Effect of awn on aerodynamic properties of paddy grains (*Oryza Sativa L.*)

Mahdi Masoumi[1], Asghar Mahmoudi[1*], Mohammad Reza Alizadeh[2] and Shamsollah Abdollahpour[3]

(1. University of Tabriz, Department of Biosystems Engineering, 29 Bahman Blvd., Tabriz, Iran, 5166616471;
2. Agricultural Research, Education and Extension Organization, Rice Research Institute of Iran, Rasht, Iran, 4199613475;
3. University of Tabriz, Department of Biosystems Engineering, 29 Bahman Blvd., Tabriz, Iran, 5166616471)

Abstract: Paddy grains (rough rice) are categorized into two groups, awned and awnless paddies. The awn is a needle-like appendage that extends from the lemmas of the florets and is important domestication and agronomic traits in paddy. The aerodynamic properties of paddy grains and understanding the effect of awn on the aerodynamic properties of paddy are important information for grain harvest and postharvest process like cleaning, handling and for designing related systems. Thus in this research, aerodynamic properties of two local varieties of paddy (Hashemi and Gilaneh) and effect of awn as specific traits on aerodynamic properties were investigated in different moisture content. Terminal velocities were measured for awned and awnless paddy grains using the suspension velocity method. Also the drag coefficient for awnless paddy and resistance coefficient for awned paddy were calculated from the experimentally obtained terminal velocities. Mean values for terminal velocity of the awned and awnless paddy were obtained 5.88 and 5.73 m s^{-1} respectively that shows the terminal velocity of awnless paddy is 2.55% less than awned paddy. Drag coefficient of awnless grains decreased with increase in moisture content, whereas resistance coefficient of awned grains increased. Obtained aerodynamic properties values provided baseline data which are useful in the design of pneumatic conveying devices.

Keywords: paddy grains, awn, terminal velocity, drag coefficient, resistance coefficient.

Citation: Masoumi, M., A. Mahmoudi, M. R. Alizadeh, and S. Abdollahpour. 2020. Effect of awn on aerodynamic properties of paddy grains (Oryza Sativa L.). Agricultural Engineering International: CIGR Journal, 22 (2):208-216.

1 Introduction

Rice is among the three most important grain contribution to fulfill the food needs across the globe. The role of rice crop is inevitable in the current and future global food security. Rice has now become a foreign exchange earner for several countries and is playing a role in the economic (Suthar and Das, 1996).

In recent years, the use of combine for harvesting paddy has been increased in Iran due to high labor cost of manual harvesting but rough rice is harvested and threshed by combine at moisture contents 20%-25% required to dry for safe storage moisture contents (14% or less for Storage period weeks to a few months, 13% or less for period 8–12 months, 12% or less for storage of farmer's seeds, 9% or less for less than 1 year) and another post-harvest process according to International Rice Research Institute recommendation. High moisture level in harvesting time causes deterioration of grains. So it is important to dry threshed rough rice as soon as possible after harvesting ideally within 24 hours.

Sundrying is practiced in many areas in Iran. But

Received date: 2018-10-20 **Accepted date:** 2019-06-02

***Corresponding author: Asghar Mahmoudi,** Ph.D., Associate Professor University of Tabriz, Department of Biosystems Engineering, 29 Bahman Blvd., Tabriz, Iran, 5166616471. Email:a_mahmoudi@tabrizu.ac.ir, Tel: +984133392779, Fax: +984133356007

challenge for farmers in the use of combine and sundrying is how to handle tons of paddies after drying. After threshing, they spread out the paddy in the drying floor. Then, the paddy is piled and is placed into a bag. All of the above operations are done manually that is time consuming and difficult.

One way to solve this problem is the pneumatic conveying method. Design a device that can do collecting and bagging of the paddy by pneumatic method.

In order to collect paddy with pneumatic collecting device, the most important parameter is air velocity. Low air velocity lead to stagnation in the system, or high air velocity, there is not only energy lost, but also result in the production of low-quality rice by cracking and breakage of the rice kernel (Khoshtaghaza and Mehdizadeh, 2006). For this reason, in order to determine of the proper air velocity and other design parameters, aerodynamic and physical properties of agricultural materials are needed (Mohsenin, 1986).

The two important aerodynamic characteristics of a body are its terminal velocity and aerodynamic drag coefficient that can be calculated or measured in the laboratory. Terminal velocity of irregularly shaped crops cannot be calculated theoretically with sufficient accuracy, and so it is better determined experimentally (Sitkei, 1986). Two commonly used methods of measuring the terminal velocity experimentally are the drop and suspension methods (Mohsenin, 1986). Drag coefficient of large objects usually is measured experimentally by horizontal wind tunnel and values are obtained over a wide range of Reynolds number. However for small particles (like grain seeds), the drag coefficient cannot be measured directly by this method. Thus drag coefficient of agricultural materials are calculated from their terminal velocity which is experimentally measured (Khoshtaghaza and Mehdizadeh, 2006).

