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Research article

Performance evaluation of a power-operated garlic (*Allium sativum* L.) bulb breaker for clove separation

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ABSTRACT

Garlic (*Allium Sativum* L.) is a valuable root crop that can be utilized to season foods and is widely utilized in Ethiopia to treat many different kinds of diseases. The cloves are separated by hand for plantation and processing functions. This technique can be very exhausting and take a lot of time. To fill this gap, a garlic bulb-breaking machine was fabricated and tested with the clove variety grown in Holeta, Ethiopia. The major component of the machine is two rollers that revolve in opposing directions, and shearing the bulbs to separate the cloves. The performance test experiments were carried out in a full factorial design with feed rate as the first factor having three levels (3.7, 4.2, and 5.2 kg/min) and roller speed as a second factor with also three levels (276, 326, and 376 rpm). All tests were done at 66 % moisture content of garlic and 19 mm clearance between the breaking rollers. The interaction effect of the two factors shows an important difference ($p < 0.05$) in machine performance. The maximum breaking efficiency of (87.05 %) occurred at a feed rate (4.2 kg/min) and roller speed (326 rpm). Likewise, the maximum breaking capacity (306.98 kg/h) was recorded for the highest (5.2 kg/min) feed rate regardless of the 276 rpm roller speed. The minimum clumps of cloves (10.27 %) were obtained at combinations of 4.2 kg/min and 326 rpm. The lowest values of damaged cloves (1.79 %) and fuel consumption (5.61 ml/kg) were observed for the combination of the 3.7 kg/min with the 276.85 rpm whereas the maximum clove damage (2.29 %) was at the 5.2 kg/min feed rate combined with the maximum roller speeds (376 rpm). Therefore, the machine could be operated at the combination of 4.2 kg/min and 326 rpm for best performance in the majority of the parameters.

1. Introduction

The Alliaceae family's widely grown plant species is allium [1] with around 700 species globally [2]. In Ethiopia, people have traditionally used garlic (*Allium Sativum* L.) as a remedy for a variety of ailments [3]. The allium plant is the most important used vegetable as a condiment in most Ethiopian meals. Two of these are referred to as "kitchen queens" and are considered to be among the most significant herbs for mass production in Ethiopia Allium sativum L. and Allium cepa L [4]. Garlic is the most popular root vegetable in Ethiopia, next to onions. Many Ethiopian groups have used it as a culinary flavoring element and as a medicinal herb to cure various ailments [5]. Garlic is a widely used spice and one of the most significant root crops in Ethiopia. It is mostly used to season

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and flavor vegetables in a variety of recipes. Additionally, it has several therapeutic benefits [6].

Garlic was planted on 13,278.55 ha in Ethiopia, yielding almost 1.2 million quintals gathered during the 2011/12 agricultural season [7]. It is often cultivated in home gardens, but its production is currently done on vast big farms [8]. Fresh garlic may be marketed for up to three months after harvest in a well-known warehouse, six months in a cold room, and a year in a controlled environment [9]. In terms of production and economic worth, garlic is one of the world's most important Allium vegetable crops. It is a spice used in a wide variety of dishes. Garlic oil has a strong smell, distinct flavor, strong taste, and health advantages since it is volatile and contains sulfur compounds [10]. Garlic is the primary source of income for any small farm with access to irrigation water [11].

Compared to other bulb crops, garlic has higher nutritional value, with 30–35 % of its dry matter, 6–7% of proteins, 0.2 % of fat, 23–28 % of dietary carbohydrates 0.7–0.9 % dietary fibers, 1.1–1.4 % ash contents, and the majority of vitamins contents such as B1, B2, B6, and C. Garlic consists of many enzymes, amino acids, known compounds, hint elements, and the antibiotics garlicin and allistatin [12]. It no longer contains only carbohydrates, but also minerals, antioxidants, vitamins, polyphenols, and carotenoids [13]. Its health benefits have traditionally been acknowledged in Egypt, China, and Greece. Not only that, but the Romans also employed it [14]. The major chemicals that provide this flavor are mainly unstable sulfur-containing amino acids (thiosulfate), among which alliin or S-allyl cysteine sulfoxide (ACSO) is the main precursor of garlic [15]. *Allium sativum* L., the pungent herb is consumed in powder form worldwide and is traditionally used to treat a wide range of illnesses. In conventional medicine, it has been said to possess a number of biological qualities, such as antidiabetic, antifungal, antioxidant, protecting, anticancer, anti-weathering, antihypertensive effects, and antibacterial **[** [16–18]**]**. Garlic bulbs may be used for savory and liquid sweets in addition to being used to flavor curries. It is also utilized in processed forms, including pickles, pastes, macerate oils, essential oils, and powders. Protein, phosphorus, potassium, calcium, magnesium, and carbohydrate are all abundant in it. Green garlic can have a very high ascorbic acid concentration [19].

Crushed, minced, peeled, and powdered garlic products are made from fresh garlic [9]. Processed garlic is used to make dehydrated products like flakes, powders, pickles, canned goods, and bottles. Apart from being exported to significant countries to enhance their international market value, garlic goods are very desirable in the domestic market, particularly for the snack and catering industries [19].

The technique of breaking a garlic bulb is how the cloves are separated to make processing easier [20]. Garlic cloves are the planting material for garlic. The cloves of garlic are separated from the entire bulb and smashed using wooden tools [19]. Instead of sacking or pounding with a wooden rod, garlic cloves are often separated by shearing the bulb between the two palms. These methods are time-consuming, laborious, and frequently result in hand injuries [20]. Because of its volatile essential oils and unique physical characteristics that are present in the epidermal cells, which give garlic its characteristic aroma, breaking garlic bulbs takes particular care and expertise [21].

