Design, development, and evaluation of a rotary potato sorting machine

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Abstract: Potato is one of the most important agricultural products that have great nutritional and industrial value. Potato seed tubers are usually used for growing this crop, but separating the seed tubers from the edible ones is a tedious, time-consuming, and costly process. Therefore, a rotating potato sorting machine was designed, developed, and evaluated in this research. This machine was able to sort potato tubers according to size in three categories: less than 35 mm, between 35 to 55 mm, and larger than 55 mm, and poured into different containers. This machine consists of main units including input unit, sorting unit, power transmission unit, electrical unit, output unit and chassis. The sorting machine consists of two rotary sieve cylinders. The diameters of inner and outer cylinders are 80 and 120 mm, respectively. The sorter is operated by a 1.33 kW, electromotor for rotating cylinders, a 0.75 kW for power supply conveyor belt, and 2 electromotors with 1.5 kW for seed and edible conveyor belts. Potato tubers are fed into the inner cylinder, moved forward by rotating, and dropped through holes of the net according to their dimensions. Effects of sieves slope angle and rotational speed on the tuber's mechanical damage, sorting accuracy, and capacity of the designed machine were evaluated. The test was conducted in the factorial experiment format with three replications based on a completely randomized experimental design. Three levels of sieves slope angle (5, 10, and 15 degrees) and three levels of sieves rotational speed (10, 20, and 30 revolutions per minute (rpm)) were considered. Results showed that the treatment involving an inclination angle of 5 degrees and a rotational speed of 10 rpm was the most appropriate.

Keywords: construction, damage tubers, edible, fabrication, grader, manufacturing, seed, separator

Citation: Bakhtiari, M. R., S. Afzalinia, and A. Heidari. 2022. Design, development, and evaluation of a rotary potato sorting machine. Agricultural Engineering International: CIGR Journal, 24 (2):227-238.

1 Introduction

Potato (*Solanum tuberosum*) is one of the most important agricultural products which plays a very effective role in the food industries all over the world production of this valuable product is increasing due to its high production power and adaptation to a very wide range of climates in the world (FAO, 2018). According to the Food and Agriculture Organization of the United Nations (FAO), Twenty-three million hectares of agricultural land in the world are planted with potatoes annually, from which more than 310 million tons of crops are harvested. In 2017, world production reached about 330 million tons. China is the world's largest producer of potatoes, producing about

Received date: 2021-01-02 **Accepted date:** 2022-04-04

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73.5 million tons, accounting for 23% of world production. The Russian Federation with 38.6 million tons, India with 23.9 million tons, the United States with 19.7 million tons, Ukraine with 19.5 million tons, and Germany with 10 million tons are the next producers of this product. Iran's share of the world's total potato cultivated area is 185,000 hectares with a production of more than 5 million tons (FAO, 2018).

According to agricultural statistics, the area of potato cultivation in the country in the 2017-18 cropping season was 154 thousand hectares, of which 98.17% was irrigated and the rest was rain-fed. Hamedan province, with 16.63% of the country's total potato cultivation area and 24% of the total production of 5 million tons of potatoes, is the first in the country in terms of area under cultivation and production. Ardabil, Isfahan, Kurdistan, Zanjan and East Azarbaijan provinces have the second to sixth positions. These six provinces together have more than 62% of the total potato cultivation area of the whole country and about 70% of the annual production of this product (Anonymous, 2016).

Due to the lack of access to seed potatoes, farmers usually use sliced potatoes for planting, which in addition to providing suitable conditions for fungal growth and tuber rot, it can also reduce crop yield and quality. Therefore, it is necessary to use uniform seed tubers so that the potato planters can plant the tubers uniformly. Thus, seed tubers should be somehow separated from the edible or food tubers and waste. Potato sorting machines can be used for this purpose.

Potato sorting machines can be made in various ways such as mechanical (mass and size), optical, pneumatic, and electronic, each of which has a special feature, which is mentioned below in several types of research in this field.

A sorting machine with an inlet conveyor belt was designed by (Ashraf et al., 2007). They evaluated the effect of inlet conveyor belt, sorting roller, and outlet conveyor belt speeds on the potato damage and found that the damage to the potatoes was the lowest when the inlet conveyor belt, sorting roller, and outlet conveyor belt speeds were 20 m min^{-1}, 50 rpm, and 10 m min^{-1}, respectively.

Another machine with three interlocking cylinders was designed and developed by El-Rahman and Magda (2011) for onion sorting. This sorting machine was evaluated at four sorting cylinders' rotational and feeding speeds. Results showed that the maximum classification yield (94.34%) and the optimum mechanical damage to onions (4.66%) were obtained at the sorting cylinders rotational and feeding speeds of 55 rpm and 125 kg h^{-1}, respectively.