The difference in terminal velocity between damaged and undamaged grain was utilized by Bueermann (1991) to separate them in a vertical wind tunnel. Khoshtaghaza and Mehdizadeh (2006) measured terminal velocity of wheat and straw materials in order to find the effects of mass and moisture content of wheat kernel, node position and length of straw on terminal velocity. Aerodynamic property of Tef grain and its straw were investigated by Zewdu (2007) for evaluating potential for developing separation machinery.

Shahbazi (2013) studied aerodynamic properties of canola and wild mustard seeds to evaluate separation of them from each other. The results showed that aerodynamic separation of wild mustard seed from canola is possible.

In order to facilitate the design and adjustment of machines that perform separation of Makhobeli from triticale and wheat, Shahbazi et al. (2014) did investigation to measure and compare the aerodynamic properties of Makhobeli, triticale and wheat seeds to provide the data based on aerodynamic properties.

Several investigators determined the aerodynamic properties of various seeds such as Hazel Nuts (Aydin, 2002), sunflower seed (Gupta et al., 2007), wheat, barley, sunflower, lentil (Güner, 2007), and arils (Khodabakhshian et al., 2018).

Paddies (rough rice) that planted in Iran are categorized into two groups, awned and awnless paddies (Figure 1). Most of awned paddies are high quality and aromatic rice cultivars like Hashemi and Gilaneh. Awnless paddies like Khazar, Dorfak and Kadus are high-yielding and low quality.

Figure 1 Awned (left) and awnless (right) varieties of paddy

Awns, spicule-like structure that are formed on the top of the lemma in the florets (Toriba and Hirano, 2014), are important domestication and agronomic traits in rice that conferred by polygenes and the environment (Ben et al., 2016).

The effect of awn on physical properties of paddy was studied by Alizadeh et al. (2006). Results of this study showed awn influenced physical properties of paddy. Minaei et al. (2007) reported husking properties of paddy were significantly influenced by de-awning. Alizadeh and Minaei (2012) evaluated effect of de-awning and moisture content of paddy on the angle of repose, coefficient of internal friction and coefficient of mobility. Results revealed that the effect of de-awning and moisture content on frictional properties of paddy was highly significant (P < 0.01). But effect of the awn on aerodynamic properties of paddy has not yet been reported.

The objectives of this research were determination of terminal velocities of two common rice varieties (Hashemi and Gilaneh), calculation of drag coefficient and study of effects of awn, variety and moisture content on terminal velocity of paddy. The results can be used to design a pneumatic device to collect paddy grains. Tests were conducted over a range of moisture content from 8% to 13%, which spans the moisture range of safe storage to processing operations.

1.1 Theoretical background

When a particle is immersed in fluid current the forces acting on the particle are F_D and F_L. Using dimensional analysis technique, the drag and lift forces are (Mohsenin, 1986):

$$F_D = \frac{1}{2} C_D A_P \rho_f v^2 \quad (1)$$

$$F_L = \frac{1}{2} C_L A_P \rho_f v^2 \quad (2)$$

Where, F_D is the drag force and F_L is the lift force. The C_D and C_L are drag and lift coefficients of the material respectively.

In most agricultural engineering applications the moving object is usually free to assume it's the own random orientation. For this reason the net resistances force F_r can be given in terms of an overall drag coefficient C as follows

The resultant force F_r can be given as (Mohsenin, 1986):

$$F_r = \frac{1}{2} C A_P \rho_f v^2 \quad (3)$$

In the condition of free fall, the particle attains a constant velocity, V_t, the net gravitational accelerating force F_g, equals the resisting upward drag force F_r (Mohsenin, 1986):

$F_g = F_r$ if $V = V_t$

By substituting the values of F_g and F_r the expression for terminal velocity will be:

$$m_p g \left[\frac{(\rho_p - \rho_f)}{\rho_p} \right] = \frac{1}{2} C A_P \rho_f V_t^2 \quad (4)$$

$$v_t = \left[\frac{2 m_p g (\rho_p - \rho_f)}{\rho_p \rho_f A_p C} \right]^{\frac{1}{2}} \quad (5)$$

$$C = \left[\frac{2 m_p g (\rho_p - \rho_f)}{V_t^2 \rho_p \rho_f A_p} \right] \quad (6)$$

$$K = C A_P = \left[\frac{2 m_p g (\rho_p - \rho_f)}{V_t^2 \rho_p \rho_f} \right] \quad (7)$$

Where: V_t is terminal velocity of the particle (m s^{-1}), A_P is cross sectional area of the particle (m^2), C is drag coefficient (dimensionless), m_P is mass of the particle (kg), ρ_P is Mass density of particle (kg m^{-3}), ρ_f is Mass density of the fluid (kg m^{-3})

The resistance coefficient K (m^2), being a parameter free from the assumption of the effective frontal area necessary when calculating drag coefficient, appears to be better criterion for separation of various particles than the drag coefficient (Mohsenin, 1986).

