DETERMINATION OF PHYSICAL PROPERTIES, MOISTURE ABSORPTION PROCESS AND AERODYNAMIC PROPERTIES OF GRAIN AND CLUSTER STRAW OF TWO WHEAT CULTIVARS

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Abstract

In this study, physical properties of grain and cluster straw including geometric dimensions, moisture absorption and aerodynamic properties of two wheat cultivars were investigated. The effect of cultivar on width, thickness, geometric diameter, spheroid coefficient and mass density was significant at 1% probability level whilst there were no significant effect on grain projected area, length and weight. Moisture absorption of the grains was rapid during the first 30–40 min and then turned to zero. The terminal velocity of wheat grain and straw in three shapes was measured by calculating the projected area in horizontal, lateral and perpendicular directions and then, the drag coefficient was obtained by the equilibrium of the gravity and drag forces at the terminal velocity. Results also showed that increasing moisture content resulted in an increase in the terminal velocity and a decrease in the drag coefficient. Results obtained in this study can be used in designing wheat-cluster straw separation and processing.

Keywords: wheat grain, cluster straw, terminal velocity, drag coefficient

INTRODUCTION

The importance of determining physical properties of agricultural products is essential in the design of processing machines for post harvesting and food systems (Mohsenin, 1986). These properties are especially important in production of cereals such as wheat and barley in order to design of planting and harvesting machineries as well as transportation and processing (Baryeh, 2002). Kalkan and Kara (2011) have measured the length, width, thickness, mean geometric diameter, spheroid weight, 1000-seed weight and dynamic friction coefficient of five wheat cultivars as a function of moisture to optimize the different planting, harvesting and post harvesting processes, as well as to reduce the losses and increase the quality of wheat grains. For agricultural products, quality is defined by the degree of products' desirability which depends on physical, mechanical and chemical properties of products along with their storage time. The proper characteristics can be divided into two groups: apparent properties such as size, shape and external defects, and internal factors such as acidity, amount of herb sap, rigidity and internal fractures (Soltani *et al.*, 2011).

One of the new methods for seed separating from impurities is the use of electrostatic separators. In these methods, the grains that cannot be separated

by other common methods, are disassociated from other materials based on their electrical properties (Sarmadnia, 1997). Physical and aerodynamic characteristics of the particles are the factors that determine the performance of an electrostatic separator.

The particles' drag coefficient and terminal velocity are of the most important aerodynamic and hydrodynamic characteristics which influence gravity acceleration and fluid flow around them. Terminal velocity is an important factor in separating processes of seeds from straw material and Materials other than Grain (MOG) (Rabbani, 2002; Tabatabaeefar, 2003). This is important for determining the terminal velocity in the separation of grain particles and is therefore an effective factor in designing agricultural machines (Mohsenin, 1986).

The drag coefficient used to determine drag force is actually a factor that acts on a moving particle in the air and depends on the particle's properties such as mass, surface area, shape, and terminal velocity. The projected area and the drag coefficient in agricultural products, consistently change during pass through a separating system (Gursoy and Guzel, 2010). In most studies, the projected area of a particle is usually calculated based on its mean geometric diameter (Gorial and O'Callaghan, 1990; Khoshtaghaza and Mahdizadeh, 2006). Zewdu (2007) measured the grain drag coefficient and the straw resistance coefficient resulting from the multiplication of the drag coefficient and the projected area of the particle at the terminal velocity. In evaluating the effects of moisture on the terminal velocity of chopping forage using wind tunnel method, Hemmat *et al.* (2007) reported that the terminal velocity values were 1.7, 7.3 and 7.8 m/s at three moisture content levels of 40–50, 50–60 and 60–70%, respectively. They stated that only the shape of crushed forage particles has a significant effect on the terminal velocity.

A literature review reveals the lack of data on the wheat-related properties which are effective in design and development of grain separation machines. The aim of this study was to investigate physical properties of grain and cluster straw including geometric dimensions, moisture absorption and aerodynamic properties of two wheat cultivars.

MATERIALS AND METHODS

Sample Preparation and Applying of Moisture Levels

The clusters of Chamran 2 (Cham) and Mehregan (Mehr) wheat cultivars were obtained from the Research Farmland of Lorestan Agricultural Research Center and were then manually separated from the straw. Dry basis moisture content ($MC_{db.}$) of grain and straw were measured for each of cultivars in five replications using an oven. For increasing the $MC_{db.}$ each grain sample was kept soaked separately for 5 to 25 min in distilled water at 25 °C to study its effects on their properties (Khoshtaghaza and Mehdizadeh, 2006). Afterwards, apparent moisture was removed from the external surfaces and the samples were immediately weighed. Finally, they were placed in a hot oven at 104 °C for 72 h (ASABE, 2006).

