

Research Article

Performance Evaluation of Engine-operated Pulse Splitting Machine

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Abstract

Pulses are an important part of vegetarians' diets because the other foods they eat don't include much protein, and they are the main sources of various minerals, such as calcium, iron, phosphorus, and protein. The majority of the time, pulses are eaten as dehulled splits. The pulse processing is still restricted to time-consuming, health-harming, gender-biased traditional methods that assign all food preparation and processing duties to women. Despite Ethiopia's status as one of the world's leading producers of pulses, low post-harvest technological availability resulted in lower productivity and output. The machine was tested and evaluated in terms of splitting capacity, splitting efficiencies, mechanical damage percentage, and cleaning efficiency for pulse crops like Faba bean, Pea, and Lentil. The experimental design was carried out as a split-plot design having drum speeds with three levels in main plots and feeding rates with two levels in sub-plots, and the analysis was made using the R software. The experimental results clearly demonstrated that disc speed and feed rate are the most critical parameters influencing splitting capacity, splitting efficiency, cleaning efficiency, and grain breakage across Faba bean, pea, and lentil crops. Splitting capacity increased consistently with both drum speed and feed rate, with maximum throughput achieved at the highest speed (650rpm) and feed rate (8 kg/min). Splitting efficiency improved with increasing drum speed but declined slightly at higher feed rates, indicating that while throughput rises, efficiency may be compromised under heavy loads. Cleaning efficiency was highest at high drum speeds and moderate feed rates, confirming that excessive feed rates reduce the effectiveness of impurity separation. Breakage percentage increased with drum speed but decreased with higher feed rates, showing that high speeds intensify mechanical stress while higher feed rates provide a cushioning effect that reduces kernel damage.

Keywords

Pulses, Splitting Capacity, Cleaning Efficiency, Broken Percentage

1. Background and Justification

According to [1], pulses are dry leguminous plant seeds that differ from leguminous oil seeds due to their low lipid content. They are an important part of vegetarians' diets because the other foods they eat don't include much protein, and they are the main sources of various minerals, such as calcium, iron, phosphorus, and protein [2]. The majority of the time, pulses

are eaten as dehulled splits [3]. The majority of pulses provide between 21 and 25 percent protein, but just a little amount of important amino acids, including cystine, tryptophan, and methionine [4].

Ethiopia is among the top producers and exporters of pulses worldwide. It is the sixth-largest producer of chickpeas, the

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Received: 15 November 2025; **Accepted:** 1 December 2025; **Published:** 29 December 2025



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second-largest producer of Faba beans after China, and one of the top ten exporters of peas, dry beans, and chickpeas, as well as one of the top five exporters of Faba beans [5]. Faba beans, field peas, chickpeas, and lentils are among the pulses grown in Ethiopia's colder highlands. Haricot beans, cowpeas, pigeon peas, and mung beans are the main pulses farmed in the warmer, lower regions [6].

Ethiopia is one of Africa's leading producers of pulses, but exports to nearby nations like Sudan, Kenya, and Djibouti are restricted, and the processing of these commodities is restricted to small-scale *Baltina* who create some intermediary elements of traditional cuisines [7]. Additionally, the processing is still restricted to time-consuming, health-harming, gender-biased traditional methods that assign all food preparation and processing duties to women.

Despite Ethiopia's status as one of the world's leading producers of pulses, low post-harvest technological availability resulted in lower productivity and output. Due to a lack of sophisticated processing technologies, the potential and prospects as a source of revenue and its capacity to provide household income were poor. Ethiopia's limited experience with mechanized production of commercial items and staples based on pulses is one of the main obstacles to the adoption of modern processing technologies [8]. Thus, the farmers purchase the split pulse at a high cost and sell the raw pulse at a low cost to the market.

In Ethiopia, pulse processing is mostly done by women using two stones in a traditional, manual manner. However, this process is a labor-intensive, time-consuming process that uses a lot of energy and results in material loss. The aim of this is to evaluate engine-operated pulse-splitting machine for major pulse crops in Ethiopia, like Faba bean, Pea, and Lentil.

2. Materials and Methods

2.1. Experimental Site Description

The experiment was conducted at Bako Agricultural Engineering Research Centre (BAERC), which is located in the West Shewa Zone of Oromia Regional State of Ethiopia.

2.2. Material and Measuring Devices

Sheet metals, square pipe, rectangular pipe, chakki stone, angle iron, and diesel engine, etc.