Considering the issues raised above [19,20], and [21] performed an experiment to investigate the influence of rubber materials on the breaking effectiveness of a rubber roll garlic bulb separator, as well as to examine the processes of breaking. The findings indicated that shearing stress is the determining factor in the breaking ratio. They recommended that bulbs circulate between rubber rollers before breaking, which resulted in a large impact and shearing force at the bulb's apexes that facilitates breaking.

Summing up the above research [19,20], and [21], it has been found that the breaking mechanism of garlic bulbs to garlic cloves under either feed rate or roller speed is substantially different. The preceding study has made important contributions to our knowledge of the mechanism by which garlic bulbs to garlic cloves under different feed rates or roller speeds. However, it can be seen that the size of the breaking unit, feed rates, or roller speeds on the garlic bulb breaking in all the above-cited studies are selected based on the garlic bulb properties of some Asian countries. Two rolls with highly elastic rubber coverings serve as the major part of the rubber roll garlic bulb separator, and garlic bulbs are sheared and impacted during the breaking. Rubber has a lower hardness than the garlic bulb, thus its deformation during the breaking process is more than that of the garlic bulb, based on the force needed to remove the garlic cloves from the entire garlic bulb, which is 40.7 N, as suggested by Ref. [19]. However, there has been no linked study report on the breaking mechanism of garlic bulbs into garlic cloves caused by rubber roll materials in Ethiopia even if in Africa. Therefore, the separate method of the garlic bulb in the breaking operation with two rubber roller separators needs investigation based on varieties of garlic cultivated in Ethiopia.

Farmers thus requested a machine to extract garlic clove from bulbs for plantation. However, a machine is not available in Ethiopia. In China and India, a machine for removing garlic cloves from a bulb has been created. But such machines were built for Chinese and Indian garlic kinds, and they were exceedingly pricey. Because Ethiopian garlic types differ significantly from those of other nations in terms of their engineering features, such machines require modification and additional expenditures. Building a cheap and efficient garlic bulb-breaking machine with materials from the Asella Agricultural Engineering Research Center, Asella, Ethiopia is crucial to filling this gap.

In this study, the garlic bulb breaker performances due to the influence of feed rates, and roller speeds were evaluated alongside the garlic bulb breaker that resulted from the breaking to initially analyze the garlic bulb breaking method in the breaking operation and to build an accurate evaluation technique. The breaking mechanism and how to increase the breaking capacity were clarified and the results were confirmed by experiments with a rubber roll breaker. In consideration of the need for large quantities of garlic for cultivation, sorting, and an orhers processing, a garlic bulb breaker is essential to its ability to separate garlic bulbs into cloves. Hence, this research was proposed to evaluate the performance of a power-operated garlic bulb separator for clove separation.

2. Materials and methods

2.1. Experimental location

The study took place in the Asella Agricultural Engineering Research Center in Asella, Ethiopia, from May 2021 to April 2022. Fabrication and performance testing were completed at the Asella Agricultural Engineering Research Centre (AAERC) in Asella, Ethiopia.

2.2. Experimental materials

From the Holeta local market, a 150-kg native variety garlic bulb was purchased. After being packaged in polyethylene plastic bags and transported to the Asella Agricultural Engineering Research Center (AAERC) in Asella, Ethiopia, the research samples were kept at room temperature (25 °C) until needed for machine performance evaluation.

2.3. Experimental design

The experiment was conducted with a 3^2 full factorial in a completely randomized design (CRD), which had two factors that are feed rate and roller speed. The first factor was feed rate with three levels 3.7 kg/min (F_1), 4.2 kg/min (F_2), and 5.2 kg/min (F_3)) and the second factor was roller speed with three levels (276 rpm (V_1), 326 rpm (V_2) and 376 rpm (V_3)). These factors are randomly selected based on the size of the garlic bulb-breaking unit and related research work with the current topic reported by **[** [19,20,22,23]**]** . Each treatment combination was done in triplicate. The total number of treatments in this experiment was 27. The experimental plan is shown in Table 1 below.

2.4. Machine description

The machine separates cloves from garlic bulbs is achieved using a combination of impact and shearing forces [21]. Based on this principle, the engineering properties of garlic varieties cultivated in Holota, Ethiopia conducted by Ref. [3], and the design of a garlic bulb breaker developed by Ref. [24], a clove separator from the whole garlic bulb was fabricated. The machine had an input hopper, a pair of rollers, a blower, an exit for garlic cloves and husk, a power location, and a driving mechanism (engine, belt and pulley). A passageway was constructed above the input entrance of the roller casing for delivering the garlic bulbs. The rubber-covered rollers had a diameter of 208 mm and a length of 402 mm, and they rotated in opposing directions to generate a shearing effect on the bulbs, resulting in cloves. To protect the cloves from injury, an additional coating of rubber padding was placed.

A blade blower, measuring 460 mm in length, 95 mm in width, and 191 mm in diameter was employed to generate an airflow for cleaning the material that passed between two rollers. A machine prime mover, which powered its many components, was a petrol engine. The roller and blower components received power transmission via the belt and pulley system. All of the aforementioned components are fitted with the appropriate supports and attached to the mainframe. The whole measurements of the machine were 505 mm in length, 463 mm in width, and 830 mm in height. To make the machine easier to transport, four 200 mm diameter metal wheels were fitted to each of the four legs.

A garlic bulb breaker is created based on several engineering features of garlic bulb and clove, including moisture content, angle of repose, bulk density, garlic bulb weight, average diameter, geometric mean diameter, and sphericity, which were acquired by Ref. [3]. [24] explained the machine components in the subsections below.

2.4.1. Feed hopper

The angle of repose, weight, and bulk density of the garlic bulbs were taken into consideration while designing the hopper seen in Fig. 2 below. The feed hopper's inclination was adjusted to 77.27°, which is greater than the garlic bulb's angle of repose of 49.7°. This allows the bulbs to easily flow to the bottom of the hopper and the bulbs breaking unit. The hopper, which was constructed of a mild steel sheet that was 1.5 mm thick, was shaped like a trapezoidal prism as seen in Figures (2 and 4). It has a lid that can be opened easily with the handle at the top [24].

