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Assessment of oat (*Avena sativa*) varieties unveiled the variation in nutritional quality

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Oat (*Avena sativa* L.) stands as the sixth most cultivated crop globally, belonging to the Poaceae family. The worldwide production of oat is 25.13 million metric tonnes (USDA 2023) and Punjab, Haryana and some regions of western Uttar Pradesh are the top oat producing states in India. It is regarded as unique among cereals since it is the only one that possesses globulin protein called avenalin. Besides it, oat is an excellent source of phenolic compounds, unsaturated fatty acids, essential vitamins like (thiamine, biotin, folic acid, pantothenic acid), zinc, selenium, iron, copper, magnesium and manganese. It is an excellent source of different dietary fiber compounds like β-glucan, arabinoxylans and cellulose (Shah *et al.* 2016, Solanki *et al.* 2019, Syed *et al.* 2020). As oat grain has well balanced nutritional profile, it becomes popular among consumers. The shift in lifestyle choices towards healthier and lighter meals has led to an increased interest in exploring functional ingredients for oats (Mao *et al.* 2022). They are typically consumed in their whole grain form, thereby ensuring the retention of essential nutrients throughout processing.

Oats have emerged as a focal point of interest among scientific researchers and industries primarily attributed to their soluble fibre fraction i.e. β-glucan. This biologically active natural polysaccharide has garnered attention for its multifaceted health benefits, encompassing the prevention and regulation of obesity, diabetes, cancer, and various cardiovascular ailments (Maheshwari *et al.* 2019, Poonia *et al.* 2022). β-glucan also possesses immune-modulating effects, thus, serving as an adjuvant agent for solid and haematological malignancies, concerning immune-mediated conditions such as respiratory infections or allergic rhinitis, to enhance healing (Murphy *et al.* 2020). Consequently, food industries are engaged in the development of innovative food products by incorporating oats into formulations such as breakfast cereals, bread, beverages, and infant foods to improve the nutritional composition (Boukid *et al.* 2018).

Due to the critical significance of selecting optimal varieties tailored for food processing and various applications, the process of identifying characteristic genotypes assumes paramount importance. Therefore, the primary objective of the current investigation was to evaluate the physical, gravitational, nutritional, and functional parameters of 10 oat varieties. This comprehensive analysis seeks to elucidate the quality characteristics of these varieties and their inherent potential for β-glucan extraction, thereby providing valuable insights into their suitability for food applications.

The present study was carried out during 2022 at Punjab Agricultural University, Ludhiana, Punjab. 10 oat varieties, viz. namely, JHO 822; OL 12; OL 10; Kent; OL 14; OL 13; OL 15; OL 1876-2; OL 1882 and OL 1967-1 were obtained from Punjab Agricultural University, Ludhiana, Punjab. OL 1882 and OL 1967-1 represent elite cultivars while the remaining varieties are classified as released varieties. Grain samples underwent dehusking using an oat dehusker, followed by aspiration and manual removal of any extraneous material. The resultant product of this dehusking process is denoted as oat groats, representing the intact, husk-free oat grains. Subsequently, the grains were meticulously cleaned and ground into flour utilizing a Hammer mill (Avity Agrotech Private Limited, Vadodara, Gujarat). The resultant flour was then carefully packed and stored under refrigeration conditions. Prior to each analytical procedure, the requisite quantity of samples was withdrawn from refrigeration and allowed to equilibrate to ambient temperature for further analysis.

The 1000-grain weight was determined by randomly selecting and accurately weighing 250 grains of each oat variety using an electronic balance. The average weight per 1000-grains was calculated by multiplying the obtained weight of the sample by 4. For seed dimension assessment, a random sample of 100-seeds were chosen. The length, width, and thickness of each of the 50 grains were measured using a