2 Material and Methods

2.1 Sample preparation

Varieties namely Hashemi and Gilaneh that are most popular in Iran, were selected for the present study. These varieties were planted at the RRII research farms. Grains were cleaned in cleaner to remove foreign matter, broken and immature seeds. To obtain awnless samples of paddy, awns were removed manually without damage to grains.

Initial moisture content of samples was determined by using oven method at 105°C±3°C for 24 hours (Corre et al., 2007; Razavi and Farahmandfar, 2008). The samples were gently dried in a thin-layer drying chamber at 40°C air temperature for different periods to achieve grain moisture contents within the range of 8%-13% wet basis (w.b.) (Yang et al., 2003). After preparing three levels of moisture contents, the samples poured in polyethylene bags and bags sealed tightly. The experimental work was conducted at Biosystem laboratory of RRII.

2.2 Measurement of terminal velocity

Along with most agricultural products, paddy isn't spherical so is better to measure terminal velocities experimentally rather than predicting them from mathematical relationships.

The terminal velocity of paddy was measured using an air column that had been developed at RRII (Figure 2). It consists of a cylindrical glass (Plexiglas) pipe posed vertically with a fitted air blower from the bottom side, in which the material was suspended in the air stream. The air flow rate was controlled by changing the velocity of the electric motor through an inverter set. Sample placed on the mesh screen in vertical column. In the beginning, the blower output was set at minimum then air flow rate was gradually increased till the grain mass gets suspended in the air stream. Air velocity was measured using a digital hot wire anemometer (Testo, V1-405) with the accuracy of ±0.1 m s^{-1}. Similar procedure was reported by other researchers (Ghamari et al., 2014; Nimkar et al., 2005; Ozarslan, 2002; Patel et al., 2013). This procedure repeated five times at different moisture content from 8% to 13% (w.b.).

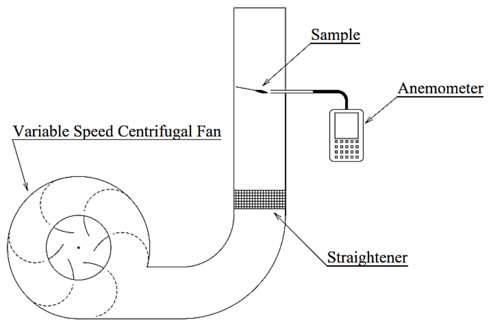

Figure 2 Schematic diagram of wind tunnel for terminal velocity measurement

2.3 Statistical analysis

In this research, the effects of awn (awned and awnless paddy), variety (Hashemi and Gilaneh) and moisture content (8%, 10.5%, 13% (w.b.)) on the terminal velocity of paddy were studied. Tests were conducted over a range of moisture content from 8% to 13% (w.b.), which spans the moisture range of safe storage to processing operations. The factorial experiment was conducted as a randomized design with five replicates. Analysis of variance was done by SPSS Statistics 23 software. Significant differences of means were compared using Duncan's Multiple Range Test (DMRT) at the 5% level using above mentioned software. The terminal velocity and moisture content data of paddy were fitted to regression models. The models were evaluated according to the statistical criterion R^2 for verifying the adequacy of fit. The best model with the highest R^2 was selected. The results have been presented in the paper and discussed.

2.4 Calculation of drag coefficient

The drag coefficient was calculated using Equation 6 (El-Sayed et al., 2001; Güner, 2007; Gupta et al., 2007; Sitkei, 1986). For calculations using Equation 6, values of terminal velocity were measured using the experimental methods procedure mentioned above. The ρ_p of paddy at different moisture content was determined experimentally using the toluene (C_7H_8) displacement method. The volume of toluene displaced was found by immersing the weighed quantity of grain in toluene (Alizadeh et al., 2006; Güner, 2007; Shahbazi et al., 2014; Sitkei, 1986). The thousand grain mass of the awned and awnless paddy samples was determined by means of an electronic balance (DENVER) with accuracy of 0.001 g. A_P was estimated using Equation 8 (Gharekhani et al., 2013; Sitkei, 1986). The values of length (mm) and width (mm) of paddy grains (L and W) were also measured using a micrometer (Miutoyo) with accuracy of 0.01 mm.

$$A_P = \frac{\pi}{4} WL \quad (8)$$

3 Results and discussion

3.1 Some physical properties of the paddy

In the present study some physical properties of the paddy for Hashemi and Gilaneh varieties in two forms of awned and awnless paddy were measured. The experimental results for some physical properties are shown in Tables 1-5.