In a study conducted by Farhadi et al. (2012), a rotating potato sorting machine with variable spirals was designed and developed. Evaluation results showed that the theoretical and actual transfer volumes of the product were 4.36 and 3 tons h^{-1}, respectively.

An online potato sorting system was designed and developed using a visual machine and image processing method (Golmohammadi et al., 2013). This machine was able to arrange the potato tubers with 97% accuracy and at a speed of two potatoes per second.

A rotary cylinder sorting machine was developed (Huda et al., 2019) and the effects of its cylindrical rotational speeds and inclination angles on the machine efficiency and capacity, mechanical damage to potato tubers, and electrical energy consumption were investigated. Results showed that the optimum efficiency, capacity, mechanical damage, and electricity consumption (91.57%, 420.10 kg h^{-1},%1.17, and 9.30 watts h^{-1}, respectively) were obtained at the rotational speed of 6 rpm and the inclination angle of 3 degrees.

A rotating potato sorting machine was designed and developed, and the effect of sieves inclination angle (5, 10, and 15 degrees) and rotational speed (10, 15, and 20 rpm) on the machine classification capacity and tubers mechanical damage was evaluated. Results showed that sorting capacity increased with increasing the rotational speed of the cylinder while the mechanical damage to the tubers decreased with increasing the inclination angle (Alemu, 2019).

Existing potato sorting machines are mostly made of several flat sieves parallel to each other and with different dimensions. Potato tubers are poured on the upper sieve and the tubers are classified into one or two batch sizes of seeds, edible tubers, and waste according to the dimensions of the sieve networks and are discharged into different containers. In this method, the blows created by the machine crankshaft rotation are transmitted to the tubers and some extent cause mechanical damage to them endangering the health of the seed tubers and causing the spoilage of the edible tubers in storage.

In another study, a rotary sorting machine with spiral rails was developed, and effects of rotational speed and inclination angle on the machine efficiency and capacity, mechanical damage to potato tubers, and energy consumption were investigated (Valentin et al., 2016). Results showed that the optimum efficiency, capacity, mechanical damage, and energy consumption (92.56%, 56.44 kg h^{-1}, less than 1.83%, and 6.22 watts h^{-1}, respectively) were obtained at the rotational speed of 15 rpm and the inclination angle of 10 degrees.

The performance of an engine-operated potato grader was evaluated by Alemu et al. (2021). Grading capacity, grading system efficiency, mechanical damage, and fuel consumption were used to determine the performance of the machine. A split-split-plot experimental with grading cylinder speeds (10, 15, 20 rpm) as the main plots, angle of inclinations (5, 10, and 15°) as sub-plots, and feeding rates (20, 30, 40 kg min^{-1}) as sub-sub-plots with three replications were used. The results indicated that grading capacity and fuel consumption increased with increasing cylinder speed and feed rate while percentage mechanical damage and grading system efficiency decreased with increasing angle of inclination. The maximum grading system efficiency of 97.57% and 97.67% was observed when the machine was operated at speed of 15 rpm, an angle of inclination of 5°, and a feed rate of 20 and 30 kg min^{-1}, respectively.

Bahadirov et al. (2020) conducted a study to improve the design of potato belt sorting machines, to increase the accuracy of potato sorting according to their external dimensions, without damage. The results showed that for increasing the accuracy of the sorting machine to 95%, the speed of a slow-moving and fast-moving belt must be 0.4 and 0.6 m s^{-1}, respectively.

The less the tubers move on the sorter to classify the seed and edible tubers, and the more rolling motion is used instead of vibration and slip, the lower the percentage of mechanical damage. Also, these machines are large and compact, are made fixedly, produce a lot of noise, and over time, potato tubers get stuck in the sieve networks and block them, which reduces the efficiency of these machines.

To overcome the above-mentioned problems, a potato rotary sorting machine was designed, developed, and evaluated in this research. This machine can classify potato tubers into three categories: small (less than 35 mm), medium (between 35 and 55 mm) and large (more than 55 mm) (Kadaja and Tooming, 2004; Roy et al., 2005; Swarnalakshmi and Kanchanadevi, 2014). In this machine, a rotating classification mechanism was designed and developed instead of a transfer and sliding one. Thus, instead of using flat sieves, cylindrical sieves have been used. The reciprocating and vibrating motion of the sieves is converted to the rotational motion in the newly designed machine. The potato tubers, instead of the direct transfer motion of the slippery line, roll slowly in the inner wall of the cylinders and are separated according to different dimensions (less than 35 mm, between 35 and 55 mm, and more than 55 mm). Therefore, in this method, the friction of the tubers and their collision with the inner wall of the cylinders is greatly reduced, which reduces the mechanical damage to the potato tubers. Also, due to the rotational movement of the sieves, the networks are not blocked.