Geometry Properties

A total of 100 grains and 20 straw particles in four levels of chaff, rachis, cluster awn and stem were selected randomly from each cultivar. Their three-axis dimensions including length (D_L), width (D_W) and thickness (t) were measured using a micrometer with 0.01 mm accuracy. The mean geometric diameter (D_{gm}) and spherical coefficient (φ) were calculated using the Eqs. (1) and (2), respectively (Mohsenin, 1986).

$$D_{gm} = (D_L D_W t)^{\frac{1}{3}} \tag{1}$$

$$\varphi = \frac{D_{gm}}{D_l} \tag{2}$$

According to the elliptic form of the wheat grains, their surface area (S) was calculated using the Eq. (3) (Jia *et al.*, 2008):

$$S = 2\pi a^2 (1 + FG), \tag{3}$$

where

$$F = \frac{A}{\left(2\sqrt{A-1}\right)}, \tag{4}$$

$$A = \frac{c^2}{a^2}, \tag{5}$$

$$G = \frac{\pi}{2} + \arcsin\left(\frac{A-2}{A}\right), \tag{6}$$

where *a* and *c* are the lateral and longitudinal radius of the particles, respectively. Surface area of the chaff was calculated using Eq. (3). The surface area of the rachis-straw stems was calculated by considering the particle as a rectangular cube. Finally, the cluster awn was considered as a cylinder in its dimensions.

Gravity Properties

A number of 1,000 handcrafted and cleaned grains from each cultivar were separately collected and weighed using a digital scale (SATTORIUS, with 0.0001.g accuracy). In order to measure the apparent density of the wheat mass, the samples were poured into a cylindrical vessel with a volume (V_b) of 0.1 L. By weighing the total mass of the container, the mass weight (m_b) was obtained by calculating the weight difference between the empty and filled container. According to Eq. (7),

the volume density (ρ_b) of the material (wheat and straw) was obtained by dividing the mass weight by the mass volume (Mohsenin, 1986).

$$\rho_b = \frac{M}{V_b} \qquad (7)$$

To measure the particle density, 100 grains of wheat were first weighed (M_r) and then poured into a calibrated burette containing 50 ml toluene (Nalbandi *et al.*, 2010; Unal *et al.*, 2006). The volume of the sample (V_r) was measured by rising the volume of the toluene. According to Eq. (8), the ratio of the mass (M_r) to the volume of wheat (V_r) was equal to the particle density (ρ_p) (Mohsenin, 1986).

$$\rho_p = \frac{M}{V_r} \qquad (8)$$

The density of straw particles was obtained by adding water to a certain mass of straw (V_{bulk}) until its flotation. The difference in total volume and replaced water determined the volume of the straw particles (Mohsenin, 1986).

Porosity percentage (*e*) is defined by dividing the volume of empty space between the particles to the total volume (Eq. 9).

$$e = (1 - \frac{V_r}{V_b}) \times 100 \approx (1 - \frac{\rho_p}{\rho_s}) \times 100 \qquad (9)$$

Determination of Initial $MC_{d.b.}$ of Grain and Straw

The $MC_{d.b.}$ of the samples was measured in accordance with ASABE Standard (ASABE, 2006). Using Eq. (10) at 20 °C:

$$\%MC_{d.b.} = \frac{(w_i - w_d)}{w_d} \times 100, \qquad (10)$$

where w_i is the weight after applying moisture (initial weight) and w_d is the weight of the dried samples in the oven. The $MC_{d.b.}$ for grains and straw were 10.6% and 8.3% in Cham, and 11.1% and 8.7% in Mehr cultivars. The weighed samples were then placed in immersion water for 1 to 135 min to study their moisture absorption behavior over time.

Particle Surface and Aerodynamic Properties

The separation of the wheat grains and straw in a harvesting process is based on their gravity, aerodynamic dimensions and atmospheric properties. These properties are used to separate seeds from other impurities (Nalbandi *et al.*, 2010). The experimental method for determining the terminal velocity of agricultural products that do not have a geometric shape is more preferred than calculation method (Zewdu, 2007). For experimental measurement of the terminal velocity, the particles were placed at the center of the cross-section of a vertical wind tunnel. Increasing the airflow in this tunnel continued until the particles were suspended. The wind velocity was adjusted by varying the fan velocity through a frequency inverter and a diaphragm mounted to the system. At a time when the particle had the lowest spin, the wind velocity was measured by a hot wire with 0.1 m/s accuracy. This experiment was carried out at two moisture content levels with four replications for each cultivar. The density of air was considered to be 1.206 kg/m³ (Shahbazi *et al.*, 2014).