As it can be seen from Table 1, three axial dimensions increased as moisture content increased from 8% to 13% (w.b.). Alizadeh et al. (2006) reported increase in three axial dimensions of paddy with moisture content level in the range 6.92% to 23.16% (d.b.).

Sphericity, arithmetic mean diameter, geometric mean diameter and cross sectional area increased with an increase in moisture content level in two varieties (Table 2).

Mass density of Hashemi variety increased from 1338.56 to 1354.21 kg m^{-3} and 1358.30 to 1381.00 kg m^{-3} respectively for awned and awnless paddy when moisture content increased from 8% to 13%. Mass density of Gilaneh variety increased from 1273.65 to 1301.23 kg m^{-3} and 1317.55 to 1336.13 kg m^{-3} respectively for awned and awnless paddy when moisture content increased from 8% to 13 % (w.b.) (Table 3).

Thousand grain mass of Hashemi variety increased from 24.34 to 25.59 g and 23.99 to 25.24 g respectively for awned and awnless paddy when moisture content increased from 8 to 13% (w.b.). For Gilaneh variety, thousand grain mass of awned and awnless paddy increased respectively from 21.02 to 22.42 g and 20.50 to 21.92 g with moisture content level in the range 8% to 13% (Table 4). Gharekhani et al. (2013) reported thousand grain mass increased from 22.07 to 29.45 g and from 19.81 to 27.83 g respectively for Fajr and Tarom varieties as the moisture content increased from 5% to 37% (w.b.).

According to Table 5, the porosity of awned paddy is more than awnless. As it is seen, the porosity of awned and awnless paddies decreased with increasing moisture content.

Table 1 Mean values of dimensional properties of Hashemi and Gilaneh varieties

Variety	Moisture content (%w.b.)	Length (mm)	Width (mm)	Thickness (mm)
Hashemi	8	10.19(0.36)^a	2.17(0.13)^b	1.79(0.10)^c
	10.5	10.22(0.38)^a	2.19(0.11)^b	1.83(0.13)^b
	13	10.22(0.33)^a	2.29(0.13)^a	1.87(0.09)^a
Gilaneh	8	9.46(0.44)^a	2.12(0.11)^b	1.79(0.12)^c
	10.5	9.47(0.35)^a	2.14(0.10)^b	1.82(0.12)^b
	13	9.52(0.39)^a	2.17(0.10)^a	1.83(0.11)^a

Note: Figures in parenthesis are standard deviation. In each column and for each variety, means followed by a common letter are not significantly at the 5% level.

Table 2 Mean values of sphericity, arithmetic mean diameter, geometric mean diameter, and cross sectional area of Hashemi and Gilaneh varieties

Variety	Moisture content (%w.b.)	Sphericity (mm)	Arithmetic mean diameter (mm)	Geometric mean diameter (mm)	Cross sectional area (mm^2)
Hashemi	8	0.335(0.012)^b	4.72(0.12)^b	3.41(0.08)^c	17.36(0.91)^b
	10.5	0.337(0.011)^b	4.75(0.15)^b	3.45(0.11)^b	17.61(1.19)^b
	13	0.345(0.011)^a	4.79(0.12)^a	3.52(0.09)^a	18.34(1.18)^a
Gilaneh	8	0.349(0.013)^b	4.46(0.15)^b	3.30(0.09)^c	15.77(1.09)^b
	10.5	0.351(0.013)^b	4.48(0.12)^b	3.33(0.09)^b	15.91(0.91)^b
	13	0.355(0.011)^a	4.52(0.14)^a	3.38(0.10)^a	16.40(1.05)^a

Note: Figures in parenthesis are standard deviation. In each column and for each variety, means followed by a common letter are not significantly at the 5% level.

Table 3 Mean values of mass density (kg m^{-3}) of Hashemi and Gilaneh varieties

Moisture content (%w.b.)	Hashemi variety		Gilaneh variety	
	awned	awnless	awned	awnless
8	1338.56(7.31)^b	1358.30(5.96)^b	1273.65(8.59)^b	1317.55(6.58)^b
10.5	1347.93(9.25)^{ab}	1366.91(6.33)^b	1276.39(7.66)^b	1325.68(9.70)^{ab}
13	1354.21(5.03)^a	1381.00(9.57)^a	1301.23(7.80)^a	1336.13(9.42)^a

Note: Figures in parenthesis are standard deviation. In each column and for each variety, means followed by a common letter are not significantly at the 5% level.

Table 4 Mean values of thousand grain mass (g) of Hashemi and Gilaneh varieties

Moisture content (%w.b.)	Hashemi variety		Gilaneh variety	
	awned	awnless	awned	awnless
8	24.34(0.60)^b	23.99(0.65)^b	21.02(1.06)^b	20.50(1.10)^b
10.5	24.97(0.27)^{ab}	24.62(0.26)^{ab}	21.94(0.21)^{ab}	21.47(0.23)^{ab}
13	25.59(0.25)^a	25.24(0.28)^a	22.42(0.58)^a	21.92(0.58)^a

Note: Figures in parenthesis are standard deviation. In each column and for each variety, means followed by a common letter are not significantly at the 5% level.