2.4.2. Bulb breaking unit

The separator comprises two rollers and an outer covering that holds the garlic to be processed. The spacing between the two rollers

Table 1
Experimental design of 3^2 factorial arrangements.

Feed rate (F)	Roller speed (V)		
	V_1	V_2	V_3
F_1	F_1V_1	F_1V_2	F_1V_3
F_2	F_2V_1	F_2V_2	F_2V_3
F_3	F_3V_1	F_3V_2	F_3V_3

Where; F = Feed rate, V = Roller speed.

was determined by the dimensions of the garlic cloves, which averaged 19 mm. The rollers were constructed from mild steel sheets with a thickness of 2.5 mm, which had a 200 mm outside diameter and 402 mm length. The pair of rollers were attached to the main frame using the requisite ball bearings and supports. To protect the garlic from injury, 4 mm thick rubber was used to cover the roller's surface. Steel sheet metal with a thickness of 1.5 mm was used to fabricate the roller housing. It is appropriately attached to guard the rollers and avoid the leakage of cloves [24]. The roller's dimensions are shown in Fig. 1.

2.4.3. Outlets of the machine

The exits were provided beneath a pair of rollers for the collection of light items and cloves. The cloves' departure was constructed as a chute, with the surface where the materials exited the machine at a 45° angle with the horizontal. This angle is more than the 37.56° angles of repose of a garlic clove. The waste material exit was situated on the opposite side of the air fan in which the air current was capable of removing the husk from the machine. The rectangular form of the husk exit is angled upward at the inner end for receiving the husks conveyed by air and then acquires an arcing length with its outer tip oriented downwards to direct the light items to the ground underneath [24]. The outlets of the machine are shown in Figs. 2 and 4.

2.4.4. Machine mainframe

The machine mainframe is constructed from mild steel angles measuring 40 × 40 × 6 mm. The frame measured 505 mm in length, 465 mm in width, and 830 mm in height. To improve machine mobility, four 200 mm diameter support wheels were attached to the four angles of a mainframe. The input hopper, two rubber rollers, fan, outlets, and engine location were attached to the frame [24]. Other components of the machine were mounted and supported by the frame seen in Figs. 2 and 4.

2.4.5. Power transmission system

The husk and garlic cloves separated from the bulb by rollers were powered by the five (5) horsepower petrol engine placed on the engine set up as an additional frame linked to the left edge of the mainframe. A 'V' belt and pulley arrangement transmits power to the rollers and fan. Consideration was provided for getting the necessary belt tensions [24]. The power transmission system is shown in Figs. 2 and 4 below.

2.4.6. Air blower

The machine included an air blower with four blades (Fig. 3), which was fixed on a shaft and covered with mild steel sheeting that was 1 mm thick to form a housing. This housing had an air outlet on the inner side to direct pressured air toward the material that was flowing downwards immediately below the rollers, as well as opens on the two ends that permitted air in. Through a pulley and belt system connected to the two rollers' pulleys, the fan is powered at a rate of 1200 rpm [24]. Fig. 3 below shows the dimensions of the air-blower unit.

2.5. Mechanism and operation of the machine

The operation of the machine starts with turning on the engine on the machine engine set. The machine could be set to run at three different feeding rates (3.7, 4.2, and 5.2 kg/min), three different roller speeds (276, 326, and 376 rpm), and a 19 mm clearance depending on the size of the garlic clove. The bulb of garlic is resting on the hopper. The garlic bulb descends to the hopper's lower section. Next, the garlic bulb is sent to the breaking equipment situated beneath the hopper. The garlic bulb is distributed evenly and falls onto the subsequent operation.

The rubber roller assembly consists of two rubber rollers that rotate in opposite directions at different speeds. One of the rubber

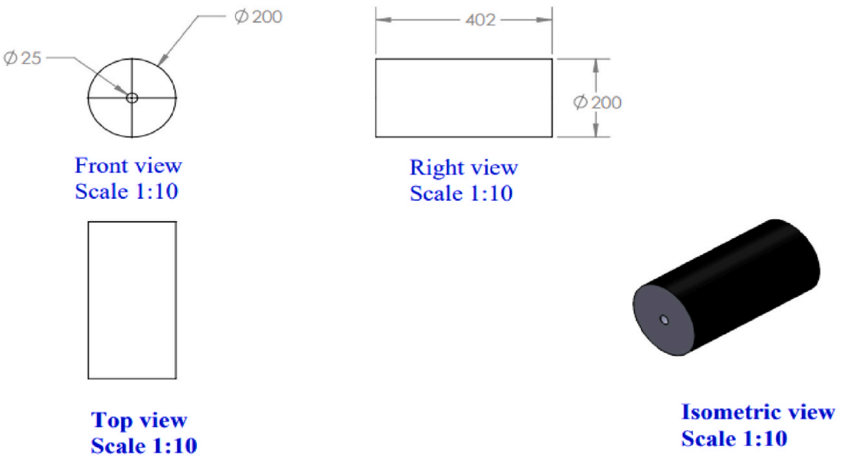

Fig. 1. Diagrams show a roller size in (mm).

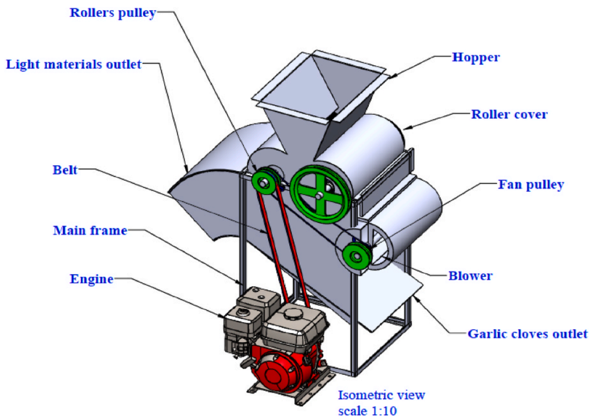

Fig. 2. Components of designed garlic bulb breaker.