When a suspended particle is at terminal velocity (V_t), the particle weight (F_g) is equal to the upward drag force (F_d) and therefore, the velocity of the airflow in the wind tunnel equals to the suspended particle velocity. By placing the weight force instead of the drag force, the terminal velocity can be obtained using Eq. (11) (Mohsenin, 1986):

$$V_t = \sqrt{\frac{2Mg(\rho_p - \rho_f)}{r_p \rho_f A_p C_d}}, \qquad (11)$$

where A_p is the projected area of the particle (m²), C_d is the drag coefficient (dimensionless), *g* is gravity acceleration (m/s²), *M* is particle mass (kg), V_t is terminal velocity (m/s),ρ_f = 1.29 kg/m³ and ρ_p is the air and particles' densities, respectively (kg/m³). C_d can be calculated using Eq. (12).

$$C_d = \frac{2mg(\rho_p - \rho_f)}{\rho_p \rho_f A_p V_t^2} \qquad (12)$$

$$A_p = \frac{\rho}{4} D_l D_w \qquad (13)$$
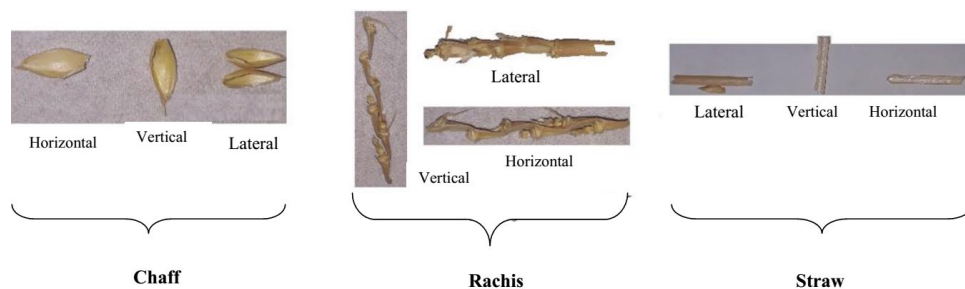
1: *The shape and position of cluster straw in falling*

where D_l and D_w are the length and width of the particle (m), respectively (Fig. 1). As the projected areas of grains and straw may vary due to their irregular geometric shape and their position in airflow, the drag coefficient of grain and straw was calculated according to the projected area in their different positions.

Statistical Analyses

Means and standard deviations obtained in the experiments along with nonlinear regression models were calculated in Excel 2017 software environment. Analysis of variance and means comparison were performed using SAS (Ver. 9.1).

RESULTS AND DISCUSSION

Geometric Dimensions

Tab. I shows the mean and standard deviation of geometric dimensions of the wheat grain and straw. According to the results, the length, width, thickness, and mean geometric diameter of Cham cultivar were 6.6, 2.1, 3.6, and 4.0 mm, respectively. For Mehr cultivar, these parameters were 6.6, 2.5, 3.3, and 3.8 mm, respectively. These values for MOG including straw and rachis and cluster awn had more variations in the range of less than 1 mm to 30 mm. The sphericity coefficient of grain, chaff

and straw for Cham and Mehr cultivars were 61, 19.8, 32.1, 57.5, 28.3 and 29.1%, respectively, and for rachis and cluster awn in both cultivars were measured approximately 21 and 9%, respectively. The total volume and surface area were 45.5 mm³ and 63.9 mm², in Cham cultivar and 37.3 mm³ and 59.0 mm² in Mehr cultivar. The apparent density for grains and straw were 852.3 and 55.1 kg/m³ in Cham, and 858.4 and 60.66 kg/m³ in Mehr cultivar. The particle density was 1290 and 97 kg/m³ in Cham, and 1200 and 110 kg/m³ in Mehr cultivar. The porosity of these particles was 25 and 40% in Cham, and 22 and 39% in Mehr. The 1000-grain weight of Cham and Mehr cultivars were measured 49.7 and 48.9 g, respectively (Tab. II).

Moisture Contents

The average values of moisture contents for the two wheat cultivars at different moisture saturation periods are shown in Tab. III. The $MC_{db.}$ was calculated at seven levels of moisture saturation times equal to 1, 15, 45, 75, 105, 120 and 135 min (Fig. 2). Regression models for moisture absorption versus time in wheat grains and straw of the two cultivars are shown in this figure.

In these equations, there is an acceptable correlation between the water absorption of grain and straw mass and their soaking period. According to Fig. 2, the increase in moisture content reduced

I: *Mean of dimensions, geometric diameter and spherical coefficient of grain and straw of wheat cultivars in common moisture. Data for length, width, thickness, equivalent diameter, and spherical coefficient are shown as mean values ± standard deviations.*