Table 5 Mean values of porosity (%) of Hashemi and Gilaneh varieties

Moisture content (%w.b.)	Hashemi variety		Gilaneh variety	
	awned	awnless	awned	awnless
8	71.23(0.32)^a	66.91(0.12)^a	73.03(0.18)^a	68.08(0.20)^a
10.5	70.97(0.30)^a	66.37(0.20)^b	72.69(0.16)^{ab}	67.62(0.14)^b

13	70.52(0.20)^b	65.96(0.30)^c	72.56(0.32)^b	67.47(0.36)^b

Note: Figures in parenthesis are standard deviation. In each column, means followed by a common letter are not significantly at the 5% level.

3.2 Terminal velocity

In this study, the terminal velocity and drag coefficient for Hashemi and Gilaneh varieties in two forms of awned and awnless paddy, were measured and calculated, respectively in moisture content from 8% to 13% (w.b.). Also in the present study, the effects of variety, awn and moisture content on the terminal velocity of paddy were investigated. The results of the measured terminal velocity are presented in Table 6.

Table 6 Mean values of terminal velocity (m s^{-1}) of the awned and awnless paddy of Hashemi and Gilaneh varieties

Moisture content	Hashemi variety		Gilaneh variety	
(%w.b.)	awned	awnless	awned	awnless
8	5.82(0.08)^b	5.68(0.06)^b	5.62(0.05)^b	5.45(0.09)^b
10.5	5.96(0.09)^b	5.85(0.1)^{ab}	5.75(0.06)^{ab}	5.62(0.09)^{ab}
13	6.26(0.19)^a	6.01(0.17)^a	5.90(0.17)^a	5.75(0.17)^a

Note: Figures in parenthesis are standard deviation. In each column, means followed by a common letter are not significantly at the 5% level.

According to Table 6, the terminal velocity of awned and awnless paddy for Hashemi variety varied within range of from 5.82 to 6.26 m s^{-1} and 5.68 to 6.01 m s^{-1}, respectively as moisture content increased from 8% to 13%. For paddy of Gilaneh variety, it ranged from 5.62 to 5.90 m s^{-1} and 5.45 to 5.75 m s^{-1}, respectively in moisture content from 8 to 13% (w.b.) .The values of terminal velocity reported in the range of 5.7 to 6.1 m s^{-1} by Patel et al. (2013) for PB1 and PB1121 varieties of paddy.

Güner (2007) reported the minimum and maximum terminal velocities for wheat, barley, sunflower and lentil varied from 9.86 to 10.27 m s^{-1}, 7.44 to 8.25 m s^{-1}, 6.13 to 6.61 m s-^{1} and 6.99 to 7.72 m s^{-1}, respectively in moisture content 6% to 9%. Gupta et al. (2007) reported the terminal velocity for NSFH-36, PSF-118 and Hybrid SH-3322 variety of sunflower seed increased from 2.93 to 3.28 m s^{-1}, 2.54 to 3.04 m s^{-1} and 2.98 to 3.53 m s^{-1}, respectively when moisture level increased from about 6% to 14% (d.b.).

3.3 Effect of variety on terminal velocity

Table 7 shows the results of statistical analysis carried out to examine the effects of awn, variety and moisture content on the terminal velocity.

Table 7 Analysis of variance for terminal velocity

Source	df	Mean square
Awn	1	0.296**
Moisture	2	0.452**
Variety	1	0.730**
Moisture × awn	2	0.007^{ns}
Moisture × variety	2	0.010^{ns}
Awn × variety	1	0.001^{ns}
Moisture × awn × variety	2	0.004^{ns}
Error	36	0.014

Note: ** Significant at 1% level;^{ns} not significant

There was significant difference among the varieties in terms of terminal velocity at 1% level. The average values of terminal velocity for Hashemi and Gilaneh varieties were 5.93 m s^{-1} and 5.68 m s^{-1}, respectively. Hashemi variety exhibited higher terminal velocity compared to Gilaneh variety in the moisture content between 8% to 13% (w.b.) as shown in Table 6. This difference in terminal velocity is as the result of the individual varieties properties related to mass and dimension properties.

3.4 Effect of awn on terminal velocity

About the effect of awn on the terminal velocity, as shown in Table 6, generally, the terminal velocity of awned paddy was more than awnless paddy in each of the two varieties and in each level of moisture content and this difference was significant at the 1% probability level (Table 7).

