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Effects of paddy variety, air flow rate and moisture content on the performance of a pneumatic paddy collecting device

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Key words: Rice paddy, Pneumatic collecting device, Collecting capacity, Power consumption, Collecting efficiency, Broken grains

Abstract

In this research, the effect of paddy variety (VA), moisture content (MC) and air flow rate (AF) on the performance of negative pressure pneumatic collecting system and the quality of the collected product was examined. The experiments were carried out at two levels of paddy variety, namely Hashemi and Gilaneh, three levels of moisture content (8, 10.5 and 13% w.b.) and four levels of air flow rate (65, 75, 85 and 95 L/s). Parameters for evaluation of pneumatic collecting system were collecting capacity (CC), Power consumption (PC) and collecting efficiency (CE). Also quality of the collected product was evaluated based on percentage change in broken grains (ΔBG). Results showed that collecting capacity of Hashemi variety were significantly less than Gilaneh. However the power consumption for collecting of Hashemi variety was greater. Increasing the air flow rate cause an increase in the collecting capacity, power consumption and the percentage of the broken grains and decrease in the collecting efficiency. Increasing moisture content also leads to an increase in power consumption and a decrease in the collecting capacity and the percentage of broken grains.

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Introduction

Rice is one of the most important cereals that is cultivated in more than 50 countries around the world and the annual production of paddy is 730 million ton (Swain *et al.*, 2019). Rice paddy cultivars in Iran are categorized into two types of local and high-yielding varieties. Local varieties are preferred by consumers because of aroma and high quality. One of the unique specifications of local varieties that does not exist in most high-yielding varieties is awn. That is a narrow and needle structure that forms at the end of the lemma (Toriba and Hirano, 2014). The presence of awn in paddy is attributed to genetic and environmental factors (Li *et al.*, 2016).

Spreading of harvested paddy grains on cement surface and sun-drying is one of the conventional methods to reduce moisture content, for postharvest processing and prevention of deterioration of product (Imoudu and Olufayo, 2000). The challenge for farmers in using of sun-drying is how to handle a large amount of grain after drying. They spread the paddy in the surface after threshing. Then, the paddy is piled and placed in a bag. Currently, all of the above operations are done manually that is time-consuming and difficult. The presented solution is the using of a negative pressure pneumatic collecting system.

In the design of the pneumatic conveying system, many factors, including the physical and aerodynamic properties of the product, must be considered. Specification and performance of pneumatic conveying systems including conveying capacity and power consumption depend on the conveying path, operational conditions and material properties (Pan, 1999). The system's conveying capacity can be affected by the flow velocity, the air velocity, the system pressure drop, and the condition of the conveyed material. Aquino *et al.* (2013) studied the conveying capacity, fuel consumption and noise level of a pneumatic conveying device for collecting dried paddy from concrete surfaces. They concluded that an increase in the speed of fan caused an increase in conveying capacity, noise level, and fuel consumption. Power consumption is the principal parameter in the collecting system selection. It depends on various parameters such as loading ratio and air velocity. Power requirements in the positive pressure system for conveying of rice grain investigated by Chung and Verma (1993). The results showed, in a constant conveying ratio, power requirements increased then decreased when air velocity enhanced.

For transforming the paddy to white rice, operations such as threshing, drying, conveying, and milling are performed after harvest. Improper doing of any of these processs causes progressive losses in the final product of rice. One of the main differences between rice and other cereal products is the inverse effect of grain fracture on its economic value. By increasing the number of broken kernels and consequently reducing head rice yield, rice value is reduced, as the economic value of broken rice is half that of rice with the whole kernel (Siebenmorgen, 1993). Several investigations have been done to determine the quality damage of rice grains and its consequence losses due to the machine, product, and environment various factors at different stages of post-harvest (Ambardekar *et al.*, 2011; Aquerreta *et al.*, 2007; Dong *et al.*, 2010; Feliz *et al.*, 2005; Iguaz *et al.*, 2006; Imoudu and Olufayo, 2000; Kaensup *et al.*, 2006; Li *et al.*, 2014; Ondier *et al.*, 2012; Reid *et al.*, 1998; Sharma *et al.*, 1992; Xangsayasane *et al.*, 2019; Zareiforoush *et al.*, 2010a).