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digital caliper with a precision of 0.01 mm. Geometric mean diameter (Dg), arithmetic mean diameter (Da), seed volume, surface area, and aspect ratio were computed following the formula outlined by Solanki *et al.* (2019). Bulk density and tap density were determined using the method prescribed by AACC (2002). True density was assessed using the toluene (C_7H_8) displacement method, while porosity was determined according to Solanki *et al.* (2019). Hydration capacity, hydration index, swelling capacity, swelling index, water absorption capacity (WAC), and oil absorption capacity (OAC) were evaluated as per the procedure outlined by Syed *et al.* (2020). Moisture, ash, crude protein, fat, and crude fiber content were estimated using standard methods of analysis (AOAC 2017). β-glucan content was determined using an enzymatic kit from Megazyme International Ireland Ltd. Total phenols and antioxidant activity, as assessed by free radical scavenging activity of oat flour, were determined using a modified method based on Ibrahim *et al.* (2020). Total flavonoid content analysis followed the procedure outlined by Nongalleima *et al.* (2017). Mean values, analysis of variance (ANOVA), and standard deviation were calculated using the SPSS 18.0 statistical package. Duncan's multiple range tests were employed to compare the data at a 5% level of significance.

Physical parameters of oat groats: The average values of physical parameters of the oat varieties i.e. OL 14, OL 10, OL 1967-1, OL 13, Kent, OL 12, OL 1876-2, OL 15, OL 1882 (Table 1). This dimensional information holds considerable utility in the design of grain handling machinery, particularly in determining aperture sizes (Oyedeji *et al.* 2021). Based on dimensional features of grain, OL 12 was the longest of all; breadth was found greater for OL 10 whereas thickness was highest for OL 1882. The dimensional parameters of different varieties varied significantly ($P \leq 0.05$). Consequently, according to length, width, and thickness, the 10 oat varieties can be distinguished.

The geometric mean diameter (Dg) ranged from 2.77–3.56 mm across the oat varieties, with the highest and lowest values observed for varieties OL 10 and OL 14, respectively. Dg serves as a crucial parameter for determining the projected area of seeds, which in turn elucidates their behaviour in near-turbulent or turbulent fluid flow conditions. This information holds particular relevance in pneumatic cleaning procedures, facilitating efficient seed air classification and the removal of undesirable components (Adubofuor *et al.* 2021). Similarly, the arithmetic mean diameter (Da) exhibited variations across the varieties, ranging from 3.73–4.49 mm. Both Dg and Da were found to vary significantly ($P \leq 0.05$) among the oat varieties. In terms of surface area, variety OL 10 demonstrated the highest surface area (39.73 mm^2), whereas variety OL 14 exhibited the lowest surface area (24.17 mm^2). Seed volume ranged from 6.23–13.97 mm^3, with variety OL 10 displaying the highest volume. These findings are consistent with previous studies conducted by Shah *et al.* (2016) and Hamdani *et al.* (2014). The observed variance in the physical parameters of oat varieties can be attributed to a combination of genetic and environmental factors (Chaudhary and Singh 2023).

The 1000-kernel weight exhibited variability among oat varieties, with OL 14 displaying the highest weight and OL 1876-2 demonstrating the lowest weight. The sphericity and aspect ratio are typically used to express the shape characteristics of a food material. Sphericity quantifies the degree to which the form of a solid deviates from that of a sphere with equivalent volume. Across all varieties, sphericity values ranged from 34.91–42.84%, indicating an elongated and less spherical seed, with OL 12 having the least sphericity. Similarly, the aspect ratio of the seeds varied among the oat varieties, with OL 1882 exhibiting the highest aspect ratio and OL 14 displaying the lowest. The aspect ratio demonstrates the shape of the seed by relating the breadth to the length of the seed **(**Martín-Gómez *et al.* 2022).

Gravimetrical parameters of oat groats: The porosity and density are significant factors that influence grain hardness, milling characteristics, susceptibility to breakage, milling and drying rate (Siaw *et al.* 2021). The gravimetrical parameters of different varieties are represented in Table 1. The bulk density and tap density ranged from 0.63–0.70 g/ml and 0.69–0.74 g/ml, respectively. The bulk density depends on the properties such as hygroscopicity and it increases with particle size due to the more compact orientation of finer particles compared to coarser ones (Moon *et al.* 2018). On the other hand, true density exhibited a range of 1.18–1.44 g/ml, the highest and lowest being observed for varieties OL 13 (1.44 g/ml) and OL 14 (1.18 g/ml), respectively. OL 15 demonstrated the highest porosity (53.38%), whereas the lowest porosity was observed in OL 14 (41.61%).

