Toward mechanized saffron farms by a full-hydraulically mounted saffron corm sorter

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Abstract: In this research, a saffron corm sorter was designed and manufactured. Inside the drum screen, a rubber blade impeller with three vanes was installed. The speed and direction of rotation of this impeller is the same as the drum screen. The saffron corms are poured into the sorter through inlet by the worker, and while moving forward, the different sizes of corms are separated from each other. Therefore, the lumpy soil and small corms fall to the ground from the distance between the bars of the drum screen. Also, large corms are also discharged from the end of the drum screen. The excess peel of saffron corms is discharged from the end of the drum with the help of fan air flow. In order to evaluate the sorter, the effect of feeding rate at three levels of 300, 400 and 500 kg h^{-1}, drum rotation speed at three levels of 0.26, 0.42 and 0.63 m s^{-1} and the speed of rubber impeller at two levels of 1.18 and 1.77 m s^{-1} was studied. Therefore, the amount of damaged corms and grading accuracy were evaluated. The optimum performance of corm sorter was obtained in the feeding rate of 400 kg h^{-1} and the rotational speed of 8 rpm. In this condition the maximum grading accuracy and minimum level of damage can be reached. The rubber blade impeller has a better performance at the rotational speed of 1.30 m s^{-1} than the rotational speed of 1.96 m s^{-1}.

Keywords: Mechanization, Saffron corm, Sorter, Feeding rate, Damaged corm

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1 Introduction

The dried stigma of saffron flower (*Crocus Sativus L.*) is one of the most expensive spices in the world. Iran was the main producer of this product in 2020. The annual production of this product in Iran was about 480 tons (approximately 94% of the world production). After Iran, there were countries like Spain, India and Greece (Anon, 2009; Gandomzadeh et al., 2024). The production of saffron is very complicated. In addition to suitable weather

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conditions, labor is another limitation of saffron production in many countries. Compared to other agricultural products, saffron production is not mechanized. Corn planting, flower harvesting and separating the stigma are the most important stages of saffron production, which require considerable labor (Saeidirad, 2020).

The productivity of saffron farms varies from 5 and sometimes up to 10 years depending on the initial density of corn planting. After this period of time, the growing of the corms and the yield of the soil are greatly reduced. Because the corms increase and there is insufficient space for growth. Therefore, saffron corms should be harvested and transferred to a new farm. About 20 to 30 tons of corms can be harvested from such fields. These corms are connected to each other in bunches around the mother corms. These bunches should be separated and their excess peel should be removed. Most importantly, the corms should be sorted. In the first year, corms weighing less than 6 grams are not able to flower. Therefore, it is recommended to separate them from the mother corms. In most areas, sorting the saffron corms is done by labor, which is time-consuming and expensive.

The saffron corm is spherical with a hard white texture. The corm is covered with a thin brown peel, which is thicker on the outer parts and acts as a protection. The weight of saffron corms varies between 2 and 40 grams whose weight is not more than 15 grams in Razavi Khorasan province, Iran.

In general, two types of equipment are used for grading agricultural products based on weight. The first type is called mass sorter. The second type is known as size-based sorter. In this type, the product is graded based on some dimensions and geometric features. Therefore, different methods are used to grade the product in this type of sorter. The most important of these methods are screening, divergent sorters and image processing (machine vision). Most machines designed to grade saffron corms classify the corms by size and usually use a rotary sieve. Some studies used a cylindrical sieve to grade the corms. In this mechanism, the smaller corms pass through the rotating drum rods, and the larger corms discharge from the drum along its slope. The performance of the equipment was evaluated by considering different levels of design parameters, including rotation speed, longitudinal slope of drum, and feeding rate. The results showed that the sorter was able to grade saffron corms with 79% accuracy (Ghanbarian, 2013).