In southeast Asian countries, the losses in harvesting operations is 10-37% of rice production (Zareiforoush *et al.*, 2010a). A review of the researches shows the qualitative damage of different crops such as chickpea, corn, rice, and cotton seeds have been studied on positive pressure pneumatic conveying systems (Baker *et al.*, 1986; Chung and Verma, 1993; Kiliçkan and Güner, 2010; Kilickan and Güner, 2006). However, so far, no study has been done to investigate the qualitative damage of paddy grains during the conveying process by the negative pressure pneumatic conveying. Hence the objective of this study is to determine the effects of paddy variety, moisture content and air flow rates on the performance of negative pressure pneumatic collecting system and the quality of the collected product. The results of this research can be used for proper design and selection of a negative pneumatic collecting system in rice paddy handling and reduction of product damage.

Materials and methods

In this research, Hashemi and Gilaneh variety of paddy that cultivated in Iran rice research institute was used. Hashemi variety is one of the local variety in the north of Iran with the slender kernel and long awn (Zareiforoush *et al.*, 2009). Gilaneh variety is one of the new high-yielding variety produced in Iran's Rice Research Institute. Physical and aerodynamic properties of these varieties are shown in Table 1.

Firstly, foreign matter, broken and immature seeds were cleaned and removed. Initial moisture content was obtained by placing a sample in the oven at 130 °C for 24 hours (Pan *et al.*, 2008). The initial moisture content of paddy grains was 13% w.b.

Table 1. Physical and aerodynamic properties of Hashemi and Gilaneh paddy varieties.

Variety	Moisture content (%w.b.)	Thousand grain mass (g)	Mass density (kg/m^3)	Sphericity (mm)	Arithmetic mean diameter (mm)	Geometric mean diameter (mm)	Terminal velocity (m/s)
Hashemi	8	24.34 (0.60)	1338.56 (7.31)	0.335 (0.012)	4.72 (0.12)	3.41 (0.08)	5.82 (0.08)
	10.5	24.97 (0.27)	1347.93 (9.25)	0.337 (0.011)	4.75 (0.15)	3.45 (0.11)	5.96 (0.09)
	13	25.59 (0.25)	1354.21 (5.03)	0.345 (0.011)	4.79 (0.12)	3.52 (0.09)	6.26 (0.19)
Gilaneh	8	21.02 (1.06)	1273.65 (8.59)	0.349 (0.013)	4.46 (0.15)	3.30 (0.09)	5.62 (0.05)
	10.5	21.94 (0.21)	1276.39 (7.66)	0.351 (0.013)	4.48 (0.12)	3.33 (0.09)	5.75 (0.06)
	13	22.42 (0.58)	1301.23 (7.80)	0.355 (0.011)	4.52 (0.14)	3.38 (0.10)	5.90 (0.17)

Values in parenthesis are standard deviation.

The effect of three levels moisture content of grains, namely, 8, 10.5 and 13% w.b. on collecting system performance and quality of the collected grains was investigated. These moisture content levels are moisture ranges of paddy grains for post-harvest processes such as conveying, husking, and storage. The paddy samples dried in a batch type dryer to desired moisture content levels.

The moisture content was measured by using a pre-calibrated digital moisture meter (GMK 303RS Model, South Korea). When the moisture content of paddy grains reached the desired level, the grains were poured into polyethylene bag and closed tightly.

