO-114 cv., thereby indicating presence of large size granules in HFO-114 cv. flour. Trough viscosity is found to be affected by the rate of granule swelling, amylose exudation and amylose-lipid complex formation (Kaushal *et al.*, 2012). TV of oat flours ranged from 238-566 mPa whereas Breakdown Viscosity varied significantly (P<0.05) among the flours ranging from 50 to 94 mPa. Highest BV value was found in OS-7 cv. and lowest in PLP-1 cv., suggesting that PLP-1 cv. could form the most stable hot paste than other oat cultivars. The influence in viscosity during heating cycle is influenced by amylose length, granular swelling, solubility and extent of friction between granules (Zhou *et al.*, 2000). Setback viscosity measures the stability of the paste after cooling. The SV value of the flours ranged from a low of 104 mPa (PLP-1 cv.) to a high of 324 mPa (OL-9 cv.) thereby indicating tendency of PLP-1 flour paste to retrograde. The lower tendencies to retrograde are advantageous in food products such as soups and sauces, which undergo loss of viscosity and precipitation. Final viscosity is used to determine the ability of the material to form a viscous paste which is influenced by the retrogradation of soluble amylose upon cooling (Kaushal *et al.*, 2012). FV was highest for flours from HFO-114 cv. (939 mPa) and was lowest for PLP-1 cv. (324 mPa).

Principal component analysis

Various physical, functional, antioxidant and pasting properties of flour were analysed by PCA to learn about differences and similarities between the samples. The results of PCA of oat flours are shown in Figure 3 and 4. The first and second principal component described 28.1% and 49.7% of the variance, respectively. Together the first two components represented 67.7% of the total variability. The loading plot of two principal components provided information about correlation between measured properties of different oat flours (Figure 3). Sphericity was positively correlated to ES (r=0.774, P<0.05) and negatively correlated to L/W ratio (r=-0.861, P<0.01). Seed weight showed a negative correlation to OAC (r=-0.834, P<0.01) and a positive correlation to surface area (r=0.882, P<0.01) whereas seed volume was negatively correlated to AOA (r=-0.759, P<0.05). Fat was positively correlated to PT (r=0.868, P<0.01) and negative to EA (r=-0.859, P<0.01). A significant positive correlation between WAC and OAC (r=0.776, P<0.05) and negative between WAC and L/W ratio (r=-0.707, P<0.05) were observed. TPC was negatively correlated to seed weight (r=-0.780, P<0.05) and positive to OAC (r=0.740, P<0.05). PV showed a highly significant correlation with FV (r=0.987, P<0.01), L* (r=0.710, P<0.05) and LGC (r=0.790, P<0.05). Hunter colour a* was negatively correlated to L* (r=-0.771, P<0.05), LGC (r=-0.696, P<0.05), PV (r=-0.969, P<0.01) and FV (r=-0.956, P<0.01). PCA showed that PLP-1 cv. was located at far right of score plot with a large positive score while Kent cv. was located at far left of score plot with a negative score in first principal component (Figure 4).

4. Conclusions

The study revealed flours from different oat cultivars differed significantly in their physical characteristics which influenced their functional, pasting and antioxidant

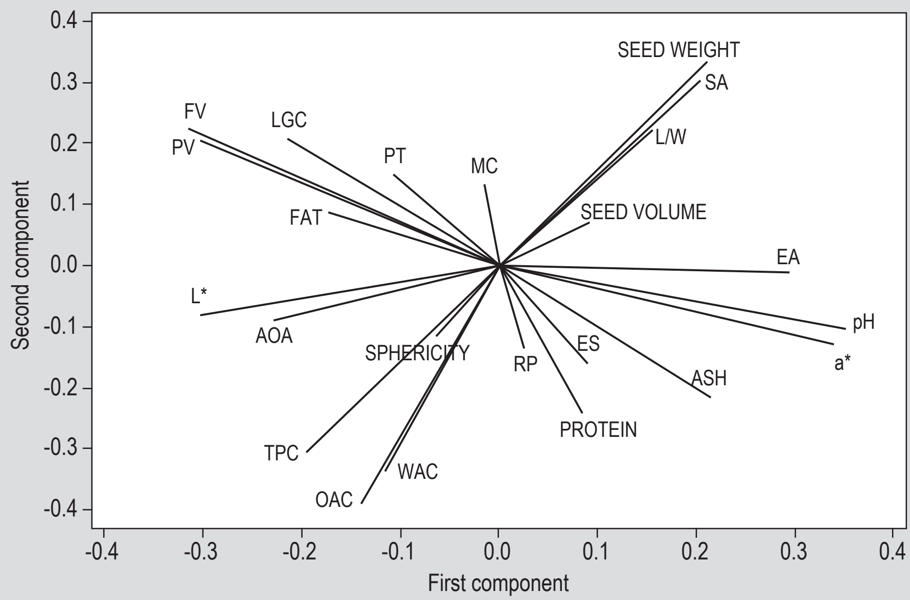

Figure 3. Principal component analysis: loading plot of PC1 and PC2 describing the variation among the physical, functional, antioxidant and pasting properties of flours from different oat cultivars (a* = redness and greenness; AOA = antioxidant activity; EA = emulsion activity; ES = emulsion stability; FV = final viscosity; L* = lightness; LGC = least gelation concentration; L/W = length to width ratio; MC = metal chelating activity; OAC = oil absorption capacity; PT = pasting temperature; PV = peak viscosity; RP = reducing power; SA = surface area; TPC = total phenolic content; WAC = water absorption capacity).