Researchers developed a manual sorter equipment for onion bulbs. This equipment was designed in such a way that it was able to classify onion bulbs in three groups: 0-40 mm, 40-60 mm and > 60 mm. This equipment had one output for each group of onion bulbs. Its input rate is about 160 onion bulbs at the same time. The length and diameter of the cylinder were 1000 and 400 mm, respectively. The length of the cylinder was divided into two sections with lengths of 600 and 400 mm. The distance between the bars in these two sections was 40 and 60 mm, respectively. The drive shaft diameter was 30 mm. The effects of feeding rate (half full and full) and rotation speed (0.31, 0.63, 0.94, 1.25 and 1.57 m s^{-1}) on efficiency and capacity were investigated. The maximum efficiency and capacity were 80% and 82.75 g s^{-1}, respectively. The results showed that feeding rate and rotation speed have a significant effect on the performance of the sorter (Umani and Markson, 2020). Others designed and evaluated a sorter for rose onions based on geometric dimensions. This device included an oscillating sieve, an outlet, and a feeding hopper with a capacity of 40 kg. The evaluation of this equipment was done on different slopes and feeding rates and oscillation in two different directions. The results showed that 4-degree slope, longitudinal oscillation and full feeding rate lead to the highest performance. In this condition, the sorter had a capacity of 1105 kg h^{-1} and an efficiency of 75% (Gayathri et al., 2016).

As can be seen in Table 1, significant studies have been conducted in the field of sorting a wide range of agricultural products such as onion, tomato, potato, apple and olive. But there is a lack of research in the field of saffron corm. On the other hand, the results show that the grading accuracy in the aforementioned products is more than 76.35%. In addition, manual roller sorter has been used in these studies, which is time-consuming and costly. Therefore, it is necessary to design, manufacture, and evaluate a non-manual sorter for saffron corm.

Table 1 Previous studies related to the sorting of agricultural products

Products	Method	Results	Ref.
Onion	Manually operated roller grader machine	Reducing the slope of the grader leads to better results	(Mishra et al., 2022)
	Roller grader machine	The grading efficiency was 96.72%	(Ghanem et al., 2021)
Saffron corm	Full-hydraulically mounted saffron sorter	The maximum grading accuracy was 96.25%	***This work***
Potato	In-line sorter	The success of in-line classification of moving potatoes was 96.2%	(ElMasry et al., 2012)
	Parallel conical rollers machine	The machine has the capacity to grade different tuber shapes	(Butler et al., 2005)
	Belt-fed potato sorter	Classification accuracy and damage rate were 98.95% and 1.26% respectively	(Wang et al., 2022)
Tomato	Rotary drum grader	The efficiency of grader was found to be 80% at 16º inclination angle, 175 kgh^{-1} feed rate and 15 rpm speed	(Preetha et al., 2016)
Apple and pomegranate	Spherical fruit grader	The grading efficiency was 76.35%	(Borkar et al., 2013)
Olive	Small cylinder type grading machine	Maximum grading efficiency of 93.92% was obtained	(Hegazy and Mady, 2018)
Sapota fruit	Roller grader machine	The maximum efficiency was 89.48%	(Ukey and Unde, 2010)

To address the need for more efficient and accurate grading of saffron corms, this study aims to design, manufacture, and evaluate a non-manual saffron corm sorter. The proposed system will be capable of separating the corms, removing soil and excess peel, and grading the corms based on their weight and geometric characteristics. In general, the main purpose of this study is to design and manufacture a corm sorter with the ability to separate seeds from each other, remove soil and excess peel, and grade.

2 Materials and methods

2.1 Materials

The saffron corms were sourced from various research fields in Khorasan province, Iran, specifically from Gonabad, Torbat Heydarieh, and Mashhad. The experiments took place at the Agricultural Engineering Research Department in Mashhad (coordinates: 36° 18' 38.5164" N, 59° 35' 58.0452" E). Table 2 presents the physical properties of saffron corms cultivated in different regions of Khorasan province, including weight, geometric diameter, arithmetic diameter, sphericity, particle density, bulk density, and static coefficient of friction (Bakhtiari-Konari et al., 2013).

Table 2 Physical properties of saffron corms (Bakhtiari-Konari et al., 2013)

Physical properties	Lowest	Highest	Mean
Weight (g)	3.85	14.82	7.77
Geometric diameter (mm)	18.34	27.17	22.96
Arithmetic diameter (mm)	18.42	27.49	23.20
Sphericity (dimensionless)	0.83	0.91	0.86
Particle density ($g\ cm^{-3}$)	1.04	1.22	1.19
Bulk density ($g\ cm^{-3}$)	0.45	0.51	0.48
Static coefficient of friction	0.65	0.73	0.70

2.2 Methods

2.2.1 The theory of design

The design of the saffron corm sorter focused on efficiently separating corms, removing excess peel, and grading them into two categories based on weight (>6 g and <6 g). The device consists of three main components: a drum screen, a three-rubber-blade impeller, and a fan. In the saffron corm sorter enhances efficiency and reliability in separation and grading by promoting uniform weight distribution (Searle et al., 2008). The corms and any lumpy soil are separated as the drum rotates, with the rubber impeller assisting in the process by rotating clockwise. The entire device is mounted on a tractor's three-point hitch, and its power is supplied through the tractor's hydraulic system. A hydraulic pump, powered by the power take-off (PTO) shaft, drives the rotation of the drum, impeller, and fan to ensure smooth operation.