The results indicated that the highest values of terminal velocity were 6.26 and 5.90 m s^{-1}, respectively for awned paddy of Hashemi and Gilaneh varieties in 13% moisture level and lowest values were 5.68 and 5.45 m s^{-1}, respectively for awnless paddy of Hashemi and Gilaneh varieties in 8% moisture level.

Variations in terminal velocity of the awned and awnless paddy (average of two varieties) in the moisture content 8% to 13% are presented in Figure 3. Mean value for terminal velocity of the awned and awnless paddy (the average of two varieties and three levels of moisture contents) was obtained 5.88 and 5.73 m s^{-1}, respectively that shows the terminal velocity of awnless paddy is 2.55%

less than awned paddy.

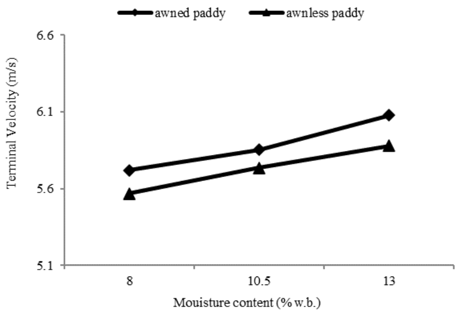

Figure 3 Variation in terminal velocity of awned and awnless paddy (average value of Hashemi and Gilaneh variety) with moisture content

As the results showed, awned paddy exhibited higher value of terminal velocity as compared to the awnless paddy in each level of the moisture content. This may due to the effect of awn on instability paddy in air stream which caused it to float vertically within the air stream. So, V_t increased because of decreasing the effective projected area in Equation 5. Also it is related to mass of paddy grain. As shown in Table 4, thousand grain mass of awned paddy is more than that of awnless paddy, so V_t increased because of increasing the mass in Equation 5.

3.5 Effect of moisture content on terminal velocity

As shown in Table 7, the effect of moisture content on the terminal velocity of paddy was significant ($P<0.01$). The variations of terminal velocity of paddy in different moisture contents are presented in Figure 4. It can be seen that with increase in moisture content from 8% to 13% (w.b.), the terminal velocity of awned and awnless paddy of Hashemi and Gilaneh varieties increased linearly.

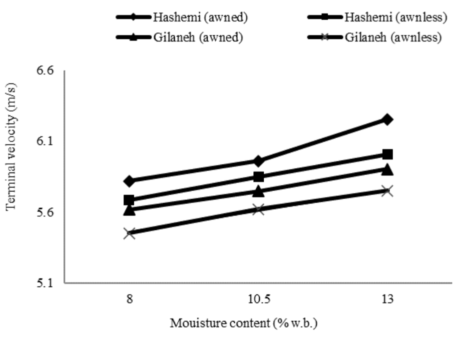

Figure 4 Variation in terminal velocity of paddy with moisture content

The variation in terminal velocity V_t in m s^{-1} with moisture content for two varieties are represented by the correlations shown in Table 8. As regression modeling shows there is linear relationship between terminal velocity and moisture content.

Table 8 Correlations between terminal velocity and moisture content

Variety	Regression modeling	R^2
Hashemi (awned)	V_t = 0.22×MC + 5.57	0.96
Hashemi (awnless)	V_t = 0.1625×MC+ 5.52	0.99
Gilaneh (awned)	V_t = 0.1425×MC+ 5.47	0.99
Gilaneh (awnless)	V_t = 0.15×MC+ 5.31	0.99

Note: MC: Moisture content level (%w.b.)

Similar results also reported for Hazel Nuts (Aydin, 2002), lentil seeds (Carman, 1996), chickpea (Ghamari et al., 2014), sunflower seed (Gupta et al., 2007), wheat and straw (Khoshtaghaza and Mehdizadeh, 2006), Moth gram (Nimkar et al., 2005), cotton seed (Ozarslan, 2002), Basmati varieties of paddy (Patel et al., 2013), wheat (Rajabipour et al., 2006), triticale, wheat seeds (Shahbazi et al., 2014), and Tef grain (Zewdu, 2007).

3.6 Resistance and Drag Coefficient

Awned paddy unlike awnless paddy was unstable in the wind tunnel and awn caused to aerodynamic instability of paddy. Same observations were reported by Khoshtaghaza and Mehdizadeh (2006) for straws of wheat and Zewdu (2007) for straws of Tef grain. Therefore, for awned paddy, because of no specific frontal area in the air stream instead of calculating drag coefficient, resistance coefficient was calculated. The resistance coefficient against moisture content is shown in Figure 5. The resistance coefficient of awned paddy of Hashemi and Gilaneh varieties varied from 11.488 to 10.457 mm^2 and 10.646 to 10.285 mm^2, respectively when moisture content increased from 8% to 13% (w.b.).