2 Material and methods

2.1 Design

The designed machine consists of the following main units, each unit was designed and built separately, and after testing the accuracy of each unit, other units were designed and developed (Figure 1).

2.1.1 Sorter input unit (supply unit)

To have a uniform and controlled input to the sorter, a feed conveyor belt unit (lift) was designed and built (Figure 4). By this unit (lifting or feeding conveyor belt), the potato tubers enter the central cylinder of the sorter uniformly. After separating the healthy tubers from the spoiled ones by the worker, the healthy potato tubers are thrown into the input unit. This unit consists of a hopper and a conveyor belt (feeder) whose speed can be changed by an inverter (Figure 5). Potato tubers from this unit are uniformly inserted into the central cylinder of the sorting unit or rotating sieve. It should be noted that an inverter is installed on this unit, which makes the speed of the conveyor belt changeable (Figure 5). Other specifications are listed in

Table 1. This unit consists of the following components and parts:

2.1.1.1. Hopper

According to the dimensions of the hopper, the volume of the hopper is 0.29 cubic meters and has a valve to adjust the feed rate of the conveyor belt. In other words, by opening and closing this sliding valve, the number of glands spilled on the feed conveyor belt (lift) can be increased or decreased.

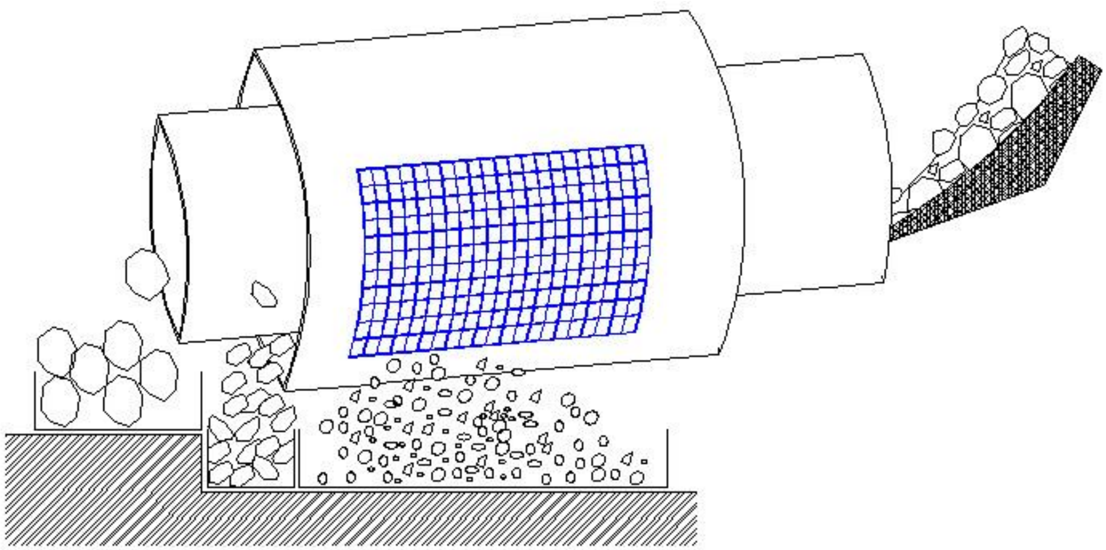

Figure 1 Schematic side view of rotating sieve during potato tuber classification