Particles	Length (mm)	Width (mm)	Thickness (mm)	Mean geometric diameter (mm)	Spherical coefficient (%)	Volume (mm³)	Surface area (mm²)
Cham grain	6.61 ± 0.5	2.1 ± .3	3.55 ± 0.2	4.04 ± 0.3	61 ± 1.6	45.5	63.9
Mehr grain	6.56 ± 0.6	2.48 ± 0.3	3.29 ± 0.3	3.77 ± 0.3	57.45 ± 0.9	37.3	59.0
Cham chaff	9.1 ± 0.3	3.02 ± 0.1	0.87 ± 0.2	4.16 ± 0.6	19.84 ± 11.5	31.2	68.21
Mehr chaff	8.6 ± 0.7	3.12 ± 0.3	0.87 ± 0.2	3.84 ± 0.7	28.26 ± 10.7	28.4	63.5
Cham rachis	21.6 ± 3.7	3.36 ± 2.3	1.42 ± 0.2	4.69 ± 1.0	21.7 ± 8.2	101.0	142.2
Mehr rachis	21.3 ± 2.8	3.33 ± 1.6	1.35 ± 0.2	4.54 ± 1.3	21.13 ± 7.8	93.3	139.8
Cham awn	29.1 ± 4.2	0.75 ± 0.4	0.85 ± .02	2.64 ± 1.9	9.07 ± 6.9	18.9	73.3
Mehr awn	24.7 ± 3.6	0.73 ± 0.3	0.72 ± 0.1	2.38 ± 1.5	9.63 ± 10.1	13.3	56.1
Cham straw	12.6 ± 2.3	4.46 ± 1.8	1.18 ± 0.2	4.04 ± 1.0	32.06 ± 15.4	64.0	918
Mehr straw	14.6 ± 2.8	4.28 ± 1.2	1.23 ± 0.2	4.24 ± 1.2	29.06 ± 14.7	73.7	104.6

II: *Apparent density, particle density, porosity and 1000-grain weight of grain and straw of wheat cultivars. Data are shown as mean values ± standard deviations.*

Particle	Apparent density (kg/m³)	Particle density (kg/m³)	Porosity	1000-grain weight (g)
Cham grain	852.3 ± 1.3	1290.4 ± 42.2	25.05 ± 0.02	49.7 ± 0.1
Mehr grain	858.4 ± 1.6	1200.5 ± 22.4	22.09 ± 0.06	48.9 ± 0.1
Cham straw	55.1 ± 9.3	97.2 ± 10.5	40.02 ± 0.20	-
Mehr straw	60.67 ± 9.3	101.1 ± 10.6	39.22 ± 0.30	-

III: *The moisture absorption values of the particles with their establishment in saturated state at different times*

Saturation time (s)	Moisture content (%)			
	Cham		Mehr	
	Grain	Straw	Grain	Straw
0	10.6	7.2	11.1	7.7
1	12.2	19.1	13.2	18.8
15	13.4	35.2	20.8	35.1
45	25.7	40.8	40.8	41.6
75	31.0	42.5	45.2	45.1
105	35.7	44.3	49.7	48.1
120	36.1	46.1	51.9	51.3
135	34.2	47.6	51.9	53.3

over time and after a certain time, the moisture absorption was stopped. The maximum grain moisture absorption for Cham and Mehr cultivars was 36% and 52%, respectively after 120 min. Yildirim *et al.* (2011) obtained similar results in terms of $MC_{db.}$ change of chickpea during soaking with ultrasound method in different temperatures from 20 to 97 °C.
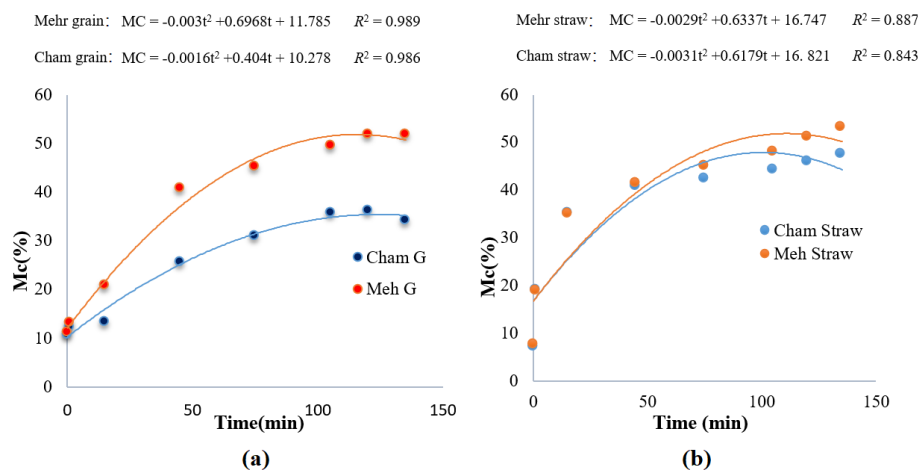
Aerodynamic Properties

The average projected area and terminal velocity measured for grains and straw particles in the two cultivars are shown in Tab. IV. The projected area decreased in both grain and straw, when their position changed from horizontal to lateral. Similar results were reported by Gürsoy and Güzel (2010) in estimating the surface area of wheat, barley, pea and lentil.

According to Tab. IV, it was found that in spite of higher drag coefficients, the terminal velocity in the vertical position was lower than the horizontal and lateral due to its low projected area. However, in the case of horizontal and lateral, the terminal

velocity difference was not significant. By changing the $MC_{db.}$ of grains and straw particles from 14 to 20%, terminal velocity and consequently, the drag coefficient decreased. The reason for this phenomena may be due to the increasing of the particle weight without increasing the projected area during falling.