Figure 1 shows the process of designing, manufacturing and evaluating the full-hydraulically mounted saffron sorter.

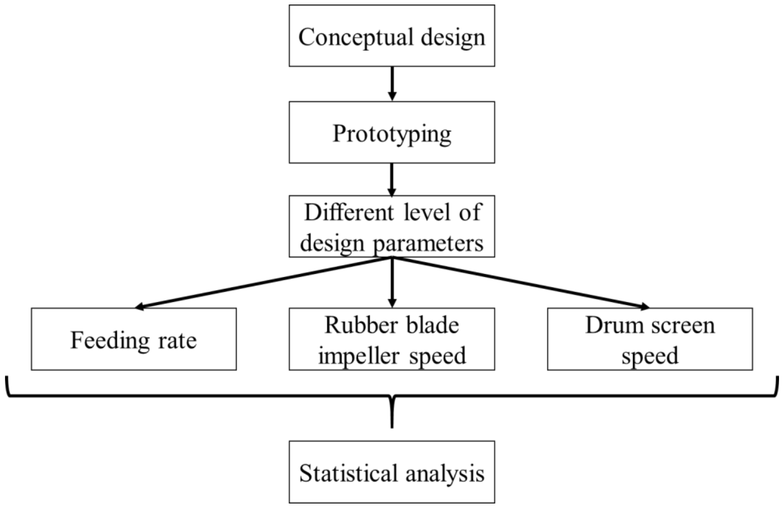

Figure 1 Flowchart of research steps

2.2.2 Design analysis

2.2.2.1 Designing the drum screen

The drum screen is responsible for sorting the saffron corms. According to the technical specifications of the rotary sieve (Jamshidi et al., 2020), in order to achieve the desired capacity (500 kg h^{-1}) the length and diameter of the drum were considered to be 2000 and 1000 mm, respectively (Figure 2). The distance between the drum bars was chosen based on the dimensions of the saffron corms. The minimum values recorded were a weight of 3.85 g measured with a caliper, an arithmetic diameter (*D*) of 18.42 mm, a geometric diameter (*G*) of 18.34 mm, and a sphericity (*S*) of 0.83 (Hassan-Beygi et al., 2010).

$$G = \sqrt[3]{L_1 \times L_2 \times L_3} \quad (1)$$

$$D = \frac{L_1 + L_2 + L_3}{3} \quad (2)$$

$$S = \frac{G}{L_1} \quad (3)$$

Where, L1, L2 and L3 are three perpendicular corm diameters (L1 is main diameter).

Due to the low sphericity of saffron corms and their variable shape, the distance between the drum bars was considered to be 18 mm (Figure 2).

2.2.2.1 Weight of the drum screen (w_c)

This drum had 89 steel bars. The diameter, thickness and length of these bars were 20, 1.5 and 2000 mm, respectively. The weight of each meter of these hollow bars was 0.74 kg. 176 meters of hollow bars were used to make the drum. The weight and mass of the drum were determined using Equations 4 and 5. Descriptions and values of the parameters used in Equations 1 to 10 are given in Table 3 (Umani and Markson, 2020).

$$m_c = m_l \times l \quad (4)$$

$$W_c (or\ W_s) = m_c (or\ m_s) \times g$$

$$m = m_c + m_s \ \ and \ \ W = W_s + W_c \quad (5)$$

2.2.2.2 Requirement of power (P) for rotating the drum screen

The required power for rotating the drum screen was determined using Equation 6-8:

$$P = \frac{2\pi NT}{60} \quad (6)$$

$$T = F_c \times r \quad (7)$$

$$F_c = m\omega^2 r \quad (8)$$

2.2.1.3 Designing the rubber blade impeller

A rubber impeller was designed and manufactured in order to separate the bundles of corms and remove the lumpy soil. The rubber blade impeller was installed eccentrically inside the drum (Figure 3).