Functional parameters of oat groats: Hydration capacity ranged from 0.16–0.26 g/seed, with OL 1876-2 displaying the highest hydration capacity and OL 1882 exhibiting the lowest. The hydration index varied significantly ($P \leq 0.05$) among all 10 varieties. In case of the hydration index, variety OL 1876-2 had a higher hydration index i.e. 9.04 and cultivar OL 1882 had the lowest i.e. 6.75. Among the 10 oat varieties, OL 1876-2 showed maximum swelling capacity as well as swelling index, whereas minimum swelling capacity and index were observed in JHO 822 and OL 1882, respectively (Table 1). Similar findings regarding functional properties had also been reported previously by Mehta (2018).

Nutritional composition of oat flour: The moisture content of oat varieties ranged from 10.45–13.27%, the highest being observed for cultivar OL 1967-1 (13.27%) and the lowest for variety OL 10 (10.45%) (Table 2). The ash content varied from 1.70–1.92% and a non-significant difference was observed in varieties OL 12 and OL 1876-2. Crude fat content was found to be lowest in OL 12 (4.57%) and highest in OL 15 (5.99%). Furthermore, the crude protein content ranged between 6.53–8.94% across the oat varieties. The crude fiber content was highest in OL 10 and β-glucan was highest in OL 1876-2. The values of moisture, fat,