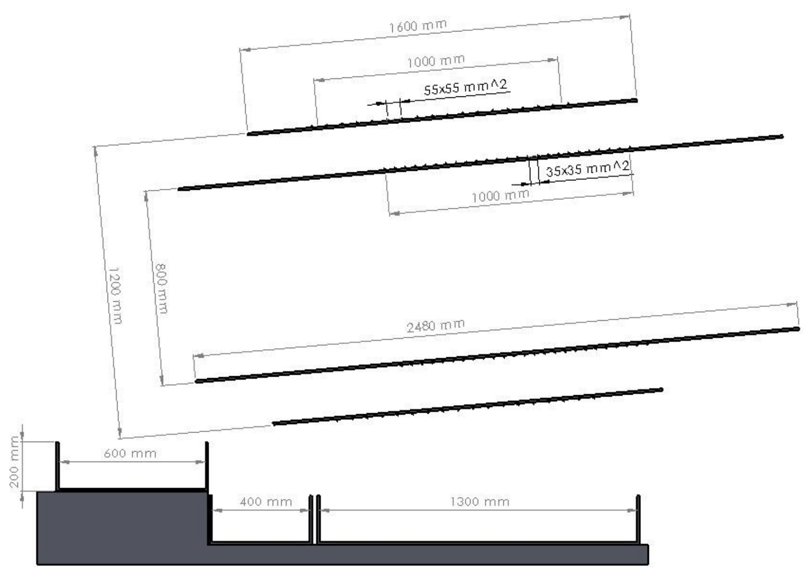

Figure 2 Schematic side view of rotating sieve

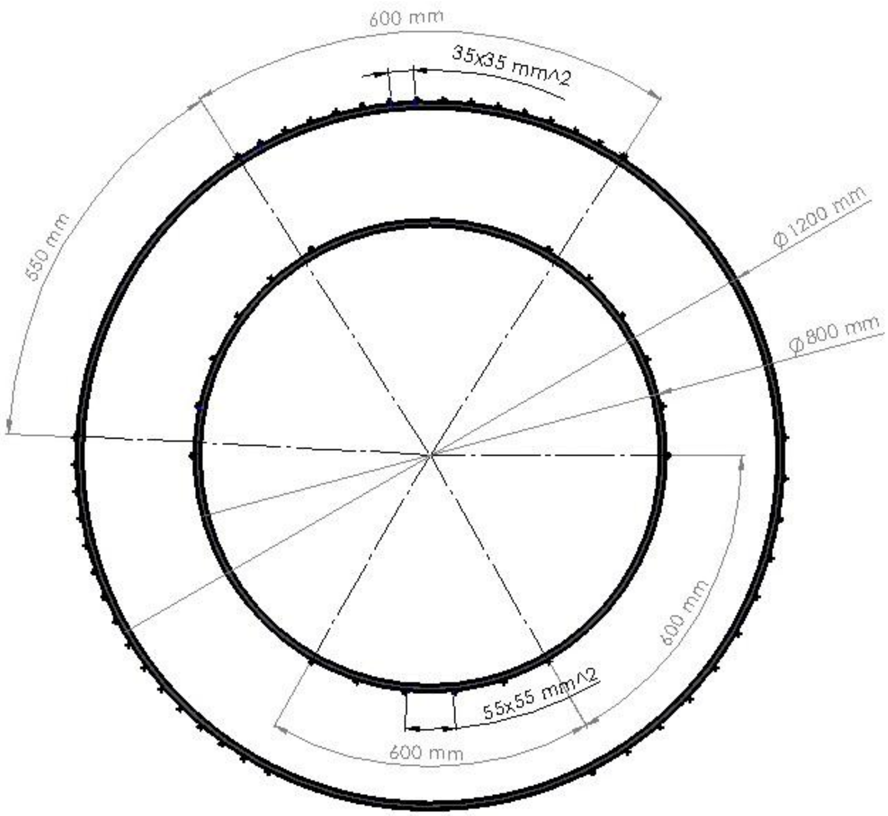

Figure 3 Schematic front view of rotating sieve

Figure 4 Side view of rotating sieve after assembling

Table 1 Specifications of feed conveyor belts for transporting seed and edible potato tubers

Conveyor belt type	Belt dimensions (cm)		Chassis dimensions (cm)		Linear velocity (m min-1)	The angle of position relative to the horizon (degree)
	Length	Width	Length	Width		
Feed (lift)	428	40	200	51	0 to 50	0 to 90
Seed transfer	580	30	315	52.5	1.1	0
Edible transfer	583	60	315	79	1.1	0

Table 2 Specifications of attachments on the feed conveyor belt (lift)

Number of appendages	Dimensions of appendages (cm)		The distance between the appendages (cm)
	Width	Height	
10	40	6.5	42.8

2.1.1.2. Feed conveyor belt (lift)

Which itself consists of belt, electric motor, and chassis and is used to transfer potatoes in a uniform and controlled manner into rotary sieves. Its linear velocity is controlled by changing the rotational speed of the electromotor, which itself is regulated by another electrical system called an inverter. The specifications of the feed conveyor belt are also given in

Table 1. To transfer the potato tubers into a rotating sieve, several appendages are installed on the feed conveyor belt, the specifications of which are listed in Table 2.

2.1.2 Rotating unit or rotating sieve

This unit is the main part of the sorter, which is made of two cylinders (inner and outer cylinders) of all centers, the specifications of which are listed in Table 3. On each of these cylinders, three sieve plates with angles of 120 degrees are installed (Table 4). These two cylinders are connected by 20 cm distance joints and rely on four wheels, one of which is the drive wheel to rotate the rotating sieves.