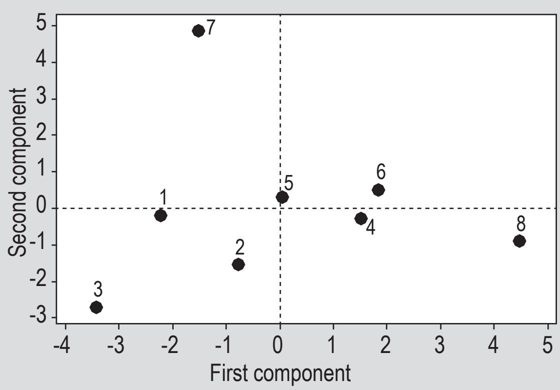

Figure 4. Principal component analysis: score plot of first principal component (PC1) and second principal component (PC2) describing the overall variation among the physical, functional, antioxidant and pasting properties of flours from different oat cultivars (1 = OL-9; 2 = OL-10; 3 = Kent; 4 = OL-6; 5 = OS-7; 6 = OS-346; 7 = HFO-114; 8 = PLP-1).

properties. PLP-1 cv. differed significantly ($P<0.05$) from other cultivars with respect to its colour, ash, fibre content, and bulk density and gelation capacity. Kent cv. showed higher values for AOA and TPC whereas OS-7 cv. showed higher reducing power and metal chelating activity. Pasting and antioxidant properties showed significant dependence on various grain physical parameters and functional properties. Kent and PLP-1 cultivars were different from all other cultivars in their measured properties as revealed by PCA

Conflict of interest

None.

References

Alrahmany, R. and Tsopmo, A., 2012. Role of carbohydrases on the release of reducing sugar, total phenolics and on antioxidant properties of oat bran. Food Chemistry 132: 413-418.

Association of Official Analytical Chemists International (AOAC), 1990. Official methods of analysis (15th Ed.). AOAC, Washington, DC, USA.

Aremu, M.O., Olaofe, O. and Akintayo, E.T., 2007. Functional properties of some Nigerian varieties of legume seed flours and flour concentration effect on foaming and gelation properties. Journal of Food Technology 5: 109-115.

Brand-Williams, W., Cuvelier, M.E. and Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. LWT – Food Science and Technology 28: 245-251.

Choi, O.K., Han, J., Chun, C.S., Kang, K.H., Kim, Y.K., Kim, Y.K., Cheong, T.I., Park, J.S. and Choi, K.J., 2012. Hydration and pasting properties of oat (*Avena sativa*) flour. Preventive Nutrition and Food Science 17: 87-91.

Decker, E.A., Rose, D.J. and Stewart, D., 2014. Processing of oats and the impact of processing operations on nutrition and health benefits. British Journal of Nutrition 112: 58-64.

Dinis, T.C., Maderia, V.M. and Almeida, L.M., 1994. Action of phenolic derivates (acetoaminophen, salycilate, and 5-aminosalycilate) as inhibitors of membrane lipid peroxidation and peroxylradicals scavengers. Archives of Biochemistry and Biophysics 315: 161-169.

Doehlert, D.C., Zhang, D., McMullen, M.S. and Moore, W.R., 1997. Estimation of mixed linkage beta-glucan concentration in oat and barley from viscosity of whole grain flour slurry. Crop Science 37: 235-238.

Doehlert, D.C., McMullen, M.S. and Jannink, J.L., 2006. Oat grain/groat size ratios: a physical basis for test weight. Cereal Chemistry 83: 114-118.

Elkhalifa, A.E.O. and Bernhardt, R., 2010. Influence of grain germination on functional properties of sorghum flour. Food Chemistry 121: 387-392.

Evers, T. and Millar, S., 2002. Cereal grain structure and development: some implications for quality. Journal of Cereal Science 36: 261-284.

Ganssmann, W. and Vorwerck. K., 1995. Oat milling, processing and storage. In: Welch, R.W. (ed.) The oat crop: production and utilisation. Chapman and Hall, London, UK, pp. 369-408.

Gao, L., Wang, S., Oomah, B.D. and Mazza, G., 2002. Wheat quality: antioxidant activity of wheat millstreams, in wheat quality elucidation. AACC International, St Paul, MN, USA, pp. 219-233.