Table 1 Physical, gravitational and functional properties of oat groats

Parameter	OL 14	OL 10	OL 1967-1	JHO 822	OL 13	Kent	OL 12	OL 1876-2	OL 15	OL 1882
1000-Kernel weight (g)	27.94^{a} ± 0.11	24.04^{d} ± 0.55	27.57^{ab} ± 0.18	25.00^{cd} ± 0.01	26.24^{abc} ± 0.03	25.92^{bc} ± 0.06	24.90^{cd} ± 0.28	21.76^{e} ± 0.07	27.23^{ab} ± 0.05	27.40^{a} ± 0.09
Length (mm)	7.91^{j} ± 0.04	8.72^{d} ± 0.04	8.99^{b} ± 0.06	8.64^{e} ± 0.11	8.39^{f} ± 0.02	8.02^{i} ± 0.07	9.43^{a} ± 0.05	8.19^{g} ± 0.04	8.75^{c} ± 0.05	8.12^{h} ± 0.06
Breadth (mm)	1.63^{h} ± 0.04	2.74^{a} ± 0.02	2.03^{g} ± 0.05	2.48^{e} ± 0.05	2.54^{c} ± 0.03	2.52^{d} ± 0.05	2.54^{c} ± 0.01	2.43^{f} ± 0.04	2.57^{b} ± 0.03	2.72^{a} ± 0.03
Length/Breadth	4.85^{a} ± 0.12	3.18^{h} ± 0.04	4.44^{b} ± 0.14	3.49^{d} ± 0.04	3.30^{g} ± 0.04	3.18^{h} ± 0.07	3.71^{c} ± 0.03	3.37^{f} ± 0.05	3.40^{e} ± 0.02	2.99^{i} ± 0.03
Thickness (mm)	1.66^{f} ± 0.04	1.88^{b} ± 0.06	1.75^{d} ± 0.03	1.64^{g} ± 0.06	1.76^{d} ± 0.04	1.73^{e} ± 0.05	1.49^{h} ± 0.02	1.83^{c} ± 0.01	1.75^{d} ± 0.02	1.91^{a} ± 0.08
D_g (mm)	2.77^{h} ± 0.02	3.56^{a} ± 0.03	3.17^{g} ± 0.04	3.27^{f} ± 0.01	3.35^{d} ± 0.04	3.27^{f} ± 0.01	3.29^{ef} ± 0.01	3.31^{e} ± 0.03	3.40^{c} ± 0.01	3.48^{b} ± 0.06
Surface area (mm^2)	24.17^{f} ± 0.06	39.73^{a} ± 0.77	31.54^{e} ± 0.78	33.61^{d} ± 0.12	35.20^{cd} ± 0.82	33.63^{d} ± 0.31	34.02^{d} ± 0.28	34.48^{d} ± 0.59	36.41^{bc} ± 0.23	37.99^{b} ± 1.40
D_a (mm)	3.73^{g} ± 0.01	4.45^{b} ± 0.03	4.25^{d} ± 0.01	4.25^{d} ± 0.03	4.23^{d} ± 0.03	4.09^{f} ± 0.01	4.49^{a} ± 0.02	4.15^{e} ± 0.03	4.36^{c} ± 0.02	4.25^{d} ± 0.05
Seed volume (mm^3)	6.23^{d} ± 0.03	13.97^{a} ± 0.38	9.39^{c} ± 0.38	10.69^{bc} ± 0.07	11.57^{abc} ± 0.42	10.88^{bc} ± 0.18	10.79^{bc} ± 0.13	11.18^{abc} ± 0.31	12.11^{abc} ± 0.12	13.23^{ab} ± 0.75
Sphericity (%)	35.08^{de} ± 0.19	40.80^{ab} ± 0.24	35.26^{de} ± 0.63	37.87^{cd} ± 0.49	39.88^{bc} ± 0.37	40.80^{ab} ± 0.54	34.91^{f} ± 0.20	40.46^{abc} ± 0.23	38.92^{bc} ± 0.11	42.84^{a} ± 0.62
Aspect ratio	20.62^{d} ± 0.52	31.43^{ab} ± 0.36	22.55^{d} ± 0.70	28.67^{bc} ± 0.30	30.30^{b} ± 0.34	31.42^{ab} ± 0.72	26.98^{c} ± 0.18	29.64^{bc} ± 0.40	29.42^{bc} ± 0.17	33.47^{a} ± 0.37
Bulk density (g/ml)	0.69^{ab} ± 0.03	0.66^{abc} ± 0.01	0.63^{bc} ± 0.06	0.67^{abc} ± 0.05	0.62^{c} ± 0.04	0.68^{abc} ± 0.01	0.64^{abc} ± 0.04	0.65^{abc} ± 0.01	0.66^{abc} ± 0.05	0.70^{a} ± 0.07
Tap density (g/ml)	0.73^{ab} ± 0.01	0.69^{c} ± 0.01	0.72^{b} ± 0.07	0.70^{c} ± 0.05	0.70^{c} ± 0.03	0.74^{a} ± 0.02	0.72^{b} ± 0.04	0.72^{b} ± 0.04	0.72^{b} ± 0.07	0.74^{a} ± 0.06
True density (g/ml)	1.18^{d} ± 0.02	1.26^{c} ± 0.01	1.25^{c} ± 0.01	1.25^{c} ± 0.06	1.44^{a} ± 0.04	1.25^{c} ± 0.08	1.25^{c} ± 0.02	1.25^{c} ± 0.04	1.42^{b} ± 0.03	1.43^{ab} ± 0.01
Porosity (%)	41.61^{f} ± 0.01	47.62^{d} ± 0.02	49.44^{cd} ± 0.05	53.47^{a} ± 0.12	50.80^{bc} ± 0.07	45.60^{e} ± 0.03	49.12^{cd} ± 0.02	48.00^{d} ± 0.01	53.38^{a} ± 0.10	51.33^{ab} ± 0.08
Hydration capacity (g/seed)	0.18^{c} ± 0.03	0.25^{a} ± 0.01	0.22^{b} ± 0.04	0.21^{b} ± 0.08	0.21^{b} ± 0.08	0.18^{c} ± 0.12	0.19^{c} ± 0.12	0.26^{a} ± 0.12	0.22^{b} ± 0.01	0.16^{d} ± 0.14
Hydration index	6.85^{i} ± 0.05	8.98^{b} ± 0.04	8.14^{c} ± 0.07	7.99^{e} ± 0.12	8.02^{d} ± 0.08	6.99^{h} ± 0.04	7.01^{g} ± 0.14	9.04^{a} ± 0.12	7.96^{f} ± 0.15	6.75^{j} ± 0.05
Swelling capacity (ml/seed)	0.08^{cd} ± 0.01	0.10^{ab} ± 0.18	0.09^{bc} ± 0.02	0.08^{cd} ± 0.03	0.08^{cd} ± 0.14	0.09^{bc} ± 0.09	0.08^{cd} ± 0.05	0.11^{a} ± 0.04	0.10^{ab} ± 0.05	0.07^{d} ± 0.12
Swelling index	2.94^{c} ± 0.13	3.58^{ab} ± 0.14	3.47^{ab} ± 0.11	2.84^{c} ± 0.07	2.89^{c} ± 0.15	3.29^{b} ± 0.04	2.82^{c} ± 0.07	3.69^{a} ± 0.12	2.87^{c} ± 0.03	2.72^{d} ± 0.10