The diameter of the inner cylinder is fourteen times the largest potato size (14 × 5.5 = 77 ≈ 80 cm), ie 80 cm. The distance between the inner and outer cylinders is based on 4 times the average diameter of the seed tubers, ie 20 cm, 4 × ((3.5 + 5.5) /2) = 18 ≈ 20 cm. Therefore, the diameter of the outer cylinder is determined according to the diameter of the inner cylinder and the distance between the inner and outer cylinders (120 cm). On the side surface of each cylinder, three sieves are installed with square-shaped grids that classify the tubers according to their size, so that the dimensions of the grids on the inner cylinder are 55 × 55 mm square and the grids on the outer cylinder are 35 × 35 mm (Table 4). The inner wall of the cylinders is covered with a layer of soft rubber to prevent mechanical damage to the tubers. The length and width of the mesh part (sieve) were designed based on the below calculations.

Inner Cylinder	
Length of mesh part (sieve)	(16×5.5) + (14×0.7) = 97.8 ≈ 100 cm
Width of the mesh part (sieve)	(10×5.5) + (8×0.7) = 60.6 ≈ 60 cm
Outer Cylinder	
Length of mesh part (sieve)	(24×3.5) + (22×0.7) = 99.4 ≈ 100 cm
Width of the mesh part (sieve)	(16×3.5) + (14×0.7) = 65.8 ≈ 65 cm

Note: The diameter of the bars that make up the grids is considered to be 7 mm.

Table 3 Characteristics of cylinders and dimensions of sieves

Cylinder	The diameter of the cylinders (cm)	The length of the cylinders (cm)	Cylindrical environment (cm)
Inner	80	248	251.2
Outer	120	160	376.8

Table 4 Other specifications of cylinders and sieves

Cylinder	Dimensions of sieves mesh (mm × mm)	Number of sieves on each cylinder (Number)	Length of mesh part (sieve) (cm)	Width of the mesh part (sieve) (cm)	The length of the top sieve (cm)	The length of the lower sieve (cm)	The total width mesh (cm)
Inner	55 × 55	3	100 (I)	60 (II)	63	85	180
Outer	35 × 35	3	100 (III)	65 (IV)	31	29	195

This unit is the main part of the sorter which, by rotating itself, classifies the potato tubers in different dimensions. The rotational speed and the angle of inclination of this unit affect the accuracy and capacity of the machine and the amount of mechanical damage to the tubers.

After the tubers enter the cylindrical sieves, which are integrated, they rotate at the specified speeds and angles of slopes. The seeds and edible tubers from the sieves are then poured onto two conveyor belts and the tubers are guided into bags for packing. Exhaust waste is also discharged directly through the special outlet channel.

2.1.3 Output unit (transfer)

The edible and seed tubers taken out of the rotary sieves are poured or flowed on two independent conveyor belts which act as a control (monitoring) table. Therefore, another opportunity is given to the supervising workers to separate damaged potatoes, clods, and stones from healthy potatoes before packing the potatoes. Also, due to the softness of the belt, it prevents mechanical damage to the seed and edible tubers. The waste is also dumped on the outlet channel and directed to the outside.

2.1.4 Rotational speed reduction unit

This machine can be built in two ways in terms of energy consumption:

A: Using the PTO shaft of the tractor.

B: Using an electric motor.

A three-phase electric motor was used, the power of which is calculated after evaluating the sorter. Since the rotational speed of the power supply needed to be reduced to provide three rotational speeds of 10, 20, and 30 rpm, an inverter was used to provide these speeds.

Thus, four three-phase electric motors with speed reduction gearbox were used to provide rotational energy in this project. Two inverters were also used to change the speed of the feed conveyor belt motors (1.5 hp motor) and the sorter cylinders (2 hp motor). To transfer torque from the electric motors to the conveyor belts and rotating sieve, a chain and sprocket system was used. The specifications of the electric motors are listed in Table 5.

Table 5 Specifications of electric motors used in the sorter

Location of the electric motor	Electromotor power (hp)	Electromotor power (kW)	Gearbox input (rpm)	Gearbox output (rpm)	Speed reduction ratio by sprocket	Voltage (Volt)	Current (Amper)	Frequency (Hertz)
Power supply conveyor belt	1	0.75	1700	120	1 to 1	380	3.6	50
Rotary Sieves	1.8	1.33	1380	46	1 to 3	380	3.6	50
Seed conveyor belt	2	1.5	1400	32	7 to 13	380	3.6	50
edible conveyor belt	2	1.5	1400	32	7 to 13	380	3.6	50

2.1.5 Chassis

The rotating sieves with their mechanisms are mounted on the chassis and can be transported by traction wheels and the tractor drawbars.