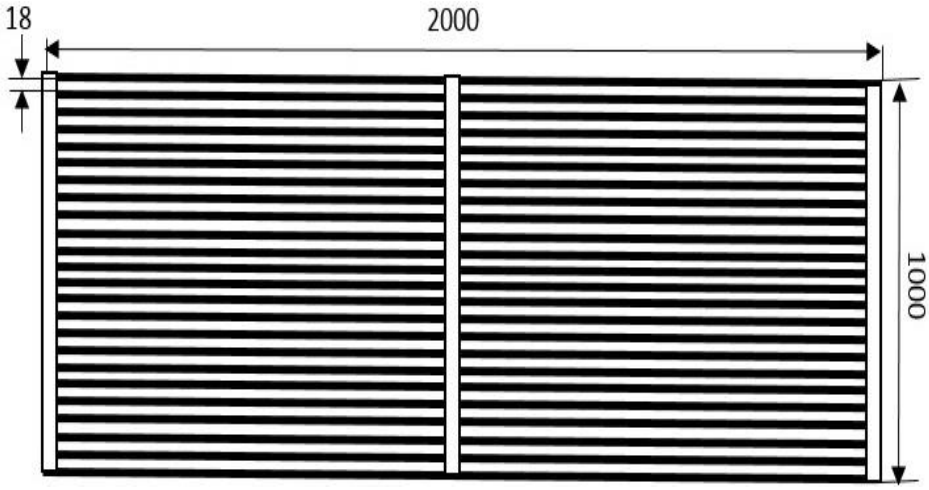

Figure 2 The schematic of drum screen

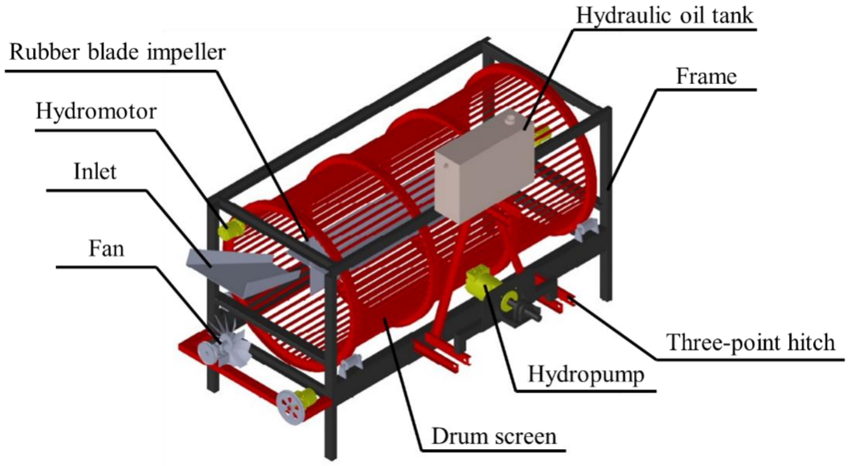

Figure 3 Different parts of corm sorter

The rubber blade impeller has three rubber blades whose thickness, width and length are 20, 200 and 1000 mm respectively. Due to the fact that the separation of corm bundles and the removing the lumpy soil are done in the first half of the drum screen, the length of the rubber blade impeller was considered equal to 50% of the length of the drum. The diameter of the rubber impeller shaft was determined using Equation 9 (Spotts et al., 2004).

$$d^3 = \frac{16}{\pi\tau_{max}}\sqrt{M^2 + T^2}$$

$$R = \frac{W}{2}, \quad M = R \times \frac{L}{2} \quad (9)$$

The drum screen mass was determined using Equation 10:

$$m_{cr} = \rho \times v$$

$$m_T = m_{cr} + m_{sr}, \quad W_T = m_T \times g \quad (10)$$

2.2.1.4 Air blower fan

An air blower fan was used to separate the excess peel of saffron corms. This 6-blade fan had a speed of 4.2 m s^{-1} and capacity of 400 m^3hr^{-1}, which was mounted in the front of the drum and below the rubber blade impeller.

2.2.2 Hydrostatic transmission system

The power required to rotate the drum screen, rubber blade impeller and blower fan was supplied through the hydrostatic transmission system. This system included parts such as hydraulic pump (hydropump), oil tank and three hydraulic motors (hydromotor) that were mounted on the frame of the sorter. The power of the hydropump was provided through the PTO shaft.