Gupta *et al.* (2007) showed that the average terminal velocity increased from 2.93 to 3. 28 m/s by increasing $MC_{d.b.}$ from 6 to 14% for sunflower seeds. Rajabipour *et al.* (2006) reported similar trends with a linear equation and R^2 of 0.95, 0.91 and 0.92 for Mahdavi, Marvdasht and Pishtaz wheat cultivars, respectively. The maximum terminal velocity was obtained 6.9 m/s for Mahdavi and 1.6 m/s for Marvdasht cultivars (Rajabipour *et al.*, 2006). Khoshtaghaza and Mehdizadeh (2006) reported an increase in the terminal velocity from 2.35 to 4.85 m/s in length changes of wheat straw from 10 to 100 mm. In their study, the changes in terminal velocity and the resistance coefficient depended on the node place in straw and its length (Khoshtaghaza and Mehdizadeh, 2006).

As shown in Fig. III, there was no significant difference in terminal velocity and the drag coefficient of grains in different moisture contents, especially in horizontal and lateral sections, but this difference was obvious between grains and rachis particles. The terminal velocity in grains was higher and the drag coefficient was lower than rachis particles. There was also a difference between the straw in the form of rachis and other forms of straw. Nalbandi *et al.* (2010) reported a significant difference between the terminal velocity of wheat grains and *Turgenia latifolia* seeds. In their study, the effect of $MC_{d.b.}$ of grains on this property was significant. The terminal velocity of wheat grains at both A and B grades increased from 9.25 to 9.59 m/s and from 8.353 to 8.757 m/s, respectively, as the $MC_{w.b}$ increased from 7 to 20.8%. $MC_{d.b.}$ did not significantly affect the terminal velocity of *Turgenia latifolia* seeds at both cases. They also showed that

Mehr grain: $MC = -0.003t^2 + 0.6968t + 11.785$ $R^2 = 0.989$

Cham grain: $MC = -0.0016t^2 + 0.404t + 10.278$ $R^2 = 0.986$

Mehr straw: $MC = -0.0029t^2 + 0.6337t + 16.747$ $R^2 = 0.887$

Cham straw: $MC = -0.0031t^2 + 0.6179t + 16.821$ $R^2 = 0.843$

2: *Moisture content in wheat (a) grain and (b) straw in two cultivars*

IV: *Wheat grain and straw project area of Cham and Mehr cultivars in two levels of moisture contains*

	Section	$MC_{d.b.}$ (%)	Cham Grain	Mehr Grain	Cham cluster straw			Mehr cluster straw		
					Chaff	Rachis	Straw	Chaff	Rachis	Straw
Projected area (mm²)	Horizontal	14	18.43	16.95	3.29	44.25	50.39	3.14	43.98	49.48
		20	18.87	17.49	3.21	45.1	53.19	3.09	44.81	51.19
	Lateral	14	14.53	12.77	13.13	11.23	33.56	12.56	11.00	32.98
		20	16.58	12.96	13.48	12.4	35.97	12.89	12.12	35.02
	Vertical	14	7.81	6.41	0.71	3.78	5.23	0.78	3.15	4.71
		20	9.15	6.73	0.86	3.59	5.37	0.82	3.03	4.8
Terminal velocity (ms⁻¹)	Horizontal	14	7.28	7.3	0.35	2.21	0.6	0.35	2.45	0.6
		20	7.75	7.81	0.41	2.35	0.69	0.42	2.59	0.71
	Lateral	14	7.38	7.42	0.37	2.36	0.80	0.38	2.55	0.8
		20	7.68	7.73	0.46	2.52	0.83	0.48	2.72	0.85
	Vertical	14	8.21	8.34	0.49	3.63	1.2	0.52	3.89	1.8
		20	8.69	8.86	0.6	3.98	1.39	0.64	4.21	1.93
Drag coefficient	Horizontal	14	0.083	0.087	8.39	0.5	1.03	8.4	0.5	1.03
		20	0.071	0.074	5.7	0.42	0.72	5.7	0.41	0.72
	Lateral	14	0.102	0.112	1.78	0.68	2.32	1.78	0.69	2.32
		20	0.083	0.102	1.04	0.55	1.81	1.06	0.55	1.82
	Vertical	14	0.154	0.178	15.22	2.07	1.6	15.2	2.07	1.69
		20	0.117	0.15	9.2	1.55	1.24	9.2	1.55	1.22
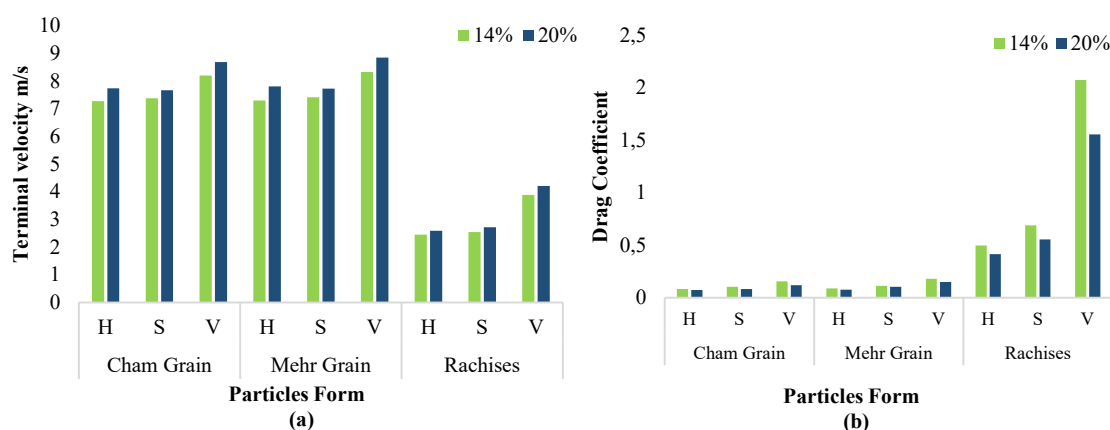
3: *Comparative of wheat grain and rachis (a) terminal velocity and (b) drag coefficient in two cultivars*