In order to investigate the air flow rate influence on collecting system performance and quality of the collected grains, a negative pressure pneumatic collecting apparatus designed and constructed. Effect of air flow rate in four levels, namely, 65, 75, 85 and 95 L/s was evaluated. The apparatus consist of a fan connected to an 1.5kW electromotor, 1D2D cyclone with inlet diameter of 3 inches, 6 inches rotary valve with power of 1.1kW, 4m long flexible pipe with 3 inch diameter, a galvanized nozzle with a rectangular inlet of 200×22mm included two wheels to keep constant angle of 50 degree between the nozzle and the pipe relative to the ground. All of the parts assembled on a mobile chassis. The choice of this angle was due to the way the nozzle and pipe were placed in the actual working conditions.

The schematic of the apparatus is shown in Fig. 1. To create different levels of air flow rate, the rotating speed of the electromotor of the fan was changed using a digital inverter (SINUS VEGA 00003 2S, Italy). Air flow rate was measured using air flow meter (AM-4206M, Taiwan).

Experimental procedure

In each replication, paddy was spread on the concrete surface at 3 to 4cm thickness proportional to real work conditions with 20cm width proportional to the width of the nozzle. Then by moving nozzle on paddy, collecting of grains from the concrete surface into the bags was carried out.

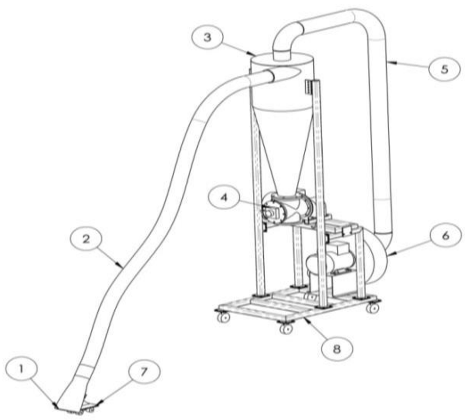
Collecting capacity was obtained by measuring the amount of conveying paddy in certain time using equation (1). $CC = 3600 \times \frac{m_c}{t}$ … … … … … … . (1)

Where,

CC = Collecting capacity, kg/hr

m_c = Weight of collected paddy, kg

t = Time of collecting, s



1-Nozzle
2- Air-paddy suction line
3- Cyclone
4- Rotary valve
5- Air Suction line
6- Fan
7- Wheel
8- Chassis

Fig. 1. Schematic of the negative pressure pneumatic conveyor of rice paddy.

The weight of collected paddy was measured using an electronic balance reading weight to an accuracy of 0.01g (model PDS-600). The collecting time was measured by a chronometer. Power consumption of the system was measured using a power meter with the ability of monitoring which was connected to a computer (Zareiforoush *et al.*, 2010b). The instantaneous values of measured data were monitored by a continually on-line monitoring program. By dividing collected paddy weight by spread out paddy weight, the yield of the machine was obtained (equation 2).

$$CE\ (\%) = \frac{m_c}{m_t} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where,

CE = Collecting capacity, %

m_c= Weight of collecting paddy in outlet of rotary valve, kg

m_t = Weight of paddy spread out on concrete surface, kg

In order to determine percentage changes in broken in each replication, 100g samples were taken prior to the entry of the paddy to the conveying device and after passing through a device at the rotary valve output and the corresponding inlet and outlet values compared. The samples were poured inside a polyethylene bag and closed tightly. Their mass was measured by a precision electronic balance reading mass to an accuracy of 0.001g (Sartorius 6124, Germany). Broken grains were manually separated from samples. Equation 4 was applied to determine the broken grains percentages (Zareiforoush *et al.*, 2010a). $BG\ (\%) = \frac{m_{BG}}{m_S} \times 100$ … … … … … … … (3).