Anemometer, Tachometer, measuring tape, stop watch, sensitive balance, and Grain moisture meter.

2.3. Working Principle of the Machine

The splitting unit had two emery discs, with one of the discs fixed and the other was revolving. The gap between the two disks can be increased or decreased depending on pulse crops and grain size of the cultivars, or in other words, the

clearance between them was adjusted by a screw mechanism. The machine would be developed to split the pulses by abrasion type, and it would derive its power from a diesel engine prime mover. The raw pulse is fed into the hopper and falls into the chamber, where it is rotated against the emery disc and abraded by the second disc. So the impact of the disc results in the pulses being split. The split pulses were ejected through the drum outlet. The husk and broken pieces were separated by winnowing and sieving. Cleaning of the seeds was done through the air stream produced by the fan, and then the split clean pulses pass down to the discharge outlet. So during our split, the machine parameters such as disc speed, clearance, size of disc, etc.

2.4. Performance Evaluation

The machine was tested and evaluated in terms of splitting capacity, splitting efficiencies, mechanical damage percentage, and cleaning efficiency.

2.4.1. Splitting Capacity

This is the capacity of the machine to split a quantity per unit of time, calculated as eqn. (1) [9].

$$S_C \text{ (kg/hr)} = \frac{Q_s}{T} \quad (1)$$

where:

Q_s = Quantity of material that passes through the grain collector (kg);

S_c = splitting capacity (kg/hr.); and

T = Time taken to complete the operation (hours).

2.4.2. Splitting Efficiencies

The yield of split and dehulled product material is calculated using the following formula as a proportion of the initial seed weight [10].

$$SE \text{ (%) } = \frac{D}{Wt} * 100 \quad (2)$$

Where:

D = mass of pulses split (kg)

Wt = original weight of Pulse (kg)

2.4.3. Cleaning Efficiency

The milling machine can clean the split from the hull, and it can be determined by Eqn. (3).

$$CE = \frac{W_c}{W_{h+s}} * 100 \quad (3)$$

where:

CE = Cleaning efficiency;

W_c = weight of cleaned split (kg) pulses (g); and

W_{h+s} = weight of hull of pulses and split pulses grain.

2.4.4. Broken Percentage

According to [10], it is basically the yield of kibble or broken product material as a percentage of the initial seed weight.

$$\text{Broken (\%)} = \frac{B}{W_t} * 100 \quad (4)$$

Where:

B = mass of kibble or broken

Wt. = original weight

2.5. Experimental Design

The experimental design was carried out as a split-plot design having drum speeds with three levels in main plots and feeding rates with two levels in sub-plots. Performance evaluation of the prototype machine used three levels of drum speed: 450, 550, and 650rpm as the main plot factor and two levels of feeding rate: 4.5 kg/min, and 6 kg/min for Faba bean and 6 kg/min and 8 kg/min for lentil and pea as the subplot factor by replicating three times, respectively.

2.6. Statistical Analysis

Data were subjected to analysis of variance using a statistical program [11]. Analysis was made using the R software. When the treatment effect was found to be significant, an LSD test was performed to assess the difference among the treatments at a 5% level of significance.

3. Results and Discussions

3.1. Performance Evaluation of the Faba Bean

3.1.1. Splitting Capacity for the Faba Bean

Table 1. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Capacity for Faba Bean.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	4.5	6	
450	261.60 ^c	290.14 ^{bc}	275.87
550	279.87 ^{bc}	347.88 ^{ab}	313.88
650	315.36 ^{abc}	387.58 ^a	351.47
Mean	285.61	341.87	313.74
LSD	18.28		
CV%	13.63		

Table 1 shows how the pulse splitting machine's splitting capability is affected by feed rates and drum speeds. According to an analysis of variance, splitting capacity was significantly ($p < 0.05$) impacted by feeding rates and drum speeds. Table 1 shows that when the cylinder was run at a velocity of 650rpm and a feed rate of 6 kg/min, the maximum splitting capacity of 387.58 kg/hr was recorded; when the drum speed was 450rpm and the feed rate was 4.5 kg/min, the lowest splitting capacity of 261.60 kg/hr was recorded. Generally speaking, the splitting capacity will rise with the disc's feeding and speed.

3.1.2. Splitting Efficiency for the Faba Bean

The study shows that splitting efficiency increases with both drum speed and feed rate. The best performance was achieved at 650rpm drum speed and 6 kg/min feed rate, with efficiency reaching 92.34%. At 450rpm, efficiency was relatively low (75–78%), reflecting insufficient impact energy for effective splitting. As speed increased to 650rpm, efficiency rose to 89 – 92%, showing that higher rotational energy enhances kernel separation. This trend confirms that drum speed is a critical factor in achieving high splitting efficiency.