there was a significant difference between the drag coefficients of wheat and *Turgenia latifolia* grains. Reduction in drag coefficients of wheat grains was between 1.8% to 2.8%, and in *Turgenia latifolia* grains, it was between 11.8 to 12.7% as the $MC_{w.b.}$ decreased from 7 to 20.08% (Nalbandi *et al.*, 2010). In another research, the terminal velocity of millet grain varied from 2.75 to 4.63 m/s due to an increase in $MC_{d.b.}$ from 5 to 22.5% (Baryeh, 2002). Zewdu (2007) measured the terminal velocity of Tef grains. He reported that it increases linearly from 3.08 to 3.96 m/s by increasing $MC_{w.b.}$ from 6.5 to 30%. Similar results were reported for African yam bean (Irtwange and Ugbeka, 2003), coffee cherries and beans (Júnior *et al.*, 2007) and cotton seeds (Tabakand Wolf, 1998).

Results of Statistical Analyses

Physical Properties of Grains

The analysis of variance for physical characteristics of the two wheat cultivars is shown in Tab. V at $MC_{d.b.}$ from 14 and 20%. In this analysis, it was determined that the effect of cultivar was significant at 1% probability level on diameter (width), thickness, geometric diameter, sphericity coefficient and

V: *Analysis of variance of cultivar and $MC_{d.b.}$ and their interactions on physical properties of wheat grain*

Sources of variations	DF	Mean of squares							
		Projected area (A)	Length (D_L)	Width (D_w)	Thickness (t)	Weight (w_g)	Geometric diameter (D_{gm})	Sphericity (φ)	Density (ρ)
Cultivar	1	23.61^{ns}	0.067^{ns}	1.12^{**}	0.71^{**}	227.6^{ns}	0.78^{**}	0.027^{**}	246288.9^{**}
MCdb.	1	2.12^{ns}	0.00004^{ns}	0.05^{ns}	0.077^{ns}	78.9^{ns}	0.046^{ns}	0.001^{*}	838.49^{ns}
Cultivar × MC$_{db.}$	1	0.14^{ns}	0.0073^{ns}	0.002^{ns}	0.0006^{ns}	0.12^{ns}	0.002^{ns}	0.0^{ns}	1946022^{ns}
Error	36	7.34	0.29	0.079	0.085	136.96	0.103	0.0002	4676.08

ns = non-significant, * = $P \leq 0.05$; ** = $P \leq 0.01$

VI: *Mean comparison of the effects of cultivar and $MC_{db.}$ and their interactions on physical properties of wheat grain*

Physical properties of wheat grain	Cultivar		Moisture content		Cultivar × moisture content			
	Cham	Mehr	14%	20%	Cham 14%	Cham 20%	Mehr 14%	Mehr 20%
Projected area (mm²)	18.8^a	17.2^a	17.8^a	18.3^a	18.5^a	19.1^a	17.1^a	17.4^a
Length (mm)	6.6^a	6.6^a	6.6^a	6.6^a	6.6^a	6.6^a	6.5^a	6.5^a
Width (mm)	2.8^a	2.5^b	2.6^a	2.7^a	2.8^a	2.9^a	2.5^b	2.5^b
Thickness (mm)	3.6^a	3.3^b	3.4^a	3.5^a	3.6^{ab}	3.6^a	3.3^b	3.4^{ab}
Weight (mg)	51.2^a	46.4^a	47.4^a	50.2^a	49.7^a	52.6^a	45.1^a	47.8^a
Geometric diameter (mm)	4.6^a	3.8^b	3.9^a	4.0^a	4.0^{ab}	4.1^a	3.8^b	3.8^{ab}
Sphericity (%)	61.5^a	58.0^b	59.2^b	60.2^a	61.0^a	62.0^a	57.4^b	57.5^b
Density (kgm³)	1424^b	1581^a	1498^a	1507^a	1426^b	1421^b	1569^a	1592^a