Gharekhani, M., Kashanniejad, M., Garmakhany, A.D. and Ranjbari, A., 2013. Physical and aerodynamic properties of paddy and white rice as a function of moisture content. Quality Assurance and Safety of Crops & Foods 5: 187-197.

Gujral, H.S., Sharma, P. and Singh, R., 2011. Effect of sand roasting on β-glucan extractability, physicochemical and antioxidant properties of oats. LWT – Food Science and Technology 44: 2223-2230.

Hall, M.B. and Tarr, A.W., 2000. Oat starch quality and relationships to other quality traits. In: Cross, R.J. (ed.) In: Proceedings of the 6th International Oat Conference, November 13-16, 2000, Christchurch, New Zealand.

Huttner, E.K., Bello, F.D. and Arendt, E.K., 2010. Rheological properties and bread making performance of commercial wholegrain oat flours. Journal of Cereal Science 52: 65-71.

Jain, R.K. and Bal, S., 1997. Properties of pearl millet. Journal of Agricultural Engineering Research 66: 85-91.

Kaur, M. and Singh, N., 2005. Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. Food Chemistry 91: 403-411.

Kaushal, P., Kumar, V. and Sharma H.K., 2012. Comparative study of physicochemical, functional, antinutritional and pasting properties of taro (*Colocasia esculenta*), rice (*Oryza sativa*) flour, pigeonpea (*Cajanus cajan*) flour and their blends. LWT – Food Science and Technology 48: 59-68.

Kilci, A. and Gocmen, D., 2014. Phenolic acid composition, antioxidant activity and phenolic content of tarhana supplemented with oat flour. Food Chemistry 151: 547-553.

Lásztity, R., 1998. Oat grain – a wonderful reservoir of natural nutrients and biologically active substances. Food Reviews International 14: 99-119.

Lin, M.J.Y., Humbert, E.S. and Sosulski, F.W., 1974. Certain functional properties of sunflower meal products. Journal of Food Science 39: 368-370.

Liu, Y., Bailey, T.B. and White, P.J., 2010. Individual and interactional effects of β-glucan, starch and protein on pasting properties of oat flours. Journal of Agricultural and Food Chemistry 58: 9198-9203.

Mohsenin, N.N., 1986. Physical properties of plant and animal materials (2nd Ed.). Gordon and Breach Science Publishers, New York, NY, USA.

Naczk, M., Diosady, L.L. and Rubin, L.J., 1985. Functional properties of canola meals produced by a two-phase solvent extraction system. Journal of Food Science 50: 1685-1692.

Niba, L.L., Bokonga, M.M., Jackson, E.L., Schlimme, D.S. and Li, B.W., 2001. Physicochemical properties and starch granular characteristics of flour from various *Manihot esculenta* (cassava) genotypes. Journal of Food Science 67: 1701-1705.

Ozcan, M.M., Ozcan, G. and Topal, A., 2009. Characteristics of grains and oils of four different oats (*Avena sativa* L.) cultivars growing in Turkey. International Journal of Food Science and Nutrition 57(5-6): 345-352.

Peterson, D.M., 2001. Oat antioxidants. Journal of Cereal Science 33: 115-129.

Pietrzak, L.N. and Fulcher, R.G., 1994. Polymorphism of oat kernel size and shape in several Canadian oat cultivars. Canadian Journal of Plant Science 75: 105-109.

Sandhu, K.S., Godara, P., Kaur, M. and Punia, S., 2017. Effect of toasting on physical, functional and antioxidant properties of flour from oat (*Avena sativa L.*) cultivars. Journal of Saudi Society of Agricultural Sciences 16: 197-203.

Sathe, S.K. and Salunkhe, D.K., 1981. Functional properties of great northern bean proteins: emulsion, foaming, viscosity and gelation properties. Journal of Food Science 46: 71-75.

Sosulski, F.W., 1962. The centrifuge method for determining flour absorption in hard red spring wheat's. Cereal Chemistry 39: 344-350.

Verardo, V., Serea, C., Segal, R. and Caboni, M.F., 2011. Free and bound minor polar compounds in oats: different extraction methods and analytical determinations. Journal of Cereal Science 54: 211-217.

Yang, J., Ou, B., Wise, M.L. and Chu, Y., 2014. *In vitro* total antioxidant capacity and anti-inflammatory activity of three common oat-derived avenanthramides. Food Chemistry 160: 338-345.

Zhao, H., Fan, W., Dong, J., Lu, J., Chen, J., Shan, L., Lin, Y. and Kong, W., 2008. Evaluation of antioxidant activities and total phenolic contents of typical malting barley varieties. Food Chemistry 107: 296-304.

Zhou, M., Robards, K., Glennie-Holmes, M. and Helliwell, S., 2000. Effects of enzyme treatment and processing on pasting and thermal properties of oats. Journal of the Science of Food and Agriculture 80: 1486-1494.