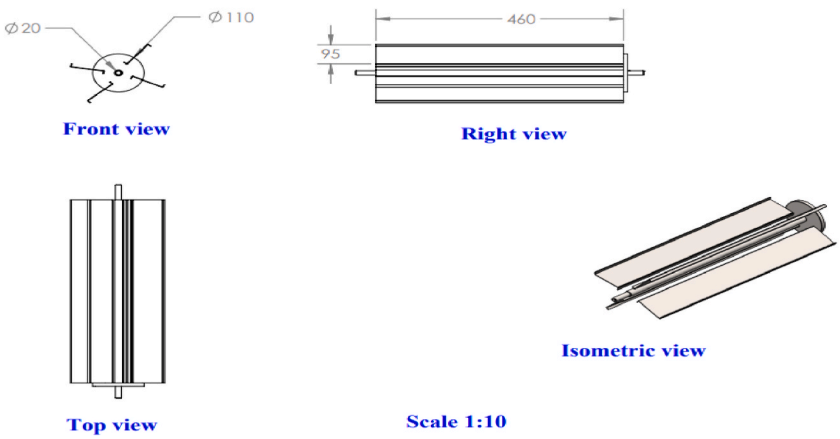

Fig. 3. Diagrams show the size (in mm) and the fan components.

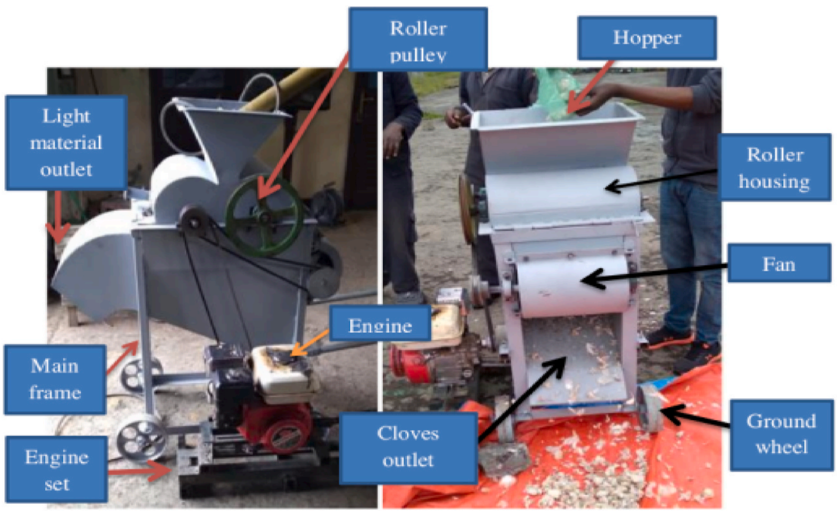

Fig. 4. Constructed garlic bulb separator prototype.

rolls is stationary and the other is movable or adjustable. The movable one is about three times faster in speed than the stationary rubber roll. The breaker releases a combination of skin and clove. It travels via an inclined plane sheet to transport cloves on the left side of the machine, near the clove output. The current air created by the blower separates the combination of light materials and cloves, directing light materials to the light materials exit. The cloves discharge and glide down to the clove collecting area, where they are sent to the clove output valve. If there are no more garlic bulbs to break, the operation comes to an end. Fig. 4 shows the components of the built clove separator from a garlic bulb.

2.6. Performance evaluation

In advance of the performance evaluation, the following procedures and safeguards were explained. The operator wears his safety clothes and shoes. Twenty-seven garlic bulb samples were prepared at three feed rates, and the speed of the rollers was monitored using a digital tachometer for each treatment. Garlic bulb samples were fed continuously via a feeding hopper for all the treatments. The husk and separated garlic cloves between two rollers were collected at the light materials and cloves outlets. The time taken to separate each sample of garlic was measured using a stopwatch. The broken cloves had fragments of single cloves, clove clumps, broken cloves, and light components (skin, stem, and root sections). A digital weight balance was used to weigh each fraction independently after it had been separated. There were three runs of each experiment.

The following parameters were determined using the data collected from the aforementioned fractions. Machine performance was evaluated in terms of garlic bulb breaking efficiency, garlic bulb separating capacity, fuel consumption, percent of clumps of cloves, clove damage, clove loss, and clove germination, and calculated according to Ref. [21].

2.6.1. Breaking efficiency of garlic bulb separator

The breaking efficiency of garlic bulbs was determined according to Ref. [21] using the formula below:

$$\text{BE}\ (\%) = \frac{\text{s}}{\text{I-F}} \times 100 \tag{1}$$

where;

BE = breaking efficiency, %,

S = mass of individual cloves separated and collected through the main outlet, kg,

I = total input mass, kg,

F = mass of garlic husk collected through the chaff outlet, kg.

2.6.2. Percent of clumps of cloves

The percentage of clove clump was calculated by the formula below according to Ref. [21]:

$$\text{CC}\ (\%) = \frac{\text{C}}{\text{I-F}} \times 100 \tag{2}$$

where;

CC = clumps of cloves, %,

C = weight of two or more non-separated cloves received via a main exit, kg,

I = total mass of input, kg,

F = mass of garlic husk received through the trash exit., kg.

2.6.3. Fuel consumption

First, the garlic bulb breaker was placed on a flat surface to calculate the amount of petrol consumed. Before the test began, the fuel container was filled up to overflowing. After the breaking process was completed, the engine was turned off, and a container was refilled to its initial amount at each treatment. The volume of petrol refilled in the fuel container was determined using a graduated measuring device and recorded. The differences between the volume of petrol before and following breaking were utilized to evaluate fuel consumption.