Where,

BG = mass percentage of broken grains

m_{BG} = mass of broken grains, g

m_S = mass of sample, g

Experimental design and statistical analysis

In this research, experiments were conducted based on the factorial design. In order to investigate performance of device, 24 treatment include paddy variety in two-level namely Hashemi, Gilaneh, moisture content in three levels namely 8, 10.5 and 13%, and air flow rate in four levels, namely, 65, 75, 85 and 95 L/s were evaluated on the basis of randomized complete block design. At each treatment, the experiments were replicated three times and the average values were reported. The mean, standard deviation, and correlation coefficient of the parameters were determined using Microsoft Excel 2013 software program. The difference between the treatments was determined by analysis of variance (ANOVA) and comparison of the treatment mean by least significant difference (LSD) test using SPSS 23 software.

Results and discussion

Collecting Capacity

The effects of paddy variety, moisture content and air flow rate on the performance parameters of pneumatic collecting device are shown in Table 2. The results of ANOVA showed the effects of air flow rate, moisture content, and paddy variety and interaction effect of paddy variety and air flow rate and, interaction effect of paddy variety and moisture content are significant ($p<0.01$) on collecting capacity. Comparing the interaction effect of paddy variety and air flow rate showed collecting capacity of Hashemi and Gilaneh variety increased significantly with the increase of air flow rate from 65 to 95 L/s (Table 3). Increasing the air flow rate causes more suction in the nozzle and thus increases the flow of the paddy into the conveying pipe. According to Table 3 and 5, by increasing the moisture content from 8 to 13%, the collecting capacity of the device decreases for both varieties. Increasing the moisture content of the grains increases the internal friction coefficient (Alizadeh and Minaei, 2012) and the terminal velocity of paddy, which can slow the Input flow paddy to the conveying path and consequently reduce the collecting capacity. As shown in Fig. 2, collecting capacity of the Hashemi variety is lower than that of the Gillaneh at all levels of air velocity and all levels of moisture content.

This can be attributed to higher thousand grain mass, true density, internal friction coefficient, and terminal velocity of Hashemi variety compared to Gilaneh (Table 1). Higher friction coefficient, thousand grain mass, and terminal velocity caused more drop pressure in the inlet of the nozzle and the results of these factors will reduce the collecting capacity. Mean values of collecting capacity in the different levels of air flow rate and moisture content for Hashemi and Gilaneh variety is shown in Table 6. The maximum value of collecting capacity is 675.06 kg/hr for Gilaneh at moisture content of 8% and air flow rate of 95 L/s and the minimum value is 275.54 kg/hr for Hashemi at moisture content of 13% and air flow rate of 65 L/s.

The equations correlating the relationship between the air flow rate and the values of the collecting capacity, are presented in Table 8. As it can be seen, the presented equations are linearly related with high coefficients of determination.

Table 2. ANOVA indicating the effects of air flow rate, moisture content and variety on the paddy collecting machine performance.

Source	DOF	"F" values			
		CC (kg/hr)	PC (W)	CE (%)	ΔBG (%)
AF	3	4881.106^{**}	7165.855^{**}	86.604^{**}	144.496^{**}
MC	2	56.276^{**}	36.591^{**}	0.027^{ns}	43.002^{**}
VA	1	188.629^{**}	1.057^{ns}	7.230^{**}	5.069^{*}
AF×MC	6	1.517^{ns}	0.579^{ns}	0.597^{ns}	0.649^{ns}
AF×VA	3	24.220^{**}	6.976^{**}	2.709^{ns}	3.112^{*}
MC×VA	2	16.342^{**}	2.082^{ns}	1.673^{ns}	0.289^{ns}
AF×MC×VA	6	0.836^{ns}	1.845^{ns}	0.437^{ns}	2.171^{ns}

**: Significant on the 1% probability level, *: Significant on the 5% probability level, ns: not statistically significant. AF: Air flow rate, MC: Moisture content, VA: Paddy variety, CC: Collecting capacity, PC: Power consumption, CE: Collecting efficiency, ΔBG: Broken grains variation.

Table 3. Comparsion of means of parametes at different levels of the air flow rate, moisture content and paddy variety using the Duncan test method.