Table 2. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Efficiency for Faba Bean.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	4.5	6	
450	75.34 ^e	78.67 ^d	77.01
550	83.56 ^c	85.0 ^c	84.28
650	89.34 ^b	92.34 ^a	90.84
Mean	82.75	85.34	84.04
LSD	2.00		
CV%	1.19		

3.1.3. Cleaning Efficiency for the Faba Bean

Table 3. The Interaction Effect of the Disc Speed and Feed Rate on the Cleaning Efficiency for the Faba Bean.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	4.5	6	
450	85.51 ^d	82.71 ^e	84.11
550	88.27 ^c	87.48 ^{cd}	87.88
650	96.64 ^a	92.21 ^b	94.43
Mean	90.14	87.47	88.80

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	4.5	6	
LSD	2.08		
CV%	1.17		

The results show that the cleaning efficiency of faba beans increases significantly with drum speed, while higher feed rates tend to slightly reduce efficiency. The best performance was achieved at 650rpm and 4.5 kg/min, with 96.64% cleaning efficiency. The interaction between drum speed and feed rate was significant. The highest cleaning efficiency (96.64%) was achieved at 650rpm and 4.5 kg/min, while the lowest (82.71%) occurred at 450rpm and 6 kg/min. This demonstrates that optimal cleaning requires high drum speed but

moderate feed rate. Excessive feed rates compromise efficiency even at high speeds.

3.1.4. Breakage Percentage for the Faba Bean

Table 4 shows that the interaction between disc speed and feed rate of the pulses splitting machine was significant on the Breakage percentage for Faba bean. The lowest breakage (3.44%) occurred at 450rpm and 6 kg/min, indicating that low speed combined with a higher feed rate is gentler on beans. The highest breakage (9.30%) occurred at 650rpm and 4.5 kg/min, showing that high speed combined with low feed rate is most damaging. This suggests that high disc speeds should be paired with moderate feed rates to reduce kernel damage, while low speeds can tolerate higher feed rates without compromising quality.

Table 4. The Interaction Effect of the Disc Speed and Feed Rate on the Broken Percentage for Faba Bean.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	4.5	6	
450	4.44 ^d	3.44 ^e	3.94
550	5.67 ^c	7.11 ^b	6.39
650	9.30 ^a	7.81 ^b	8.56
Mean	6.47	6.12	6.30
LSD	0.75		
CV%	5.94		

3.2. Performance Evaluation of the Machine on Pea

3.2.1. Splitting Capacity for the Pea

Splitting capacity increased consistently with drum speed. At the lowest speed (450rpm), capacity was limited (210–258 kg/h), while at the highest speed (650rpm), capacity rose sharply (405 – 454 kg/h). This demonstrates that higher disc speeds provide greater mechanical energy and throughput, enabling more peas to be split per unit time. Similar findings have been reported in grain processing studies, where drum speed is directly correlated with machine capacity due to increased impact and friction forces. Splitting capacity of peas increases significantly with both drum speed and feed rate. The optimal condition for maximum throughput was 650rpm drum speed and 8 kg/min feed rate, achieving 454.35 kg/h. These findings are consistent with previous grain and legume

processing studies, which emphasize that both speed and feed rate are critical determinants of machine productivity.

Table 5. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Capacity for Pea.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
450	209.60 ^f	258.14 ^e	233.87
550	307.87 ^d	356.35 ^c	332.11
650	405.35 ^b	454.35 ^a	429.85
Mean	307.61	356.28	331.94
LSD	18.28		
CV%	13.63		

3.2.2. Splitting Efficiency for the Pea

Splitting efficiency of peas increases significantly with both drum speed and feed rate. Drum speed and feed rate had a substantial interaction impact, with the best efficiency (94.58%) at 650rpm and 8 kg/min and the lowest efficiency (79.73%) at 450rpm and 6 kg/min. This suggests that when both drum speed and feed rate are high, splitting efficiency is at its highest, and when both are low, efficiency is at its lowest. In order to maximize machine performance, speed and feed rate must be balanced, as the interaction effect emphasizes.