2.6.4. Percent of cloves loss

The percent of clove loss was calculated using the following formula according to Ref. [21]:

$$\text{CL}\ (\%) = \frac{\text{G}}{\text{I-F}} \times 100 \tag{3}$$

where;

CL = cloves loss, %,

G = mass of light cloves collected at the outlet of the light materials, kg.a.

2.6.5. Percentage of damaged (physically injured) cloves

The overall amount of damaged cloves within a sample taken from the outlet was separated and evaluated according to the following equation [21].

$$DC\ (\%) = \frac{E}{I\text{-}F} \times 100 \tag{4}$$

where;

DC = damaged cloves, %,

E = mass of damaged clove collected at the main outlet, kg.

2.6.6. Breaking capacity of the machine

The garlic breaker, breaking capacity was tested by weighting the overall amount of clove received per minute duration in the exit chute of a garlic separator [19].

$$BC\ (kg / h) = \frac{S + C}{T} \tag{5}$$

where;

BC = breaking capacity, %,

S = mass of individual cloves detached and received through its main exit, kg., kg,

C = mass of two or more non-separated cloves collected through the main outlet, kg,

T = time consumed, h.

2.6.7. Garlic clove germination

Germination was examined by picking 100 garlic cloves at random from each sample. Trays were made to fit (40 × 24 × 11 cm) and then the soil was filled in it. Cloves of garlic were planted in trays filled with soil. Fifteen days after planting, the number of cloves that germinated was counted and the percentage was stated [19].

2.7. Data analysis

Each experiment was run three times. The data obtained was evaluated using the statistical program R (version 3.4.3, 2017) utilizing analysis of variance (ANOVA). Treatment effects were analyzed statistically ($p < 0.05$) and mean variations were evaluated using the least significant difference (LSD). The findings are reported as the mean and standard deviation.

3. Results and discussion

The results of the performance of the prototype machine such as breaking efficiency, percent of clumps of cloves, percent of cloves loss, percentage of damaged cloves, breaking capacity, fuel consumed, and percentage of garlic clove germination are presented in Tables 2 and 3. The main and interaction effect of the three feed rates (3.7, 4.2, and 5.2 kg/min) and the three roller speeds of operations (276, 326, and 376 rpm), on these indicated performance parameters, are discussed in the subsequent subsections.

3.1. Main and interaction effect of feed rates and roller speeds on the performance of garlic bulb breaker

The performance of the constructed garlic clove separator from a bulb, such as separating efficiency, cloves clumps, loss of cloves, injured cloves, separating capacity, fuel consumption, and garlic clove germination, is affected by the main and interaction of feed rate and roller speed are shown in Tables 2 and 3

Table 2

The main effect of feed rates and roller speeds on the performance of garlic bulb breaker.

Feed rate	BE (%)	CC (%)	CL (%)	DC (%)	BC(kg/h)	FC(ml/kg)	CG (%)
F1	84.72 ± 1.24^{b}	12.88 ± 1.02^{b}	0.011 ± 0.003^{b}	1.89 ± 0.08^{c}	217.24 ± 2.00^{c}	6.16 ± 0.48^{c}	98.00 ± 1.41^{ab}
F2	85.60 ± 1.12^{a}	11.82 ± 1.24^{c}	0.012 ± 0.004^{ab}	1.97 ± 0.09^{b}	246.32 ± 0.98^{b}	6.78 ± 0.42^{a}	98.66 ± 1.00^{a}
F3	81.68 ± 1.01^{c}	15.88 ± 0.90^{a}	0.013 ± 0.004^{a}	2.15 ± 0.17^{a}	306.08 ± 1.67^{a}	6.47 ± 0.34^{b}	97.22 ± 1.85^{b}
Roller speed							
V1	84.03 ± 1.44^{b}	13.48 ± 1.49^{b}	0.007 ± 0.000^{c}	1.88 ± 0.09^{c}	256.71 ± 40.08^{a}	5.99 ± 0.30^{c}	98.22 ± 1.71^{ab}
V2	84.84 ± 2.33^{a}	12.67 ± 2.23^{c}	0.014 ± 0.001^{b}	2.03 ± 0.16^{b}	256.29 ± 38.44^{a}	6.47 ± 0.27^{b}	98.55 ± 1.33^{a}
V3	83.13 ± 2.03^{c}	14.43 ± 2.10^{a}	0.016 ± 0.001^{a}	2.10 ± 0.15^{a}	256.64 ± 39.22^{a}	6.95 ± 0.24^{a}	97.11 ± 1.26^{b}
CV%	0.88	3.64	6.42	3.26	0.61	0.62	1.25
LSD(0.05)	0.73	0.48	0.00	0.06	1.57	0.04	1.22

Where, BE = breaking efficiency, CC = clumps of cloves, CL = cloves loss, DC = damaged cloves, BC = breaking capacity, FC = fuel consumed, PG = clove germination, F1 = 3.7 kg/min, F2 = 4.2 kg/min, F3 = 5.2 kg/min, V1 = 276 rpm, V2 = 326 rpm, V3 = 376 rpm, CV = coefficient of variation; data are mean ± SD, and the means followed by the identical letter in a column are not statistically different at 5 % of significance; LSD = least significant difference.

Table 3
Interaction effect of feed rate and roller speed on the performance of garlic bulb breaker.