Means with the same letter in each column are not significantly different according to Duncan Multiple Range Test

density of grain. There were no significant differences between two cultivars in projected area, length and grain weight. The effect of $MC_{d.b.}$ on the spherical coefficient was significant at 5% probability level. Interaction effect of cultivar and $MC_{d.b.}$ was not significant on the grain physical characteristics.

According to Tab. VI, the means comparison of the projected area for the two cultivars and two levels of $MC_{d.b.}$ did not show any significant difference. The highest projected area of wheat grain was 19.1 mm² in Cham cultivar in $MC_{w.b.}$ equal to 20% and its lowest value was 17.1 mm² in Mehr cultivar at the $MC_{d.b.}$ equal to 14%, respectively. The length of the grains in both cultivars and the two levels of moisture content did not differ significantly.

The width of grains of both cultivars was in two statistical groups. Cham cultivar with 2.9 mm width at 20% MCdb. had the highest amount and Mehr cultivar grain with a 2.5 mm width in 14% MCdb. had the lowest amount. The grain thickness of the both cultivars was also in two groups. The highest thickness was 3.6 mm for Cham cultivar grains at 20% $MC_{d.b.}$ whilst the lowest was 3.3 mm for the Mehr cultivar at 14% $MC_{d.b.}$ Grain weight in both cultivars and MCdb. was at one statistical level. The highest and lowest amounts of grain weight were in the Cham cultivar at 20% $MC_{d.b.}$ and Mehr cultivar at

14% $MC_{d.b.}$, equal to 52.6 and 45.1 mg, respectively. Grain sphericity of Cham and Mehr cultivars was 61.5% and 58%, respectively. The average density of grains in Cham cultivar was 1423 kg/m and in Mehr cultivar was 1581 kg/m.

Physical Properties of Straw

The results of analysis of variance of physical properties of wheat straw in three shape of chaff, straw and cluster rachis for Cham and Mehr cultivars are shown in Tab. VII. The effect of cultivar was significant at 1% probability level on length, width and mean geometric diameter but was not significant on thickness, weight and spherical coefficient of straw particles. The effects of the shape were significant on all characteristics except spherical coefficients at 1% probability level. The interaction of cultivar and shape was significant on the thickness and mean geometric diameter at 1% probability level and on the width at 5% probability level.

The means comparison of the straw dimensions in different cultivars and shapes is presented in Tab. VII. In this comparison, the amount of straw length, width and geometric diameter of Mehr cultivar were more than of Cham cultivar, and the value of thickness, weight and spherical coefficient of Mehr cultivar were lower. The maximum length,

VII: *Analysis of variance of the effect of cultivar, shape and their interaction on physical and geometric properties of wheat straw particles*

Sources of variations	DF	Mean of squares					
		Length (D_L)	Width (D_w)	Thickness (t)	Weight (w_g)	Geometric diameter (D_{gm})	Sphericity (φ)
Cultivar	1	272.7**	11.0**	0.7ns	81.4ns	4.3**	0.01ns
Shape	2	323.8**	8.8**	4.1**	1075.2**	5.9**	0.03ns
Cultivar× shape	2	22.2ns	3.3*	1.4**	13.9ns	6.3**	0.02ns
Error	24	23.4	0.7	0.2	80.9	0.4	0.01

ns = non-significant, * = $P \leq 0.05$; ** = $P \leq 0.01$

VIII: *Comparison of the cultivar, shape and their interactions effects on the physical properties*

Straw physical properties	Cultivar		Straw shape			Cultivar × MC$_{db.}$					
						Cham			Mehr		
	Cham	Mehr	Chaff	Straw	Rachis	Chaff	Straw	Rachis	Chaff	Straw	Rachis
Length (mm)	12.5b	18.5a	9.1b	17.4a	20.1a	7.1c	12.7b	17.7a	11.1b	22.1a	22.4a
Width (mm)	2.5b	3.7a	3.9a	2.1b	3.2a	2.7bc	1.9c	2.8b	5.2a	2.3bc	3.5b
Thickness (mm)	1.3a	1.0a	0.7b	0.9b	1.9a	1.1bc	1.2bc	1.6ab	0.3d	0.6dc	2.2a
Weight (mg)	19.2a	15.9a	8.2b	15.8b	28.7a	10.9c	16.2bc	30.5a	5.4c	15.4b	26.9ab
Mean geometric diameter (mm)	2.9b	3.6a	2.7b	3.0b	4.1a	2.9b	2.9b	2.9b	2.4b	3.1b	5.4a
Sphericity (%)	24.8a	20.8a	28.2a	17.6b	22.7ab	34.1a	21.1ab	19.2b	22.3ab	14.1b	26.1ab