Table 3 Description and values of parameters used in Equations 1 to 7

Sym.	Description	Value	Unit
w_c	Weight of the drum screen	1292.17	N
g	Gravitational acceleration	9.81	m s^{-2}
m_c	Mass of the drum screen	131.72	Kg
m_l	Unit mass of the rod	0.74	kg m^{-1}
l	Total length of the rods	178	m
m_s	The average mass of each grade of saffron corms in a capacity of 500 kg.h^{-1}	12.5	Kg
w_s	Weight of saffron corms	122.62	N
m	Total mass of drum screen and mass of each grade of corms	144.22	Kg
W	Total weight drum screen and weight of saffron corms	1414.79	N
P	Required drum screen power	330.62	W
N	Rotational speed of drum screen	20	m s^{-1}
T	Rotational torque value for drum screen	157.94	m
F_c	Centrifugal force value for drum screen	315.89	N
ω	Angular velocity of drum screen	2.093	rad s^{-1}
r	Radius of drum screen	0.5	m
τ_{max}	Allowable shear stress	45	$N\ mm^{-2}$
m_{cr}	Mass of the rubber blade impeller	11.4	kg
ρ	Weight of the rubber blade impeller	0.95	$gr\ cm^{-3}$
v	Volume of the rubber blade impeller	12000	cm^3
m_{sr}	The average mass of each grade of saffron corms on the rubber blade impeller for capacity of 500 kg.h^{-1}	6	Kg
m_T	Total mass of the rubber blade impeller and the mass of the corms	17.4	Kg
W_T	Total weight of the rubber blade impeller and the weight of the corms	170.69	N
R	The reaction value on drum screen shaft	85.34	N
M	Bending moment	42.67	N
ω	Angular velocity of the rubber blade impeller	7.85	rad s^{-1}
F_c	Centrifugal force value for rubber blade impeller	21.44	N
T	Rotational torque for rubber blade impeller	0.43	N m
d	The diameter of the rubber blade impeller shaft	17	mm

2.3 Evaluating the performance of the corm sorter

The performance of full-hydraulically mounted saffron sorter was evaluated based on the design parameters. In this study, the effect of independent variables including feeding rate at three levels (300, 400 and 500 kg h^{-1}) drum screen speed at three levels (0.26, 0.42 and 0.63 m s^{-1}) and rubber blade impeller speed at two levels (1.18 and 1.77 m s^{-1}) on the damaged corm percentage and grading accuracy, as major factors of grading, was evaluated (Spetzler and Martin, 1986). The damaged corm percentage was calculated with the following Equation 11 (Umani and Markson, 2020).

$$D = \frac{WD}{WT} \times 100 \quad (11)$$

Where,

D, WD, and WT are the damaged corm percentage (%), the mass of the broken or damaged corms (kg), and the total mass of the corms (kg), respectively.

To measure the grading accuracy, corms with a mass of less than 6 g, which were collected under the drum screen, were weighed, and then the grading accuracy of the corm sorter was calculated using the Equation 12 (Umani and Markson, 2020).

$$A = \frac{W1}{W2} \quad (12)$$

Where,

W1 and *W2* are the mass of corms with a mass of less than 6 g and the total mass of the corms, respectively.

The experiments were conducted in a random complete block design with three replications. Statistical analysis was performed using analysis of variance (ANOVA) using SPSS 13 software. Duncan's multiple range test was used at a significant level of 5%.

3 Results and discussion

Variance analysis of data in Table 4 indicates that the feeding rate created a significant effect on the grading accuracy and damaged corms percentage (p<0.01). It was also found that the drum screen speed has a significant effect on the grading accuracy (p<0.01). The effect of rubber blade impeller speed on the grading accuracy and damaged corms percentage was significant at the 5% and 1% probability levels, respectively. The airspeed produced by the blower fan is crucial for the effectiveness of the saffron corm sorting process, but it can also directly affect the potential for corm damage (Gambella et al., 2013). Excessively high airspeed may lead to physical damage to the saffron corms, adversely impacting their quality (Flowers, 2013). Previous studies have shown that increased airspeed can damage stigmas due to more frequent collisions with the duct walls, which ultimately reduces the quality of the separated stigmas (Carcangiu et al., 2013). According to Table 4, the combination effects of (feeding rate × drum screen speed) and (feeding rate × rubber blade impeller speed) were significant on the grading accuracy and damaged corms percentage. In the following, the effects of each factor on the aforementioned characteristics have been discussed comprehensively.