Feed rate (kg/min)	Roller speed rpm	BE (%)	CC (%)	CL (%)	DC (%)	BC (kg/h)	FC (ml/kg)	CG (%)
3.7	276	84.69 ± 1.86^{bc}	12.21 ± 0.57^{d}	0.008 ± 0.00^{d}	1.79 ± 0.05^{d}	215.98 ± 3.43^{c}	5.61 ± 0.02^{h}	99.00 ± 1.00^{a}
	326	85.60 ± 0.41^{b}	12.39 ± 0.56^{d}	0.013 ± 0.01^{c}	1.91 ± 0.03^{c}	218.04 ± 0.33^{c}	6.16 ± 0.01^{f}	97.33 ± 1.52^{ab}
	376	83.88 ± 0.52^{cd}	14.04 ± 0.72^{c}	0.015 ± 0.01^{ab}	1.96 ± 0.04^{bc}	217.69 ± 0.73^{c}	6.73 ± 0.01^{c}	97.66 ± 1.52^{ab}
4.2	276	84.76 ± 0.19^{bc}	12.93 ± 0.56^{d}	0.007 ± 0.00^{d}	1.91 ± 0.11^{c}	247.17 ± 1.15^{b}	6.29 ± 0.05^{e}	99.00 ± 1.00^{a}
	326	87.05 ± 0.34^{a}	10.27 ± 0.37^{e}	0.014 ± 0.01^{bc}	1.95 ± 0.10^{bc}	245.91 ± 0.73^{b}	6.79 ± 0.06^{c}	99.33 ± 0.57^{a}
	376	84.98 ± 0.39^{bc}	12.26 ± 0.20^{d}	0.016 ± 0.01^{a}	2.05 ± 0.04^{b}	245.90 ± 0.65^{b}	7.27 ± 0.03^{a}	97.66 ± 0.57^{ab}
5.2	276	82.65 ± 0.69^{de}	15.30 ± 0.62^{b}	0.008 ± 0.00^{d}	1.93 ± 0.05^{c}	306.98 ± 0.42^{a}	6.08 ± 0.03^{g}	96.66 ± 2.08^{b}
	326	81.87 ± 0.40^{e}	15.35 ± 0.29^{b}	0.015 ± 0.01^{ab}	2.24 ± 0.07^{a}	304.92 ± 2.77^{a}	6.46 ± 0.06^{d}	99.00 ± 1.00^{a}
	376	80.53 ± 0.20^{f}	16.98 ± 0.16^{a}	0.016 ± 0.01^{a}	2.29 ± 0.03^{a}	306.34 ± 0.22^{a}	6.86 ± 0.05^{b}	96.00 ± 1.00^{b}
CV%		0.88	3.64	6.42	3.26	0.61	0.63	1.25
LSD(0.05)		1.26	0.84	0.001	0.11	2.72	0.07	2.11

Where, BE = breaking efficiency, CC = clumps of cloves, CL = cloves loss, DC = damaged cloves, BC = breaking capacity, FC = fuel consumed, CG = clove germination, CV = coefficient of variation; values are mean ± SD and the means followed by the identical letter in a column are not statistically different at 5 % of significance; LSD = least significance difference.

3.1.1. Breaking efficiency

The data showing the influence of garlic feeding rate and roller speed on the breaking efficiency of the built garlic clove separator are presented in Table 2. Breaking efficiency data exhibited significant differences ($p < 0.05$) due to feeding rate. The average values were 84.72 % for a feed rate of 3.7 kg/min, 85.6 % for 4.2 kg/min, and 81.68 % for 5.2 kg/min with significant differences among all three values. It can be seen that as the feed rate increased the efficiency decreased significantly. This might be due to the congestion of the machine rollers with feed materials, which might have resulted in some bulbs slipping through untouched by the rollers. Similar trends have been reported by several researchers in the degree of breaking of the clove separator from a bulb with numerous kinds of rubber padding, space between the rollers, and peripheral speeds **[** [20,21,25]**]** . On the other hand, the breaking efficiency was also influenced by the speed of the rollers. The values were 84.03, 84.84, and 83.13 % for roller speeds of 276, 326, and 376 rpm, respectively. Statistically, the highest efficiency belonged to the 326 rpm speed while 376 rpm resulted in the lowest efficiency. The data shows that breaking efficiency is not related to roller speed.

The data showing the interaction of feeding rates and roller speeds on the separating efficiency of the built garlic clove separator are shown in Table 3. The degree of breaking of the constructed machine at a feed rate of 3.7 kg/min combined with roller speeds of 276, 326, and 376 revolutions per minute (rpm) were 84.69, 85.6, and 83.88 %, respectively. Likewise, a feed rate of 4.2 kg/min combined with speeds of 276, 326, and 376 rpm resulted in breaking efficiency of 84.76, 87.05, and 84.98 %, respectively. Breaking efficiencies of 82.65, 81.87, and 80.53 %, were recorded when the highest feed rate, 5.2 kg/min, was combined with roller speeds of 276, 326, and 376 rpm, respectively. They all show significant ($p < 0.05$) differences due to the interaction of the two factors. Thus, the highest value (87.05 %) was for treatments combination of the intermediate values of the feed rate of 4.2 kg/min and roller speed of 326 rpm whereas the lowest value (80.53 %) was for a combination of the highest values of feed rate (5.2 kg/min) and roller speed (376 rpm). This shows that both factors have a strong balanced influence on their interaction [19]. reported breaking efficiency (75 %) by a machine he studied, which is lower than the one in the present finding while [20] reported a 92.16 % efficiency, which is greater than the result recorded in this work. However, the recorded efficiencies of the machine in this study were comparable with the values (61.4–90.33 %) reported by Ref. [25] and with the 85 % reported by Ref. [23].

3.1.2. Clumps of cloves

The recorded average results of clumps of cloves obtained during the test of the constructed garlic bulb breaker at different feed rates and roller speeds are shown in Table 2. The effect of feed rates on the values obtained was significant ($p < 0.05$) with values of 12.88, 11.82, and 15.88 % at feed rates of 3.7, 4.2, and 5.2 kg/min, respectively. All three values showed significant differences among them. As can be seen, no trend was observed in the data to establish a relationship between the variables. However, the highest percentage of clumps at the highest feed rate can be explained by the fact that a high feed rate can result in the congestion of the machine leading to clumps slipping through the rollers without contact with the roller surfaces. The very high difference observed between this highest value and the other two values could show that the feed rate was excessively high to have such a big impact. The data of the clumps of cloves showing the effect of roller speed on this parameter exhibited significant differences ($p < 0.05$) among all three values. The lowest speed (276 rpm) resulted in 13.48 % clumps of intermediate value whereas the highest clump (14.43 %) was recorded for the highest speed (376 rpm). Again, no trend was obviously observed in the results as related to the speed of operation.