Means with the same letter in each column are not significantly different according to Duncan Multiple Range Test

IX: *Analysis of variance of cultivar and moisture content effects and their interactions on grain and wheat straw terminal velocity*

Sources of variations	DF	Mean of squares					
		Grain terminal velocity			Straw terminal velocity		
		Horizontal	Lateral	Vertical	Horizontal	Lateral	Vertical
Cultivar	1	0.009ns	0.010ns	0.100**	0.0005ns	0.0020ns	0.159**
MCdb.	1	0.64**	0.28**	0.63**	0.008ns	0.037**	0.062**
Cultivar × MC$_{db.}$	1	0.0007ns	0.0004ns	0.004ns	0.0021ns	0.00007ns	0.0012ns
Error	8	0.0078	0.0050	0.0078	0.0018	0.0028	0.0046

ns = non-significant, * = $P \leq 0.05$; ** = $P \leq 0.01$

thickness and geometric diameter of rachis in Mehr cultivar were 22.4, 2.2 and 5.4 mm, respectively, and the largest width was 5.2 mm for chaff in Mehr cultivar. The highest weight was for rachis in Cham cultivar with the amount of 30.5 mg and the highest sphericity coefficient with a value of 34% was for chaff in Cham cultivar.

Terminal Velocity of Grain and Straw

The results of analysis of variance of terminal velocity in three positions of motion in horizontal, vertical and lateral states are presented in Tab. IX. According to these results, the effect of cultivar on terminal velocity of grain and straw was significant at 1% probability level only in vertical position which was unstable perfectly, and in other positions, it did not have a significant effect. The effect of MC$_{d.b}$ was significant at 1% probability level on terminal velocity of grains in all three positions and on straw in vertical and lateral positions. Interaction effects of cultivars and moisture content was not significant on terminal velocity of grain and wheat straw.

According to Tab. X, the maximum and minimum values of grain's terminal velocity were 8.9 and 7.3 m/s belonging to Mehr cultivar at 20% MC$_{d.b.}$ and Cham cultivar at 14% MC$_{d.b.}$ respectively. Increasing the MC$_{d.b}$, despite the slight effect on increasing the dimensions, leaded to an increase in the terminal velocity, and it can be concluded that increasing particle's weight due to moisture absorption had significant effects on an increase in terminal velocity. The maximum terminal velocity in straw

X: *Comparison of the effect of cultivar and moisture and their interactions on terminal velocity of wheat grain and straw particle*

Projected area position		Cultivar		MC$_{db.}$ (%)		Cultivar × MC$_{db.}$ (%)			
		Cham	Mehr	14	20	Cham 14	Cham 20	Mehr 14	Mehr 20
Grain	horizontal (mm^2)	7.5[a]	7.6[a]	7.3[b]	7.8[a]	7.3[b]	7.7[a]	7.3[b]	7.8[a]
	lateral (mm)	7.5[a]	7.6[a]	7.4[b]	7.7[a]	7.4[b]	7.7[a]	7.4[b]	7.7[a]
	vertical (mm)	8.4[b]	8.6[a]	8.3[b]	8.8[a]	8.2[c]	8.6[b]	8.4[c]	8.9[a]
Straw	horizontal (mm^2)	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]	0.4[a]
	lateral (mm)	0.7[a]	0.7[a]	0.6[a]	0.7[a]	0.6[c]	0.7[ab]	0.6[bc]	0.8[a]
	vertical (mm)	2.3[b]	2.5[a]	2.4[b]	2.5[a]	2.2[c]	2.4[b]	2.5[ab]	2.6[a]

Means with the same letter in each column are not significantly different according to Duncan Multiple Range Test

was in the vertical position and in the range of 2.3 to 2.5 m/s, and its lowest value was in the horizontal position. The terminal velocity in straw particles at 20% MC$_{d.b.}$ were higher than that in 14% MC$_{d.b.}$ and also were higher in Mehr cultivar compared to Cham. Shahbazi *et al.* (2014) reported an increase in terminal velocity of wheat grains from 6.3 to 8.0 m/s by increasing the MC$_{d.b.}$ from 7 to 27%.

CONCLUSION

Results of this study showed that in general, although both of the studied cultivars had the same weight, their grains had different densities. Generally, the mean dimensions of grain width and straw particles in Mehr cultivar were more than Cham cultivar but had less thickness and weight and thus, they might have different behaviors in the separation systems such as fluid bed and electric field. The shape of the straw and the falling position had different physical and aerodynamic properties, which had direct effects on terminal velocity for the two cultivars. Results of this study can be used in designing wheat- cluster straw separation and processing especially electrostatic separation systems.

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