Table 4 Variance analysis for damaged corms percentage and grading accuracy

Variation source	Grading accuracy	Damaged corms
Feeding rate	984.236^{**}	8.986^{**}
Rubber blade impeller speed	9.517^{*}	21.492^{**}
Drum screen speed	25.202^{**}	0.217^{ns}
Feeding rate × Drum screen speed	19.869^{**}	1.799^{**}
Feeding rate × Rubber blade impeller speed	6.835^{*}	0.837^{**}
Rubber blade impeller speed × Drum screen speed	1.811^{ns}	0.014^{ns}
Feeding rate × Rubber blade impeller speed × Drum screen speed	3.548^{ns}	0.250^{*}
Error	1.539	0.081

Note: ^{ns}: Corresponding to no significant difference; *: Corresponding to significant difference at p=0.05; **: Corresponding to significant difference at P=0.01.

The results of the comparison of means test performed using Duncan's test (p≤0.5) are shown in Table 5. As expected, the grading accuracy decreased from 96.25% to 82.48% with an increasing feeding rate. On the other hand, by increasing the rotational speed of the drum screen from 0.26 to 0.63 m s^{-1}, the grading accuracy increased. While there is no significant difference between the two rotational speeds of 0.26 and 0.42 m s^{-1}. By increasing the feeding rate from 300 to 400 $kg\ h^{-1}$, the amount of damaged corms reached from 3.58% to 3.79% *w/w*. In the range of 400 to 500 kg h^{-1}, there is no significant effect on the amount of damaged corms.

The amount of damaged corms is significantly affected by the rotational speed of the rubber blade impeller. As can be seen in Table 5, by increasing the rotational speed of the rubber blade impeller (from 1.30 m s^{-1} to 1.96 m s^{-1}) the amount of damaged corms also increases from 3.07% to 4.34% *w/w*.

Table 5 Means comparison of characteristics in different variations

Factors	Factors levels	Grading accuracy (%)	Damaged corms (%)
Feeding rate (kg h^{-1})	300	96.25^{a}	3.58^{a}
	400	94.03^{b}	3.79^{b}
	500	82.48^{c}	3.75^{b}
Rubber blade impeller speed (m s^{-1})	1.30	90.50^{a}	3.07^{a}
	1.96	91.34^{b}	4.34^{b}
Drum screen speed (m s^{-1})	0.26	90.24^{a}	3.58^{a}
	0.42	90.23^{a}	3.78^{b}
	0.63	92.29^{b}	3.75^{ab}

Note: The average of a factor that is in the same column and does not have a significant difference has the same letters ($p < 0.05$).

Figure 4 shows the effect of the feeding rate and rotational speed of the drum screen on the amount of damaged corms. The most damage to saffron corms occurred at the feeding rate of 300 kg h^{-1} and the rotational speed of 0.63 m s^{-1}. By increasing the rotational speed, the kinetic energy exerted on the corms increases and leads to more damage. Increasing the feeding rate causes an increase in the mass of corms in the drum screen. So the impact of the corms on the drum wall is reduced. On the other hand, by increasing the feeding rate and decreasing the rotation speed of the drum screen, the grading accuracy decreased (Figure 5). According to Figures 4 and 5, the results showed that this full-hydraulically mounted saffron sorter has the best performance in high grading accuracy and less corm damage with the feeding rate of 400 kg h^{-1} and the rotation speed of 0.42 m s^{-1}.