2.1.6 Electrical system and speed control of electric motors

In this system, safety devices have been used to prevent changing to single-phase or two-phase mode, which leads to damage to electric motors. Also, two inverters with the power of one and two horsepower were installed on Sorting Machine for electric motors of the lifting conveyor belt (feeding) and rotating sieves (Figure 5).

2.2 Construction

After completing the design stage according to the materials and methods, all parts of the rotary sieves were made step by step and installed on the sorter to obtain the prototype of the sorter. Then the final evaluation was performed.

Figure 5 Internal parts of the electrical system and speed control of electric motors

2.3 Evaluation

To evaluate the potato sorter, three rotational speeds of 10, 20, and 30 rpm and three inclination angles of 5, 10, and 15 degrees to the horizon in three repetitions were considered for the rotational sieves. Therefore, there were a total of 27 plots, and to analyze the results, a factorial experiment with the base of a completely randomized design was used.

For this purpose, the required weight of healthy potatoes from Agria cultivars (common cultivars in the country) with different dimensions and sizes were randomly harvested, then for each treatment, 400 kg of potatoes were inserted into the inlet of the sorter. It should be noted that the total potato weight required for 27 plots was 10800 kg (27 × 400 = 10800 kg). After entering the tubers to the rotary sieve unit, each test was run according to the specified rotational velocities and slope angles, and the tubers were classified in the specified dimensions. Therefore, potato tubers were collected in three groups according to the dimensions of the sieve meshes as follows:

1. Seed tubers: This group included tubers with a diameter between 35 and 55 mm.

2. Edible or food tubers: This group included tubers with a diameter of more than 55 mm.

3. Waste: This group included tubers with a diameter of less than 35 mm, which are used for starch extraction and animal feed or are considered as waste.

2.3.1 Measured parameters

2.3.1.1 Mechanical damage

The following equation was used to determine the percentage of mechanical damage to potato tubers:

$$D = \frac{W_d}{W_t} \times 100 \tag{1}$$

2.3.1.2 Sorting accuracy

To determine the accuracy of the sorter, the dimensions of the potatoes classified in each container were measured with a caliper and then the percentage of the sorter accuracy was determined by the following equation:

$$A = \frac{W_s}{W_t} \times 100 \tag{2}$$

2.3.1.3 Sorter capacity

In each treatment, the time required to classify about 400 kg of potatoes was measured so that the sorter capacity could be calculated from the following equation:

$$C = \frac{W}{t} \times 3.6 \tag{3}$$

3 Results and discussion

3.1 Effect of inclination angle on the tubers mechanical damage

According to the table of variance analysis (Table 6), the effect of the inclination angle of the rotary sieves on the mechanical damage of edible potatoes and seed potatoes was significant with 95% and 99% probability, respectively. This means that when the potatoes rotate at a lower slope angle, they have a higher number of revolutions into the cylinders of the rotating sieves, and the longer it takes for them to be driven out of the cylinders, it can lead to increased mechanical damage. Potato tubers, on the other hand, are guided out faster at greater angles and are in contact with the inner wall of the cylinders in a shorter time, which reduces the mechanical damage to them. Results of means comparison showed that damage to both edible and seed tubers decreased with the increasing sieves inclination angle so that the inclination angle of 5 degrees had the maximum damage and the inclination angle of 15 degrees had the minimum damage (Table 7). Sorting accuracy also decreased with increasing sieves inclination angle in such a way that the maximum sorting accuracy was obtained from an inclination angle of 5 degrees and the minimum one was obtained from an inclination angle of 15 degrees. In contrast, sorting capacity increased with increasing sieves inclination angle. In other words, sorting accuracy at the inclination angle of 15 degrees which had the lowest mechanical damage and highest sorting capacity, was very low and unacceptable for a sorting system. It should be noted that compared to the mechanical damage and sorting capacity, sorting accuracy is a more important and limiting factor in the sorting system. Therefore, despite having higher mechanical damage and a lower sorting capacity, 5 degrees was considered as the most appropriate sieve inclination angle because of having the maximum sorting accuracy.

Table 6 Analysis of variance of angle and different rotational speeds of rotating sieves on some machines and product parameters

Sources of change	Degrees of freedom	(Mean Square) Mechanical damages		Sorter accuracy		Sorter capacity
		Edible tubers	Seed tubers	Edible tubers	Seed tubers	
Replication	2	0.029^{ns}	0.473^{ns}	0.711^{ns}	4.626^{ns}	3.79^{ns}
Inclination angle (A)	2	27.776^{*}	6.682^{**}	8779.654^{**}	901.674^{**}	32.504^{**}
Rotational speed (S)	2	3.565^{ns}	0.015^{ns}	3681.151^{**}	714.769^{**}	56.504^{**}
Interaction (A × S)	4	9.596^{ns}	2.724^{*}	1010.727^{**}	73.865^{**}	2.519^{*}
Error	16	6.012	0.694	5.260	1.242	0.724
Total	26	-	-	-	-	-
CV%	-	36.56%	19.77%	3.68%	1.33%	10.12%