The result of this research work was greater than the average value of 1.22 % reported by Ref. [21] at different speeds and clearance of garlic bulb breaker.

The data showing the interaction of feed rate and roller speed on the clumps of cloves are presented in Table 3. Results of clumps of cloves obtained from the tests of the prototype machine for the different combinations of feed rate and roller speeds ranged from 10.27 to 16.89 % with significant differences ($p < 0.05$) between values. The lowest record was of the combination of the intermediate values of feed rate (4.2 kg/min) and roller speed (326 rpm), whereas the highest value belonged to the combination of the maximum values of feed rate (5.2 kg/min) and roller speed (376 rpm). The findings revealed that feed rate had a greater impact than roller speed on this performance parameter. The results obtained in this work are comparable from 10.79 to 18.34 %, which were reported by Ref. [19] but greater than the 1.22 % reported by another group of the same authors in a later work [21].

3.1.3. Fuel consumption

The fuel consumption data in Table 2 show significant differences at $p < 0.05$ related to feeding rate and roller speed. Average values of fuel consumption rates of 6.16, 6.78, and 6.47 ml/kg for feed rates of 3.7, 4.2, and 5.2 kg/min, respectively, showed significant differences. As can be seen in the data, the highest fuel consumption was obtained at the intermediate feed rate, unlike the expectation of many. The consumption level of 6–7 ml per kg of material is highly acceptable. The average fuel consumption rate data of 5.99, 6.47, and 6.95 ml per kg of garlic presented in the table showed significant ($p < 0.05$) increments attributed to roller operating speeds of 276, 326, and 376 rpm, respectively. As the roller speed of operation increased so did the fuel consumption of the engine.

The fuel consumption data of the garlic bulb breaker machine for the interaction of the different combinations of feed rates and roller speeds are shown in Table 3 and varied between 5.61 and 7.27 ml/kg. The highest value was recorded for the highest speed combined with the highest feed rate (6.86 ml/kg) whereas the lowest consumption (5.61 ml/kg) was for the combination of the lowest values of feed rate and roller speed. Thus, the data showed that the interaction had a more or less balanced influence of the two factors. Thus, because of the majority parameters are more acceptable at an intermediate feed rate (4.2 kg/min) and speed (326 rpm), 6.79 ml per kg fuel was used to operate the machine.

3.1.4. Cloves loss

The data showing the influence of garlic feeding rate and roller speed on the loss of cloves of the built garlic clove separator are presented in Table 2. The influence of feed rates was found to cause highly significant ($p < 0.05$) differences in cloves loss by the garlic bulb breaker. The highest clove loss (0.013 %) was recorded for the highest feed rate of 5.2 kg/min. The next lower (0.012 %) cloves loss was recorded for the intermediate feed rate of 4.2 kg/min. The lowest clove loss (0.011 %) occurred at the lowest feed rate of 3.7 kg/min. As can be seen clearly, as the feed rate increased the clove loss level increased with a significant difference between the highest and lowest values. Clove loss was also significantly affected ($p < 0.05$) by the roller speed of the garlic bulb separator. The highest clove loss (0.016 %) was recorded at 376 rpm of the roller speed. On the other hand, the lowest level of cloves loss (0.007 %) was recorded at 276 rpm of roller speed. The intermediate level of clove loss (0.014 %) was found to have occurred at the intermediate speed of the roller which is 326 rpm. It can be seen that clove loss increased as the roller speed increased. The results of this study were lower than the findings of other workers such as 1.08 reported by Ref. [21], and 0.3–2.25 %, by Ref. [20].

Data of clove loss recorded in the performance tests of the prototype machine also exhibited significant differences ($p < 0.05$) attributed to the interaction of the two factors shown in Table 3. The values ranged from 0.007 to 0.016 % with the lowest values belonging to the lowest roller speed regardless of feed rate while the highest values were associated with combinations of the highest roller speed regardless of feed rate. These show that roller speed had more influence than feed rate regarding this performance parameter. In fact, all the clove losses are considered very insignificant as they are less than 0.02 % [21]. reported clove losses of 1.08 % by the machine they evaluated, which is much higher than the one reported in this study. Likewise [20], reported cloves loss of 0.3–2.25 % for a garlic bulb breaker they studied, which is again higher than the results found in this work. Such big differences in the findings could be attributed to several factors such as differences in the moisture content of samples, the garlic varieties, the intact clump sizes, operation conditions, etc.

3.1.5. Damaged cloves

Data showing the effects of the garlic feed rate and roller speed of the prototype garlic bulb breaker on the damaged cloves are presented in Table 2. The values show significant ($p < 0.05$) differences due to the feed rate. The highest (2.15 %) damaged cloves were recorded for a garlic feed rate of 5.2 kg/min whereas the lowest (1.89 %) damaged cloves were the lowest (3.7 kg/min) feed rate. The intermediate level of clove damage (1.97 %) occurred at the intermediate level (4.2 kg/min) feed rate. The level of damage increased as the feed rate increased with significant differences among all three values. Similarly, data regarding roller speed showed a significant difference ($p < 0.05$) in the degree of damage of cloves with values of 1.88, 2.03, and 2.1 % for those samples operated at 276, 326, and 376 rpm, respectively. The data clearly show that the damage level of cloves increased as the roller speed increased. Understandably, it happened as such because roller speed increases the impact, and/or shear forces acting on the cloves increase causing more damage to them. The result of this research work was relatively in agreement with the findings of 1.7 % reported by Ref. [21] at different speeds and clearances of garlic bulb breakers. On the other hand, those values are higher than the 1.1 % value of damaged cloves of garlic bulb breaker reported by Ref. [20]. Regardless of the effect of the two factors, the performance of the prototype machine in regard to clove damage level can be considered well enough as remained below 3 %.