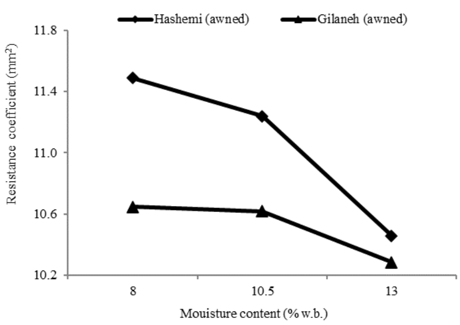

Figure 5 Variation in resistance coefficient of awned paddy with moisture content

Results of calculation of drag coefficient for awnless paddy are presented in Figure 6. The drag coefficient for awnless paddy of Hashemi and Gilaneh varieties varied from 0.685 to 0.609 and 0.701 to 0.654, respectively when the moisture level increased from 8% to 13% (w.b.).

It is also observed from Figure 6 that the value of drag coefficient for awnless paddy of Gilaneh variety was more as compared to awnless paddy of Hashemi variety. This is due to the difference in size and mass of the two tested varieties.

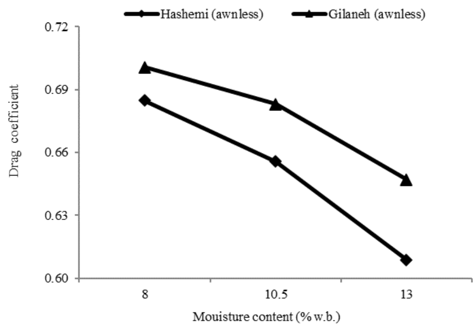

Figure 6 Variations in drag coefficient of awnless paddy with moisture content

The drag coefficient of awnless paddy decreased with the increase in moisture content for the two varieties in moisture content from 8% to 13% (w.b.). Junior et al. (2007), Gupta et al. (2007), Irtwange and Igbeka (2003), Shahbazi et al. (2014) and Zewdu (2007) reported similar results for coffee cherries, sunflower seed and African yam bean (cv. TSS 138), Tef grain, Makhobeli, triticale and wheat seeds, respectively.

The variations in drag coefficient with moisture content for the two awnless varieties of paddy are represented by the correlations in Table 9. These equations showed that the drag coefficient also has linear relationship with the moisture content.

Table 9 Correlations between drag coefficient and moisture content

Variety	Regression modeling	R^2
Hashemi (awnless)	C_d = -0.038×MC + 0.7257	0.98
Gilaneh (awnless)	C_d = -0.0236×MC + 0.7263	0.98

Note: MC: Moisture content level (%w.b.)

4 Conclusions

1. Awn, variety and moisture content influenced the aerodynamic and physical properties of paddy. Thousand grain mass, mass density, arithmetic mean diameter, geometric mean diameter, cross section area, and terminal velocity of Hashemi variety were greater than Gilaneh variety. Sphericity of Gilaneh were more than Hashemi. Thousand grain mass, porosity and terminal velocity of awned paddy were higher than awnless paddy in two varieties. But awnless paddy exhibited higher value of mass density than awned paddy in moisture content from 8% to 13% (w.b.).

2. Terminal velocity of paddy in Hashemi and Gilaneh varieties increased linearly as the paddy moisture content increased.

3. Drag coefficient of awnless grains decreased with increase in moisture content, whereas resistance coefficient of awned grains increased.

4. The presence of the awn influences the aerodynamic properties of the paddy grains and, as a result, affects the design parameters of the machines used in the post-harvest processes. Obtained aerodynamic properties values provided baseline data which are useful in the design of pneumatic conveying device.

References

Alizadeh, M. R., S. Minaee, T. Tavakoli, and M. H. Khoshtaghaza. 2006. Effect of de-awning on physical properties of paddy. *Pakistan Journal of Biological Sciences*, 9(9): 1726-1731.

Alizadeh, M. R., and S. Minaei. 2012. Effect of de-awning and moisture content on some frictional properties of paddy. *Journal of Food Process Engineering*, 35(3): 471-482.

Aydin, C. 2002. Physical properties of Hazel Nuts. *Biosystems Engineering*, 82(3): 297-303.

Ben, L., Z. Pei, L. Jie, Y. Xin, P. Qiao, H. Long,C. Chao, Z. Liang, and L. Chao. 2016. Fine mapping of two additive effect genes for awn development in rice (*Oryza sativa L.*). *PLOS ONE*, 11(8): e0160792.

Bueermann, M. 1991. Teilvisuelle Bestimmung von Koernerbruch bei Weizen (Partly vision assisted determination of damaged grains). In *6 Dresdner Landtechnisches Colloquium, 20 Jahre Maehdrescherforschung an der TU-Dresden*. Dresden: 25-26 September.

Carman, K. 1996. Some physical properties of lentil seeds. *Journal of Agricultural Engineering Research*, 63(2): 87-92.