Values are expressed as means of three replications ± standard deviation. Values with different letters in superscript differ significantly within a row ($P \leq 0.05$). D_g, Geometric mean diameter; D_a, Arithmetic mean diameter.

protein and crude fiber were found significantly ($P \leq 0.05$) different among all 10 varieties. The findings of nutritional composition were quite similar to those reported by Ibrahim *et al.* (2020) and Suzauddula *et al.* (2021).

Bioactive parameters of oat flour: Total phenolic contents across the ten oat varieties ranged from 1.29–2.62 mg GAE/g, with the highest and lowest values being observed for variety OL 1876-2 and cultivar OL 1882, respectively. The antioxidant activity exhibited a range of 6.99–18.44% DPPH radical scavenging activity. Total phenolic contents and antioxidant activity among varieties differed significantly ($P \leq 0.05$). Total flavonoid content varied between 8.46–13.75 mg QE/g and was a significant ($P \leq 0.05$) difference among the varieties (Table 2). The results are in concordance with the findings of Ibrahim *et al.* (2020).

Functional parameters of oat flour: WAC and OAC play pivotal roles in determining the functioning of flour (Singh *et*

Table 2 Nutritional composition, bioactive and functional properties of oat flour

Parameter	OL 14	OL 10	OL 1967-1	JHO 822	OL 13	Kent	OL 12	OL 1876-2	OL 15	OL 1882
Moisture (%)	11.93^{e} ± 0.45	10.45^{i} ± 0.23	13.27^{a} ± 0.28	12.35^{c} ± 0.11	11.20^{h} ± 0.45	11.48^{g} ± 0.38	12.19^{d} ± 0.38	11.64^{f} ± 0.08	12.6^{b} ± 1.9	12.2^{d} ± 0.15
Ash (%)	1.87^{c} ± 0.01	1.92^{a} ± 0.12	1.89^{b} ± 0.07	1.83^{d} ± 0.16	1.9^{b} ± 0.08	1.77^{g} ± 0.10	1.81^{ef} ± 0.10	1.81^{ef} ± 0.05	1.80^{f} ± 0.06	1.82^{de} ± 0.11
Fat (%)	5.35^{e} ± 0.05	5.15^{h} ± 0.01	5.18^{g} ± 0.03	5.23^{f} ± 0.14	4.65^{i} ± 0.02	5.45^{d} ± 0.04	4.57^{j} ± 0.04	5.54^{c} ± 0.01	5.99^{a} ± 0.07	5.61^{b} ± 0.08
Protein (%)	6.99^{g} ± 0.04	8.94^{a} ± 0.02	7.56^{f} ± 0.10	6.75^{i} ± 0.12	6.94^{h} ± 0.31	7.98^{e} ± 0.01	6.53^{j} ± 0.11	8.59^{c} ± 0.02	8.78^{b} ± 0.04	8.37^{d} ± 0.03
Crude fiber (%)	7.58^{f} ± 0.06	9.30^{a} ± 0.04	7.77^{d} ± 0.12	6.34^{i} ± 0.01	7.13^{f} ± 0.05	8.46^{b} ± 0.12	7.63^{e} ± 0.08	6.83^{h} ± 0.02	6.94^{g} ± 0.06	8.34^{c} ± 0.12
β-glucan (g/100 g)	4.40^{d} ± 0.10	4.97^{b} ± 0.11	4.43^{d} ± 0.05	4.80^{bc} ± 0.02	3.35^{e} ± 0.05	4.62^{cd} ± 0.04	3.34^{e} ± 0.02	5.42^{a} ± 0.13	4.45^{d} ± 0.11	3.83^{e} ± 0.06
Total phenolics (mg GAE/g)	1.75^{d} ± 0.11	2.56^{b} ± 0.11	1.58^{e} ± 0.02	1.51^{g} ± 0.13	1.48^{h} ± 0.08	1.35^{i} ± 0.01	1.53^{f} ± 0.11	2.62^{a} ± 0.13	1.82^{c} ± 0.02	1.29^{j} ± 0.03
Antioxidant activity (Per cent DPPH radical scavenging activity)	9.94^{d} ± 0.02	15.94^{b} ± 0.04	8.55^{e} ± 0.01	8.04^{g} ± 0.01	7.28^{h} ± 0.01	7.04^{i} ± 0.01	8.18^{f} ± 0.01	18.44^{a} ± 0.02	10.04^{c} ± 0.01	6.99^{j} ± 0.012
Total flavonoids (mg QE/g)	9.90^{e} ± 0.04	13.75^{a} ± 0.04	8.75^{i} ± 0.12	11.47^{d} ± 0.45	9.63^{f} ± 0.07	8.89^{h} ± 0.04	11.49^{c} ± 0.02	12.08^{b} ± 0.02	8.99^{g} ± 0.25	8.46^{j} ± 0.14
Water absorption capacity (g/g)	1.65^{e} ± 0.02	1.79^{b} ± 0.05	1.69^{d} ± 0.01	1.66^{e} ± 0.04	1.68^{d} ± 0.04	1.63^{f} ± 0.05	1.66^{e} ± 0.01	1.81^{a} ± 0.16	1.72^{c} ± 0.07	1.61^{g} ± 0.05
Oil absorption capacity (g/g)	1.93^{ef} ± 0.01	2.05^{a} ± 0.01	2.01^{b} ± 0.02	1.92^{f} ± 0.05	1.94^{e} ± 0.03	1.98^{cd} ± 0.05	1.92^{f} ± 0.01	1.99^{c} ± 0.04	2.02^{b} ± 0.08	1.97^{d} ± 0.04