The data showing the interaction of feed rate and roller speed on the damaged cloves of the built garlic clove separator are presented in Table 3. The damaged cloves recorded during the test of the constructed garlic bulb breaker ranged from 1.79 to 2.29 % with significant differences ($p < 0.05$) among the different values. The highest damage levels were associated with the highest roller speed

(376 rpm) irrespective of the 5.2 kg/min feed rate while the lowest values were recorded for combinations having the lowest roller speed (276 rpm) regardless of the 3.7 kg/min feed rate. Thus, the data show that operating speed had a stronger influence than feed rate in the interaction of the two factors regarding this performance parameter. Overall, the clove damage levels of the machine can be considered very low and acceptable with values of less than 3 %. The results of this study are comparable with the damage levels of 1.7 % reported by Ref. [21] and 1.1 % reported by Ref. [20].

3.1.6. Breaking capacity

The effects of feed rate and roller speed on the breaking capacity of the constructed garlic clover are shown in Table 2. The data showed significant differences ($p < 0.05$) due to the feeding rate. As was expected, the breaking capacity increased as the feed rate increased with values of 217.24, 246.32, and 306.08 kg/h of samples broken at feed rates of 3.7, 4.2, and 5.2 kg/min, respectively. Roller speeds showed no significant differences ($p \geq 0.05$) in the breaking capacity of the constructed garlic bulb separator with average values of 256.71, 256.29, and 256.64 kg/h for roller speeds of 276, 326, and 376 rpm, respectively. This shows that whatever is fed to the machine comes out as output and the roller speed could not bring any change to the quantity of material passing through the machine. This result is corroborated by the work of [25] who conducted a similar study on the breaking capacity of a machine operated at different speeds ranging from 233.33 to 460.71 kg/h.

The interaction of feed rate and roller speed on machine-breaking capacity data is presented in Table 3 and showed a significant ($p < 0.05$) difference. The three lowest values (215.98, 218.04, and 217.69 kg/h) with no statistical difference ($p \geq 0.05$) among them were the lowest feed rate (3.7 kg/min) combined with all three roller speeds. On the other hand, the three highest values (306.98, 304.92, and 306.34 kg/h) were obtained by combining the maximum feed rate (5.2 kg/min) with all three roller speeds, again with no statistical difference ($p \geq 0.05$). The intermediate values recorded belonged to the intermediate feed rate combined with the three roller speeds. These show that the interaction of the two factors was strongly dominated by the feed rate with no impact on roller speed. The results of this work are corroborated by the breaking capacity records of 233.33–460.71 kg/h reported by Ref. [25]. However, a larger breaking capacity of garlic bulb breaker was reported by Ref. [21], which ranged from 404.56 to 782.18 kg/h at lower peripheral speeds [20]. also reported a breaking capacity value of 800 kg/h. The explanations for such big differences in breaking capacity could be attributed to the difference in crop properties such as moisture content, garlic bulb size, and shape as well as machine properties such as roller clearance, surface character of rollers, speed of rollers, etc.

3.1.7. Garlic clove germination

The germination of the garlic clove sample due to the feed rates and the roller speeds of the constructed garlic clover are presented in Table 2 above and shown in Fig. 5 below. Values were 98, 98.66, and 97.22 % for feed rates of 3.7, 4.2, and 5.2 kg/min with significant differences ($p < 0.05$) in clove germination rates between the samples fed into the machine at 3.7 and 4.2 kg/min. Regardless of the feed rate, the values attained can be considered very high. The clove's germination was also significantly affected by the roller speed ($P < 0.05$) of the machine. The two lower speeds of 276 and 326 rpm resulted in germination rates of 98.22 and 98.55 %, respectively, with no statistical difference ($p \geq 0.05$) between them. However, the highest speed (376 rpm) resulted in reduced germination of 97.11 %. The results of this study are in agreement with the conclusions of [19], who reported the average germination rate of 100 % of garlic bulbs handled at a different motor speed of garlic bulb breaker.

The data of the germination of the cloves obtained from the test runs of the prototype garlic bulb breaker machine ranged from 96 to 99.33 % for the different combinations of feed rate and roller speed many of which indicated no significant ($p \geq 0.05$) differences as presented in Table 3. Those obtained from combinations of higher feed rates (5.2 kg/min) and higher roller speeds (376 rpm) were of lower values. But generally, the clove germination rates were very much high. These values are very close to the 100 % which was reported by Ref. [19] at different peripheral speeds, padding materials, and clearances of the garlic breaker machines.

4. Conclusions

Garlic (*Allium sativum* L.) is Ethiopia's most popular root vegetable behind onions, and it is cultivated mostly for food preparation and therapeutic purposes. This study found that feed rate and roller speed can significantly affect the performance of a garlic bulb-breaker including fuel consumption. One exception is that roller speed was not affecting ($p < 0.05$) the breaking capacity. Combining a feed rate of 4.2 kg/min with a 326 rpm roller speed produced the greatest separating efficiency of 87.05 %. The performance data of the machine showed clove loss of less than 0.02 % and clove damage of less than 3 % which can be considered a very good performance. Despite the above indicated weak point, the machine could be operated at an intermediate feed rate of 4.2 kg/min and intermediate roller speed of 326 rpm for best performance in the majority of the parameters, with no difference ($p \geq 0.05$) in fuel consumption. Therefore, the machine is more acceptable. However, the cloves collected from the machine have large clove clumps in the range of 12–15 % which can be considered high. This might be an assignment for researchers to improve this machine.

Ethics statement

Ethical approval and consent of patients to participate do not apply to our study.

Data availability statement

Data will be made available on request.

Fig. 5. Garlic cloves germination.

CRediT authorship contribution statement

Abe Tullo Wako: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Solomon Abera Haptegebriel:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests and personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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