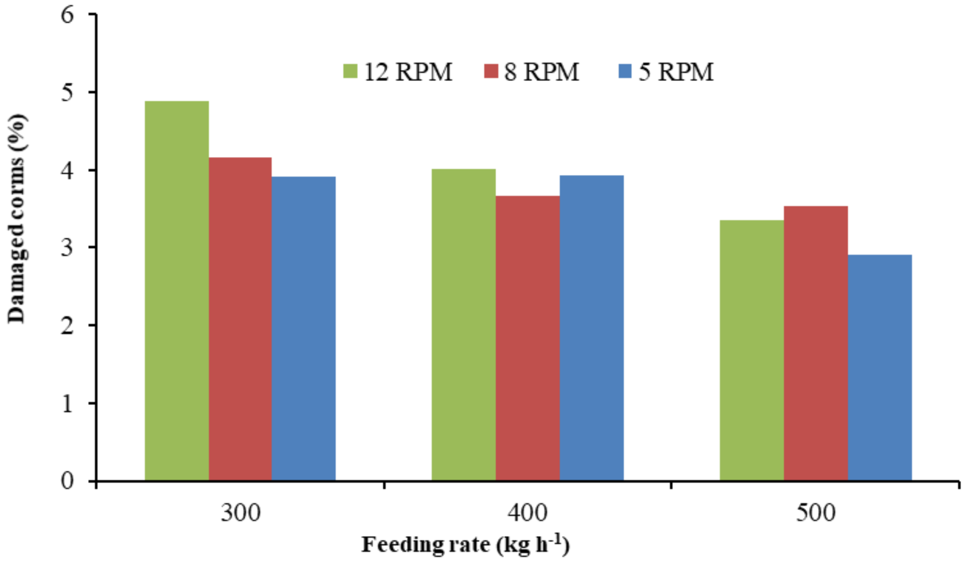

Figure 4 Effect of feeding rate and drum screen speed (RPM) on the damaged corm

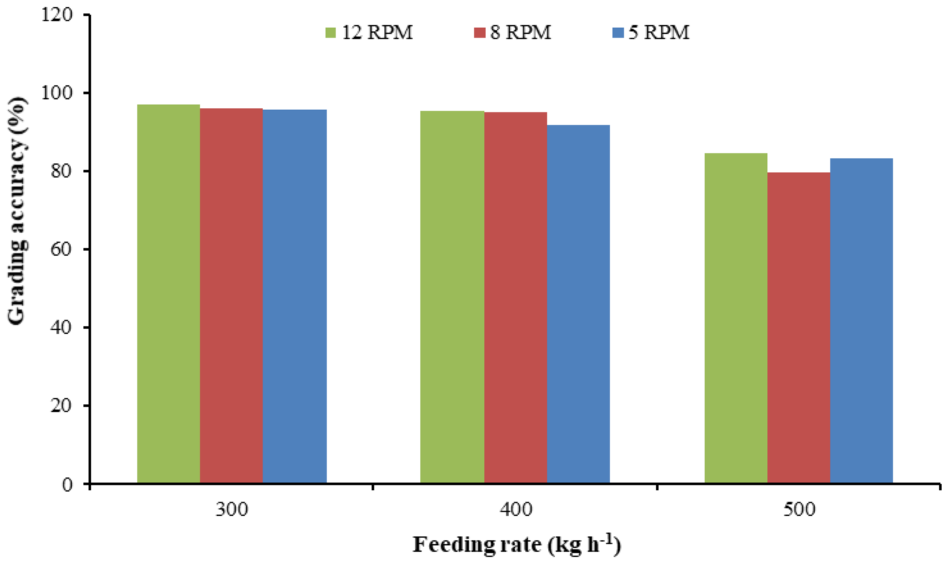

Figure 5 Effect of feeding rate and drum screen speed (RPM) on the grading accuracy

The rubber blade impeller, which plays an important role in sorting the saffron corms and crushing the lumpy soil attached to the corms, was evaluated at two levels of speed (1.30 m s^{-1} and 1.96 m s^{-1}). Figures 6 and 7 show the effect of the feeding rate and the rotational speed of the rubber blade impeller on the grading accuracy and the amount of damaged corms. The most damage to saffron corms was observed at the speed of 1.96 m s^{-1} and the feeding rate of 300 kg h^{-1}. On the other hands, the lowest damage was obtained at the speed of 1.30 m s^{-1} and a feeding rate of 500 kg h^{-1}. According to Figure 7, the highest grading accuracy is at the rotational speed of 1.96 m s^{-1} and the feeding rate of 300 kg h^{-1}. By increasing the feeding rate, the grading accuracy decreases. So that the lowest grading accuracy was in the feeding rate 500 kg h^{-1}. Moreover, as respect of grading accuracy there is no significant difference between the rotational speeds of 1.30 m s^{-1} and 1.96 m s^{-1} at the feeding rate of 500 kg h^{-1}. Therefore, it can be concluded that the rubber blade impeller has a better performance at the rotational speed of 1.30 m s^{-1} than the rotational speed of 1.96 m s^{-1}.