Factor	CC (kg/hr)	PC (W)	CE (%)	ΔBG (%)
AF (L/s)				
65	284.00d	549.27d	99.98a	0.14d
75	391.38c	666.56c	99.98a	0.22c
85	522.16b	804.83b	99.96b	0.33b
95	624.98a	970.41a	99.92c	0.43a
MC (% w.b.)				
8	469.35a	735.77c	99.96a	0.34a
10.5	455.91b	749.51b	99.96a	0.28b
13	441.63c	758.03a	99.96a	0.22c
VA				
Ha	440.97b	746.67a	99.96b	0.27b
Gi	470.29a	748.87a	99.97a	0.29a

In each column, means followed by same letter are not significantly different at 5% level. AF: Air flow rate, MC: Moisture content, VA: Paddy variety, CC: Collecting capacity, PC: Power consumption, CE: Collecting efficiency, ΔBG: Broken grains variation.

Table 4. Interaction effect of air flow rates and variety on changes in the collecting capacity, power consumption, and broken grains variation at different levels of evaluated factors.

AF (L/s)	CC (kg/hr)		PC (W)		ΔBG (%)	
	Variety		Variety		Variety	
	Ha	Gi	Ha	Gi	Ha	Gi
65	281.89 g	286.11g	558.17d	540.38e	0.12e	0.16de
75	381.30 f	401.45e	670.98c	662.13c	0.21cd	0.24c
85	497.20 d	547.11c	803.77b	805.89b	0.33b	0.33b
95	603.50 b	646.47a	971.54a	969.28a	0.44a	0.42a

Values are means of three replicates. In each parameter means followed by same letter are not significantly different at 5% level. AF: Air flow rate, MC: Moisture content, Ha: Hashemi variety, Gi: Gilaneh variety CC: Collecting capacity, PC: Power consumption, ΔBG: Broken grains variation.

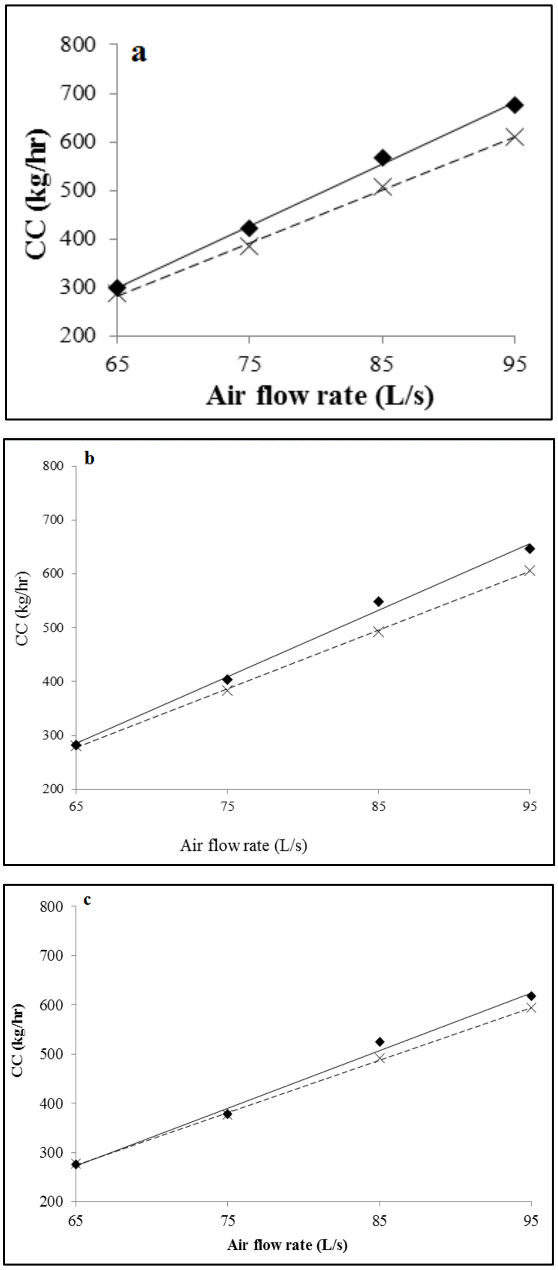


Fig. 2. Variations of collecting capacity with air flow rates and (×) Hashemi; (♦) Gilaneh paddy varieties with (a) 8%, (b) 10.5% and (c) 13% moisture content.