Values are expressed as means of three replications ± standard deviation. Values with different letters in superscript differ significantly within a row ($P \leq 0.05$); GAE, Gallic acid equivalent; DPPH, 2,2-diphenyl-1-picryl-hydrazyl; QE, Quercertin.

al. 2018). WAC reflects the flour's ability to form chemical bonds with water under limited water supply conditions, thus influencing product characteristics, cooking properties, and staling. Conversely, OAC represents a physical mechanism wherein capillary action is utilized to physically capture oil, contributing significantly to flavour retention and mouth-feel in dishes (Shah *et al.* 2016). WAC ranged from 1.61–1.81 g/g with variety OL 1876-2 exhibiting the highest and OL 1882 displaying the lowest values. OAC was found highest (2.05 g/g) for variety OL 10 and lowest (1.92 g/g) in variety JHO 822 and OL 12. OAC ranged from 1.92–2.05 g/g among all the 10 oat varieties. WAC was found to vary significantly ($P \leq 0.05$) except between the two oats varieties (JHO 822 and OL 12) where it varied non-significantly (Table 2). A significant ($P \leq 0.05$) difference was observed in OAC. The results of functional properties are similar to the findings of Ibrahim *et al.* (2020).

SUMMARY

The present study was carried out during 2022 at Punjab Agricultural University, Ludhiana, Punjab designed for the exploration and characterization of different oat varieties to understand their potential for physical, gravitational, functional, nutritional, and extraction of β-glucan parameters. All studied varieties showed variability in the grain and flour quality of oats. The preference of a variety based on nutritional and functional parameters contingent on this evaluation could help a satisfactory basis for future oat crop improvement plans for feed and food security. The current scientific intervention suggests that oat variety OL 1876-2 might be a suitable choice for β-glucan extraction due to its high content with promising nutritional and functional benefits. These findings may open a new avenue for further research on utilization of oats for food purpose that could cater the imminent demands of health conscious people.

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