Note: ^{ns}: Not significant; *: Significant at 5% level; **: Significant at 1% level

Table 7 Comparison of the means of some machine and product parameters in the levels of different angles of rotating screws relative to the ground (in degrees)

Inclination angle (degree)	Mechanical damages (%)		Sorter accuracy (%)		Sorter capacity (ton.hr-1)
	Edible tubers	Seed tubers	Edible tubers	Seed tubers	
5	8.7 a	4.9 a	93.9 a	90.0 a	6.7 c
10	6.0 b	4.5 a	61.3 b	89.1 a	8.0 b
15	5.4 b	3.3 b	31.5 c	72.3 b	10.5 a

Note: Means in the same rows followed by different letters are significantly different at the 5% level by DMRT.

3.2 Effect of rotational speed on the tubers mechanical damage

According to the analysis of variance (Table 6) and comparison of means (Table 8), the rotational speed of the rotary sieves had no significant effect on mechanical damage. This is probably due to the rubber coating on the inner wall of the rotating blades, which speeds of 10, 20, and 30 rpm are not high enough to cause mechanical damage.

Table 8 Comparison of averages of some machine and product parameters at different rotational speed levels of rotary sieves (in rpm)

Sieve's rotational speed (rpm)	Mechanical damages (%)		Sorter accuracy (%)		Sorter capacity (ton/hr)
	Edible tubers	Seed tubers	Edible tubers	Seed tubers	
10	6.4^{a}	4.2^{a}	81.6^{a}	91.7^{a}	5.7^{c}
20	6.3^{a}	4.3^{a}	63.9^{b}	85.5^{b}	8.8^{b}
30	7.4^{a}	4.2^{a}	41.2^{c}	74.2^{c}	10.7^{a}

Note: Means in the same rows followed by different letters are significantly different at the 5% level by DMRT.

3.3 The interaction effect of inclination angle and rotational speed on the tubers mechanical damage

Although the analysis of variance (Table 6) showed that mechanical damage to the edible potatoes was not significantly affected by the interaction effect of inclination angle and rotational speed, the treatment means comparison for mechanical injuries showed a significant difference between treatments at the confidence level of 95%. Also, the interaction effect of inclination angle and rotational speed of the rotary sieves on the mechanical damage of seed potatoes was significant at the confidence level of 95%. Results also indicated that A5S10 treatment inclination angle of 5 degrees coupled with the rotational speed of 10 rpm) was determined as the most appropriate treatment because of having relatively low mechanical damage and acceptable sorting accuracy (Table 9). Alemu Anawte (2019), recorded that the least percent tuber mechanical damage of 1.56% was observed at a cylinder speed of 20 rpm and inclination angle of 15 degrees. Maximum percent tuber mechanical damage of 5.31% occurred when cylinder speed was 20 rpm and inclination angle 5 degrees.

Table 9 Comparison of the means of some machine and product parameters at the levels of interaction angle interaction and different rotational velocities of rotary sieves

Interaction (Speed × Angle)	Mechanical injuries (%)		Sorter accuracy (%)		Sorter capacity (ton hr^{-1})
	Edible tubers	Seed tubers	Edible tubers	Seed tubers	
A5S10	9.2 ^{ab}	3.9 ^{bc}	98.5 ^{a}	99.2 ^{a}	3.6 ^{e}
A5S20	6.5 ^{ab}	5.6 ^{a}	96.7 ^{a}	96.2 ^{b}	7.8 ^{d}
A5S30	10.4 ^{a}	5.2 ^{ab}	86.6 ^{b}	74.6 ^{f}	8.8 ^{cd}
A10S10	5.3 ^{b}	5.5 ^{a}	96.0 ^{a}	95.6 ^{b}	4.8 ^{e}
A10S20	7.7 ^{ab}	4.2 ^{abc}	70.2 ^{c}	87.1 ^{c}	8.3 ^{d}
A10S30	5.1 ^{b}	3.7 ^{bc}	17.8 ^{f}	84.7 ^{d}	11.0 ^{ab}
A15S10	4.7 ^{b}	3.1 ^{c}	50.2 ^{d}	80.4 ^{e}	8.9 ^{cd}
A15S20	4.7 ^{b}	3.0 ^{c}	24.9 ^{e}	73.3 ^{f}	10.2 ^{bc}
A15S30	6.8 ^{ab}	3.7 ^{bc}	19.4 ^{f}	61.1 ^{g}	12.3 ^{a}

Note: Means in the same rows followed by different letters are significantly different at the 5% level by DMRT.