Power consumption

ANOVA results (Table 2) revealed the effects of paddy variety, moisture content and air flow rate and interaction effect of paddy variety and air flow rate are significant on power consumption 1% probability level. The result showed with the increase in moisture content, power consumption increased (Table 3).

Increasing the moisture content of grains increases the thousand grain mass of seeds, true density, and internal friction coefficient and reduces the porosity. The effect of these factors, as well as increasing the terminal velocity of grains, causes an increase in pressure drop of the collecting system, thus more power required to overcome the additional pressure drop. The mean values of the interaction effect of paddy variety and air flow rate on power consumption are presented in Table 4.

The result showed with the increase of air flow rate from 65 to 95L/s, power consumption of Hashemi and Gilaneh varieties increased. Increasing the air flow rate leads to an increase in air velocity, paddy velocity and the rate of collision of the grains with each other and the wall of the pipe.

Hence, the pressure drop will increase in the system and power consumption will increase, consequently. Chung and Verma (1993) reported the same result for rice conveying by a positive pneumatic conveying system. Fig. 3 shows the changes in power consumption of Hashemi and Gilaneh varieties proportional to the increase in the air flow rate at three levels of moisture content.

As you can see, at all three levels of moisture content, the power consumption proportional to the air flow rate increases linearly.

The mean values of power consumption are shown in Table 4. The maximum value of power consumption is 983.38 w for Gilaneh variety at moisture content of 13% and air flow rate of 95 L/s.

Table 5. Interaction effect of moisture content and variety on the collecting capacity.

Variety	CC (kg/hr)		
	Moisture Content (%)		
	8	10.5	13
Ha	447.29 b	441.12 b	434.51 c
Gi	491.41a	470.70 a	448.74 b

Means followed by same letter are not significantly different at 5% level.

Table 6. Mean values of the collecting capacity and, power consumption.

Variety	AF (L/s)	CC (kg/hr)			PC (W)		
		Moisture Content (%)			Moisture Content (%)		
		8	10.5	13	8	10.5	13
Ha	65	287.25*	281.49	275.54	521.70	547.11	552.33
	75	384.53	383.01	376.37	655.04	675.69	682.20
	85	507.11	493.21	491.29	788.98	800.87	821.46
	95	610.29	606.78	593.44	961.08	972.86	980.68
Gi	65	300.05	282.75	276.93	554.75	557.13	562.63
	75	422.08	404.60	377.69	658.84	660.67	666.90
	85	568.45	548.42	524.45	796.22	806.83	814.62
	95	675.06	647.04	617.31	949.53	974.94	983.38

*Values are means of three replicates.

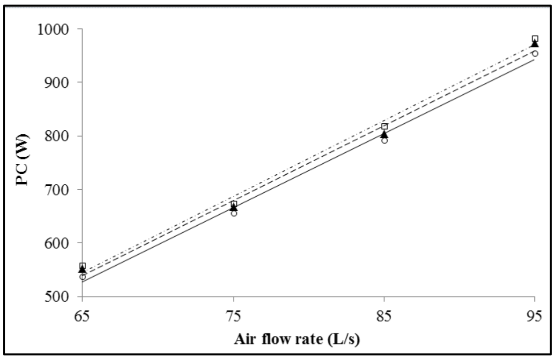


Fig. 3. Variations of power consumption with air flow rates and (○) 8%, (▲) 10.5%, (□) 13% moisture content.