Table 6. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Efficiency for Pea.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
450	79.73 ^e	84.14 ^d	81.94
550	87.88 ^{bc}	89.17 ^{ab}	88.53
650	91.90 ^{ab}	94.58 ^a	93.24
Mean	86.50	89.30	87.90
LSD	2.00		
CV%	1.19		

3.2.3. Cleaning Efficiency for the Pea

Table 7 revealed that the cleaning efficiency of peas was significantly affected by both disc speed and feed rate. The cleaning efficiency of peas increases with drum speed but decreases slightly with higher feed rates. The optimal condition for maximum cleaning efficiency was 650rpm drum speed and 6 kg/min feed rate, achieving 98.16% efficiency. These results are consistent with grain and legume processing literature, which emphasizes that excessive feed rates reduce cleaning performance, while higher drum speeds enhance separation efficiency.

Table 7. The Interaction Effect of the Disc Speed and Feed Rate on the Cleaning Efficiency for Pea.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
650	98.16 ^a	96.20 ^b	97.18
550	95.21 ^b	92.67 ^c	93.94
450	90.00 ^d	88.58 ^e	89.29
Mean	94.46	92.48	93.47
LSD	1.36		

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
CV%	0.73		

3.2.4. Breakage Percentage for the Pea

The analysis of variance (ANOVA) revealed that both drum speed and feed rate had highly significant effects ($p < 0.05$) on the broken percentage of pea grains. The mean broken percentage of the pea grain at various drum speeds and feed rates is given in Table 8. The minimum percent grain broken, 1.58%, was recorded at a drum speed of 450rpm and at a feed rate of 8 kg/min. The maximum percent grain broken of 6.23% occurred at a drum speed of 650rpm, and a feed rate of 6 kg/min.

Table 8. The Interaction Effect of the Disc Speed and Feed Rate on the Broken Percentage for Pea.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
650	6.23 ^a	5.30 ^b	5.77
550	4.23 ^c	3.30 ^d	3.77
450	2.12 ^e	1.58 ^f	1.85
Mean	4.19	3.39	3.79
LSD	0.85		
CV%	11.32		

3.3. Performance Evaluation of the Machine on the Lentil

3.3.1. Splitting Capacity for the Lentil

The results presented in Table 9 show that both drum speed and feed rate had a significant effect on the splitting capacity of lentils. At the lowest drum speed of 450rpm, the splitting capacity was 340.18 kg/h at a feed rate of 6 kg/min and increased to 467.99 kg/h at 8 kg/min. When the drum speed was raised to 550rpm, the capacity improved slightly to 350.04 kg/h at 6 kg/min and 475.88 kg/h at 8 kg/min. At the highest drum speed of 650rpm, the splitting capacity reached 359.36 kg/h at 6 kg/min and 478.58 kg/h at 8 kg/min, which was the maximum recorded value. The trend observed can be explained by the fact that higher drum speeds provide greater mechanical energy, which enhances the throughput of the machine, while higher feed rates ensure better utilization of the splitting mechanism, thereby increasing the overall capacity. However, the incremental increase in capacity with

drum speed was relatively small compared to the effect of feed rate, indicating that feed rate plays a more dominant role in determining splitting capacity.

Table 9. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Capacity for Lentil.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
450	340.18 ^f	467.99 ^c	404.09
550	350.04 ^e	475.88 ^b	412.96
650	359.36 ^d	478.58 ^a	418.97
Mean	349.86	474.15	412.01
LSD	4.95		
CV%	0.78		

3.3.2. Splitting Efficiency for the Lentil

The results in Table 10 indicate that both drum speed and feed rate had a significant effect on the splitting efficiency of lentils. Splitting efficiency increased with drum speed, reaching the highest value of 69.60% at 650rpm and 6 kg/min, while the lowest efficiency of 61.20% was recorded at 450rpm and 8 kg/min. At intermediate speed (550rpm), efficiencies ranged between 63.60% and 66.50%, showing a clear upward trend as speed increased. Feed rate, however, showed a slight negative influence, as higher feed rates generally reduced efficiency at each drum speed. Overall, the findings suggest that splitting efficiency improves with higher drum speeds but declines slightly with increased feed rates.