A (Angle): The interaction angle of the rotary sieves, in degrees

S (Speed): Rotational speed of the rotary sieves, in revolutions per minute

3.4 The effect of the inclination angle on the sorting accuracy

The analysis of variance showed that inclination angle had a significant effect on the sorting accuracy (Table 6). According to the table of comparison of treatments means (Table 7), it is also observed that there was a very significant difference between sorting accuracies at different angles of rotating sieves. The most suitable treatment was an inclination angle of 5 degrees because at lower angles, potato tubers had more time to be sorted, which increases the accuracy of the sorting action at lower angles.

3.5 Effect of the rotational speed of the rotary sieves on the sorting accuracy

The rotational speed effect was significant with a 99% probability of the accuracy of (Table 6). The comparison of treatments means (Table 8) also showed the highest accuracy of the machine at the lowest rotational speed (10 rpm). Therefore, at lower speeds, there is more opportunity for a more accurate classification of potato tubers.

3.6 The interaction effect of inclination angle and rotational speed on the sorting accuracy

The interaction effect of angle and speed of the rotary sieves was also significant with a 99% probability on the accuracy of classification operation (Table 6). The comparison of treatments means was also proved this claim. Therefore, the A5S10 treatment (inclination angle of 5 degrees coupled with the rotational speed of 10 rpm) was the most suitable treatment (Table 9), where the lower angle and lower speed created the most accuracy in performing the classification operation.

Alemu (2019) recorded that the maximum grading capacity of 2,769.91 Kg hr^{-1} was recorded when the grading cylinder speed was 20 rpm, the angle of inclination was 15 °and the feed rate was 40 kg min^{-1}.

3.7 The effect of inclination angle on the sorting capacity

The analysis of variance showed that inclination angle had a significant influence on the sorting capacity at the confidence level of 99% (Table 6). According to the results of the comparison of treatments means (Table 7), the highest capacity of the sorter occurred at the highest angle (15 degrees). But according to previous explanations, an angle of 15 degrees was less accurate in classification and caused more mechanical damage, so this angle cannot be recommended for classification.

3.8 Effect of rotational speed on the sorting capacity

The rotational speed had a significant effect on the capacity of the sorter at the confidence level of 99% (Table 6). According to the results shown in Table 8, the maximum capacity was allocated to the maximum rotational speed (30 rpm), which according to the previous explanations, it was not possible to use this speed for classification operations.

3.9 The interaction effect of inclination angle and rotational speed on the material capacity of the sorter

The interaction effect of the inclination angle and rotational speed of the rotary sieves was significant on the capacity of the sorter at the confidence level of 95% (Table 6). By referring to the table of means comparison (Table 9), it can be seen that the best treatment was the A15S30 treatment (inclination angle of 15 degrees coupled with the rotational speed of 30 rpm). However, due to the increase in mechanical damage and the decrease in the accuracy of tuber classification, this treatment cannot be recommended in practice. Therefore, A5S10 treatment (inclination angle of 5 degrees coupled with the rotational speed of 10 rpm) was selected as the most suitable option, however, it reduced the sorter capacity to 3.6 tons h^{-1} per hour which was still a reasonable and acceptable capacity.

4 Conclusions

In this research, a rotating potato sorting machine was designed and developed. To sort potato tubers, the most suitable inclination angle and rotational speed of rotary sieves were 5 degrees and 10 rpm, respectively. In this case, the mechanical damage to the edible and seed tubers were 9.2% and 3.9%, respectively. Also, sorting accuracy for edible and seed tubers was measured at 98.5% and 99.2%, respectively. In this case, the optimal sorting capacity was calculated to be 3.6 tons h^{-1}. The advantages of this rotary sorter were as follows:

1- Small size, low weight, and low cost.

2- Ease of transportation, which is easily transported by tractor and can be used on the farm.

3- Reducing mechanical damage to the tubers due to the use of rolling motion instead of sliding.

4- It can be driven using a tractor PTO shaft and electric motor.

5- By changing its sieves, it can also be used for sorting garlic, walnuts, and fruits.

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Nomenclature

symbol		symbol	
A	Percentage of sorter accuracy in each range,%	W	Weight of a certain amount of classified potatoes (in kilograms)
C	Sorter material capacity (in tons per hour)	W_d	Weight of damaged potato tubers in each range, kg
D	Percentage of mechanical damage to potato tubers in each range,%	W_s	Weight of properly classified potato tubers in each range (in kilograms), kg
t	Total time required for classification (in seconds)	W_t	Total weight of potato tubers in each range, kg