Collecting efficiency

The results of the analysis of variance of collecting efficiency (Table 2) showed that the effect of air flow rate and variety on the collecting efficiency of machine was significant at 1% probability level. The results showed with increasing of air velocity, the collecting efficiency of pneumatic collecting device decreases. The reason for this can be attributed to the increase in the velocity of the grains inside the cyclone due to the increase in the air flow rate. By increasing the velocity of the grains, the time of suspending the grains in the cyclone increases, which causes the grains to be drawn into the suction tube. Therefore, instead of being discharged by the rotary valve, the grains are entered to the inlet of fan and thrown out to outside through the outlet valve and reduce the collected grains. In Fig. 4, the variations in the collecting efficiency proportional to the flow rate are shown for the Hashemi and Gilaneh varieties. As can be seen, the type of variation function is quadratic and decreases in higher air flow rate. The highest value of collecting efficiency was 99.98 % in air flow rate of 65L/s and the lowest value was 99.90% in air flow rate of 95 L/s. The equations correlating the relationship between the air flow rate and the values of the collecting efficiency, are presented in Table 7.

Broken grains

Effects of air flow rate, moisture content, and paddy variety on percentage change of broken grains are shown in Table 1. The results showed that the effect of air flow rate and moisture content on paddy grains breakage was significant at 1% probability level and the effect of paddy variety and the interaction effect between paddy variety and air flow rates were significant at 5% probability.

Variations in broken grains percentage at different air flow are shown in Fig. 3. It can be seen that with an increase in air flow rate, the percentage of broken grains increases. This related to more force that exerts on grains at higher air flow rate due to higher air velocity. Mechanical damage of wheat, barley, sunflower, lentil (Güner, 2007), cotton seed (Kılıçkan and Güner, 2006) and chickpea (Kiliçkan and Güner, 2010) was studied during conveying by a positive pressure conveying system. The results of this study showed that the increase of air velocity, cause an increase in mechanical damage of seeds. The results of the mean comparison of the broken grains at different levels of moisture content are presented in Table 3. As can be seen, with increase in moisture content the percentage of broken grains decreases. According to Table 8 the maximum increase in broken grains percentage (0.55%) was obtained at 8% moisture and 95L/s air flow rate for Gilaneh variety and the minimum value (0.09%) was obtained at 13% moisture and 65 L/s air flow rate for Hashemi paddy.

Table 7. Mean values of the collecting efficiency and broken grains variations.

Variety	AF (L/s)	CE (%)			ΔBG (%)		
		Moisture Content (%)			Moisture Content (%)		
		8	10.5	13	8	10.5	13
Ha	65	99.98*	99.98	99.98	0.15	0.11	0.09
	75	99.98	99.98	99.98	0.30	0.19	0.12
	85	99.97	99.97	99.96	0.41	0.35	0.24
	95	99.92	99.90	99.89	0.48	0.45	0.39
Gi	65	99.98	99.98	99.99	0.21	0.15	0.13
	75	99.98	99.98	99.98	0.28	0.25	0.19
	85	99.97	99.97	99.97	0.37	0.33	0.29
	95	99.93	99.93	99.94	0.55	0.42	0.31

*Values are means of three replicates.