Table 10. The Interaction Effect of the Disc Speed and Feed Rate on the Splitting Efficiency for Lentil.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
650	69.60 ^a	67.63 ^{ab}	68.62
550	66.50 ^b	63.60 ^c	65.05
450	63.50 ^{cd}	61.20 ^d	62.35
Mean	66.53	64.14	65.34
LSD	2.62		
CV%	2.00		

3.3.3. Cleaning Efficiency for the Lentil

The results presented in Table 11 demonstrate that both

drum speed and feed rate exerted a significant influence on the cleaning efficiency of lentils. Cleaning efficiency increased consistently with drum speed, reaching the highest value of 96.03% at 650rpm and 6 kg/min, while the lowest efficiency of 89.26% was observed at 450rpm and 8 kg/min. At intermediate speed (550rpm), efficiencies ranged between 91.90% and 93.80%, confirming a clear upward trend as drum speed increased. Feed rate, however, showed a slight negative effect, as higher feed rates generally reduced cleaning efficiency at each drum speed.

Table 11. The interaction Effect of the Disc Speed and Feed Rate on the Cleaning Efficiency for Lentil.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
650	96.03 ^a	93.14 ^{ab}	94.59
550	93.80 ^b	91.90 ^{bc}	92.85
450	91.60 ^c	89.26 ^d	90.43
Mean	93.81	91.43	92.62
LSD	2.12		
CV%	1.14		

3.3.4. Breakage Percentage for the Lentil

The results in Table 12 reveal that both drum speed and feed rate had a significant effect on the breakage percentage of lentil grains. Breakage increased with drum speed, reaching the highest value of 66.70% at 650rpm and 6 kg/min, while the lowest breakage of 54.90% was recorded at 450rpm and 8 kg/min. At intermediate speed (550rpm), breakage ranged between 60.30% and 63.30%, showing a clear upward trend as drum speed increased. Feed rate, however, showed a mitigating effect on breakage, as higher feed rates generally reduced the percentage of broken grains at each drum speed. For instance, at 650rpm, breakage decreased from 66.70% at 6 kg/min to 63.90% at 8 kg/min, and at 450rpm, it declined from 57.50% to 54.90%. This suggests that higher feed rates provide a cushioning effect, where the bulk of grains absorbs impact energy more evenly, thereby reducing individual kernel damage.

Table 12. The Interaction Effect of the Disc Speed and Feed Rate on the Broken Percentage for the Lentil.

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
650	66.70 ^a	63.90 ^{ab}	65.30

Drum speed (rpm)	Feeding rates (kg/min)		Mean
	6	8	
550	63.30 ^{ab}	60.30 ^{bc}	61.80
450	57.50 ^{cd}	54.90 ^d	56.20
Mean	62.50	59.70	61.10
LSD	5.06		
CV%	4.15		

4. Conclusion and Recommendation

4.1. Conclusion

The experimental results clearly demonstrated that disc speed and feed rate are the most critical parameters influencing splitting capacity, splitting efficiency, cleaning efficiency, and grain breakage across Faba bean, pea, and lentil crops.

- 1) Splitting capacity increased consistently with both drum speed and feed rate, with maximum throughput achieved at the highest speed (650rpm) and feed rate (8 kg/min).
- 2) Splitting efficiency improved with increasing drum speed but declined slightly at higher feed rates, indicating that while throughput rises, efficiency may be compromised under heavy loads.
- 3) Cleaning efficiency was highest at high drum speeds and moderate feed rates, confirming that excessive feed rates reduce the effectiveness of impurity separation.
- 4) Breakage percentage increased with drum speed but decreased with higher feed rates, showing that high speeds intensify mechanical stress while higher feed rates provide a cushioning effect that reduces kernel damage.
- 5) Maximum capacity and efficiency are achieved at high speeds and feed rates, but this often comes at the expense of increased breakage. Conversely, lower speeds and higher feed rates minimize damage but reduce throughput.

4.2. Recommendation

The developed machine was efficient for peas and Faba bean at 650rpm disc speed and feeding rates of 8 kg/min and 6 kg/min, respectively.

- 1) The grain that splits should be of consistent size since the size of the pulse affects the splitting efficiency. As a result, a grading system that assigns a size to pulses is required.
- 2) From this crop, lentil has a small size of cotyledon; for this reason, it breaks rather than splits. And such a kind of pulse needs special treatments, and a rubbing mech-

anism which tapered rotates inside the metal.

- 3) The machine's weight should be low to make transportation simpler, and to reduce the machine's weight when it becomes suitable.

Abbreviations

BAERC	Bako Agricultural Engineering Research Center
CSA	Central Statistical Agency
CV	Coefficient of Variation
FAO	Food and Agriculture Organization
LSD	Least Significant Difference

Author Contributions

Teresa Diro: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Desta Abera: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Birtukan Mokinin: Data curation, Formal Analysis, Funding acquisition, Methodology, Project administration, Supervision, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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