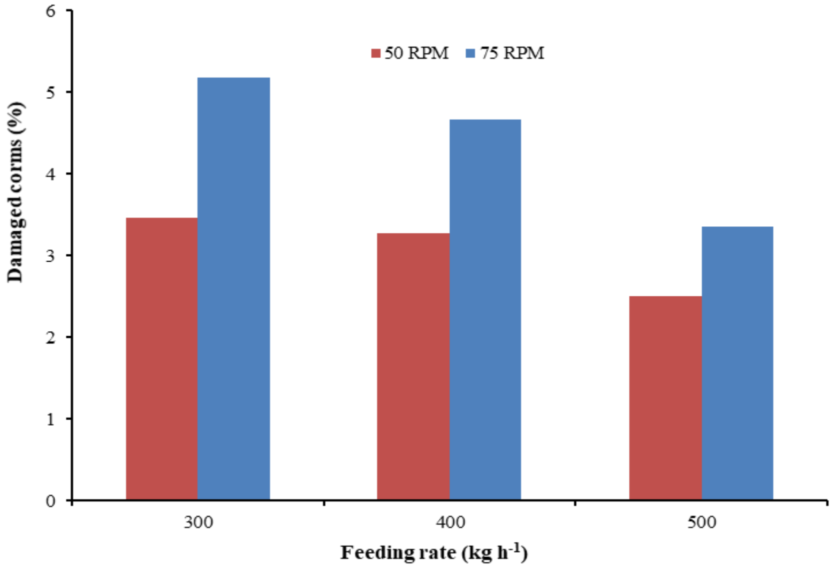

Figure 6 Effect of feeding rate and rubber blade impeller speed (RPM) on the damaged corms

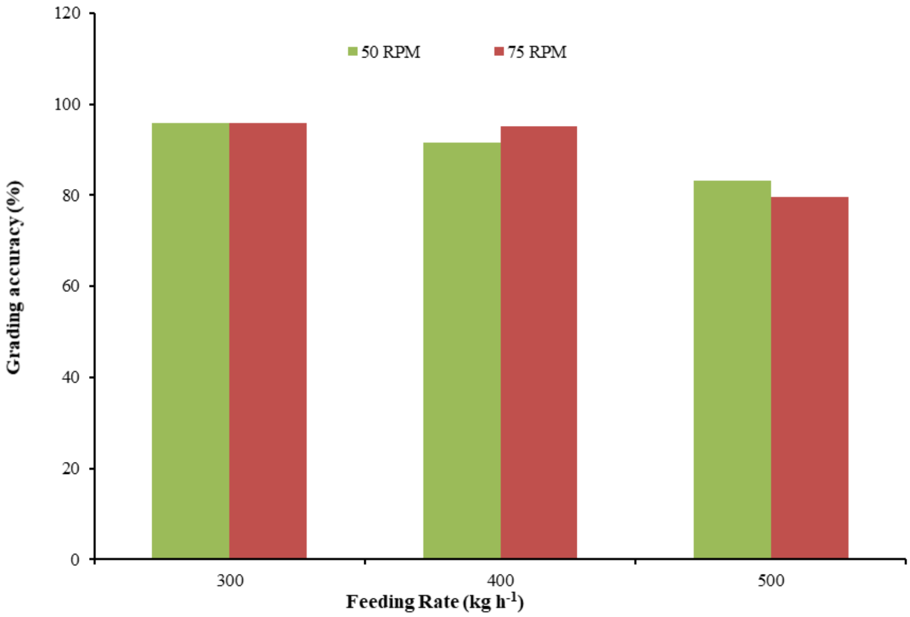

Figure 7 Effect of feeding rate and rubber blade impeller speed (RPM) on the grading accuracy

4 Conclusion

The full-hydraulically mounted saffron sorter with operating capacity approximately 10 times greater than traditional manual methods and a total energy consumption of 0.386 megajoules per kilogram, evaluated in workshop condition. The results showed that the grading accuracy and the amount of damaged corms of this innovation sorter in the average feeding rate of 400 kg h^{-1} were 94.03% and 3.79% respectively. The performance of the corm sorter was evaluated in three level of feeding rates (300, 400 and 500 kg h^{-1}) and different rotational speeds of the rubber blade impeller. The results showed that by increasing the feeding rate, the damage rate of saffron corms and the grading accuracy are decreased. The optimum performance of corm sorter was obtained in the feeding rate of 400 kg h^{-1} and the rotational speed of 0.42 m s^{-1}. In this condition the maximum grading accuracy and minimum level of damage can be reached. The rubber blade impeller has a better performance at the rotational speed of 1.30 m s^{-1} than the rotational speed of 1.96 m s^{-1}.

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