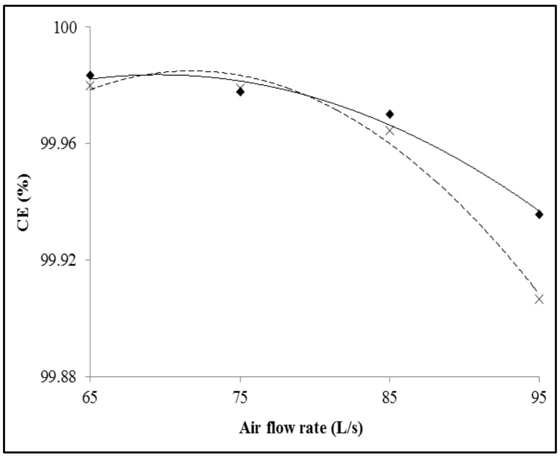
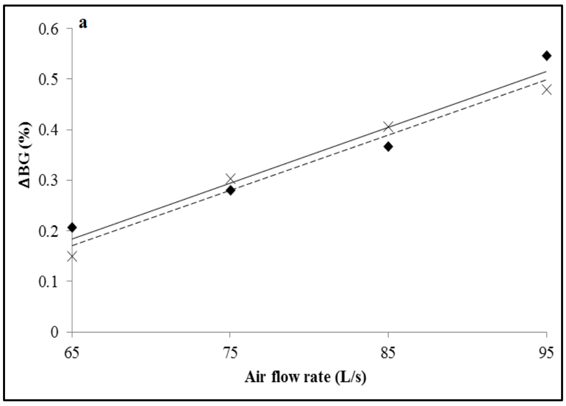
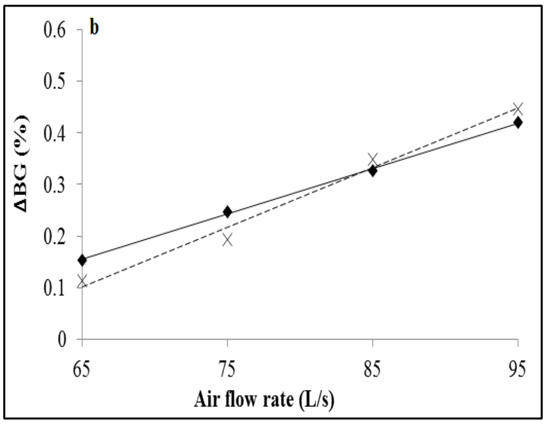


Fig. 4. Variations of collecting efficiency with air flow rates and (×) Hashemi; (♦) Gilaneh paddy varieties.





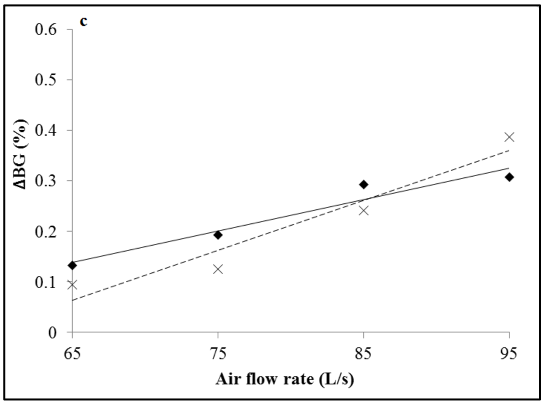


Fig. 5. Variations of broken grains with air flow rates and (×) Hashemi; (♦) Gilaneh paddy varieties with (a) 8%, (b) 10.5% and (c) 13% moisture content.

Conclusions

- The results showed that in a pneumatic collecting device, the variety changes the collecting capacity, collecting efficiency, and percentage of broken grains, but did not affect on power consumption.
- With an increase in moisture content, collecting capacity and percentage of broken grains are decreased and power consumption are increased. This means, for obtaining the highest collecting capacity and lowest energy consumption cost, paddy should be collected at the minimum level of moisture content.
- Increasing air flow rate causes to increase in collecting capacity, power consumption, and percentage of broken grains and decrease in collecting efficiency. Therefore, selecting the maximum value of air flow rate will result in the maximum value of collecting capacity but damages to the grains should be considered.

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Nomenclature

AF	Air flow rate (L/s)	MC	Moisture content (% w.b.)
CC	Collecting capacity (kg/hr)	PC	Power consumption (W)
CE	Collecting efficiency (%)	VA	Paddy variety
Gi	Gilaneh variety paddy	ΔBG	Broken grains variations (%)
Ha	Hashemi variety paddy		

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