Corre, P. C., F. S. D. Silva, C. Jaren, P. C. A. Junior, and I. Arana. 2007. Physical and mechanical properties in rice processing. *Journal of Food Engineering*, 79(1): 137-142.

El-Sayed, A. S., R. Yahaya, P. Wacker, and H. D. Kutzbach. 2001. Characteristic attributes of the peanut (*Arachis hypogaea L.*) for its separation. *International Agrophysics*, 15(4): 225-230.

Ghamari, S., H. Goli, A. Khanahmadzadeh, and K. Mohammadi. 2014. Effect of moisture content on terminal velocity of chickpea varieties. *International Journal of Agriculture and Forestry*, 4(3A): 8-11.

Gharekhani, M., M. Kashaninejad, A. D. Garmakhany, and A. Ranjbari. 2013. Physical and aerodynamic properties of paddy and white rice as a function of moisture content. *Quality Assurance and Safety of Crops and Foods*, 5(3): 187-197.

Güner, M. 2007. Pneumatic conveying characteristics of some agricultural seeds. *Journal of Food Engineering*, 80(3): 904-913.

Gupta, R. K., G. Arora, and R. Sharma. 2007. Aerodynamic properties of sunflower seed (*Helianthus annuus L.*). *Journal of Food Engineering*, 79(3): 899-904.

Irtwange, S. V., and J. C. Igbeka. 2003. Effect of accession and moisture content on aerodynamic properties of African yam bean (*Sphenostylis Stenocarpa*). *Applied Engineering in Agriculture*, 19(3): 321-328.

Junior, P. C. A., P. C. Correa, F. A. C. Pinto, and D. M. Queiroz. 2007. Aerodynamic properties of coffee cherries and beans. *Biosystems Engineering*, 98(1): 39-46.

Khodabakhshian, R., B. Emadi, M. Khojastehpour, and M. R. Golzarian. 2018. Aerodynamic separation and cleaning of pomegranate arils from rind and white segments (locular septa). *Journal of the Saudi Society of Agricultural Sciences*, 17(1): 61-68.

Khoshtaghaza, M. H., and R. Mehdizadeh. 2006. Aerodynamic properties of wheat kernel and straw materials. *CIGR Journal*, manuscript No. FP 05 007.

Minaei, S., M. R. Alizadeh, M. H. Khoshtaghaza, and T. Tavakoli. 2007. Effects of de-awning and moisture content on husking characteristics of paddy in rubber-roll husker. *American-Eurasian Journal of Agricultural and Environmental Sciences*, 2(1): 01-05.

Mohsenin, N. N. 1986. *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics, and Mechanical Properties.* New York: Gordon and Breach Science Publishers.

Nimkar, P. M., D. S. Mandwe, and R. M. Dudhe. 2005. Physical properties of moth gram. *Biosystems Engineering*, 91(2): 183-189.

Ozarslan, C. 2002. Physical properties of cotton seed. *Biosystems Engineering*, 83(2): 169-174.

Patel, N., S. K. Jagan, S. K. Jha, J. P. Sinha, and A. Kumar. 2013. Physical properties of basmati varieties of paddy. *Journal of Agricultural Engineering*, 50(4): 39-47.

Rajabipour, A., A. Tabatabaeefar, and M. Farahani. 2006. Effect of moisture on terminal velocity of wheat varieties. *International Journal of Agriculture and Biology*, 8(1): 10-13.

Razavi, S. M. A., and R. Farahmandfar. 2008. Effect of hulling and milling on the physical properties of rice grains. *International Agrophysics*, 22(4): 353-359.

Shahbazi, F. 2013. Aerodynamic properties of wild mustard (*Sinapis arvensis L.*) seed for separation from canola. *Journal of the Science of Food and Agriculture*, 93(6): 1466-1470

Shahbazi, F., S. Valizadeh, and A. Dowlatshah. 2014. Aerodynamic properties of Makhobeli, triticale and wheat seeds. *International Agrophysics*, 28(3): 389-394.

Sitkei, G. R. 1986. *Mechanics of Agricultural Materials*. Netherlands: Elsevier Science.

Suthar, S. H., and S. K. Das. 1996. Some physical properties of karingda [*Citrullus lanatus* (Thumb) Mansf] seeds. *Journal of Agricultural Engineering Research*, 65(1): 15-22.

Toriba, T., and H. Y. Hirano. 2014. The drooping leaf and osettin2 genes promote awn development in rice. *The Plant Journal*, 77(4): 616-626

Yang, W., T. J. Siebenmorgen, T. P. H. Thielen, and A. G. Cnossen. 2003. Effect of glass transition on thermal conductivity of rough rice. *Biosystems Engineering*, 84(2): 193-200.

Zewdu, A. D. 2007. Aerodynamic properties of tef grain and straw material. *Biosystems Engineering*, 98(3): 304-309.