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Design and Development of Cumin Destalker Machine

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Cumin (*Cuminum cyminum* L.), a seed spice of family *umbelliferae*, is valued as aromatic, preservative, flavoring, and therapeutic agent in the food and pharmaceutical industry. The quality standards of cumin are closely associated with processing techniques. A tiny stalk attached to cumin is one of the major quality concerns in threshed and cleaned product. To remove this stalk, a centrifugal type mechanical cumin destalking unit was developed and evaluated. Developed unit consists of a frame, vibratory feeding assembly and discharge chute, horizontal plate type destalking assembly, and a drive unit. Feed rate (30, 50, and 70 kg/h), clearance between the plates (5, 8, and 11 mm), and speed of plate (550, 750, and 950 rpm) were taken as study variables and the performance of the destalker was evaluated in terms of destalking efficiency and broken percentage (damage). Performance was evaluated under single-pass and multi-pass conditions and also with and without pre-drying. Best performance was observed when cumin was destalked under multi-pass mode with pre-drying at a feed rate of 50 kg/h and plate speed of 750 rpm. At optimum operation conditions, the machine was found to have a destalking efficiency of 82.03% with 10.88% damage.

Keywords: *Cuminum cyminum* L., Destalking efficiency, Percent broken, Spice processing

Introduction

India is the top spice producing, consuming, and exporting country in the world accounting for 50% of the global trade. India produces 2.01 million tons of seed spices from 2.08 million hectares of area. Rajasthan, Gujarat, and Madhya Pradesh are the major seed spices growing states and are known as the seed spices bowl of India.[1] Indian spices are known for their elegant aroma, flavor, and therapeutic value. The quality of any spice can be determined by its intrinsic and extrinsic traits.[2] There has been an increasing demand for seed spices in the global market and countries look at India for a quality product.[3]

Cumin (*Cuminum cyminum* L.) is one of the important high-value seed spices cultivated in the arid and semi-arid regions. India is the lead producer and exporter of cumin in the world and contributes about 80 percent of global production. Cumin contributes 65% export value of seed spices.[3,4] Cumin is a delicate seed crop (Fig. 1a) with hard and thorny stems and is susceptible to damage during harvesting and threshing. Cumin is threshed by different methods such as beating with sticks, tramping with animals, driving a tractor over the crop, and using mechanical threshers.[5] After threshing, cleaning is an indispensable post-harvest operation performed to remove chaff material, plant parts, weed seeds, stones, and other impurities.[6] Presence of tiny stalk attached to cumin (Fig. 1b) is one of the major quality issue of threshed and cleaned cumin seed. The cumin seeds with this stalk fetch lower price in the market.[7] Destalking, a process to remove stalk attached to cumin seed, is essential to improve the quality of cumin. Research on post-harvest handling and processing of cumin is mainly focused on cumin cleaner-cum-grader, quality evaluation and control, engineering properties, and development of the thresher.[8–13] Despite the importance of destalking process, there is a dearth of information on the destalking principle and machinery. Therefore, the present research is planned to develop and evaluate a small-scale cumin destalking machine.

Material and Methods

Harvested cumin seeds were collected from farmers' fields from Ajmer, Rajasthan. Engineering properties of agricultural materials play an important role in the design, development, and operation of processing, storage and handling equipment.[10,14,15] Therefore, properties of cumin seeds relevant to the development of destalking machine were determined and presented in Table 1. Angle of repose and coefficient of friction are important to understand the

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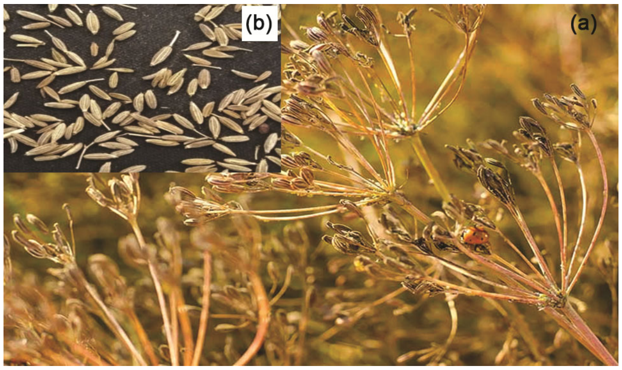

Fig. 1 — Cumin crop bush (a) and threshed cumin with stalk (b)

Table 1 — Physical properties of cumin

Properties	Mean ± standard deviation
Moisture content (% w.b)	10.35 ± 0.14
Length (mm)	5.32 – 7.23 ± 0.21
Width (mm)	1.65 – 1.85 ± 0.17
Thickness (mm)	1.32 – 1.45 ± 0.23
Bulk density (kg/m^3)	502 – 512 ± 5.96
Coefficient of friction	Mild steel: 0.45 – 0.51 ± 0.14
	GI: 0.41 – 0.54 ± 0.15
	Stainless steel: 0.35 – 0.41 ± 0.12
The angle of repose (degree)	31.25 – 35.12 ± 0.98
Length of the stalk (mm)	2 – 12 ± 0.2

flow behavior; information on length of stalk and linear dimension plays decisive role in selecting clearance between plates.

Design Consideration

The material having adequate strength and stability was used in fabrication. The machine was designed to have a capacity of up to 100 kg/h to suit small and marginal farmers. Power requirement, ease of operation and maintenance were also considered and locally available materials were used in the fabrication of different components of the prototype. The cost of items and materials used for fabrication were given due consideration with the ultimate aim of utilizing the cheapest available materials, yet satisfying strength requirements during rotation of the plate.

Principle of Operation

The developed destalking unit is based on the centrifugal principle and consists of two horizontal circular plates. The top plate is fixed while the lower plate rotates; provision has been made to adjust the clearance between the plates as per the length of cumin. Cumin, fed between the plates at the center, experiences centrifugal force and tends to stand on its tips while it travels towards the periphery; due to this action, the stalk attached to cumin detaches.

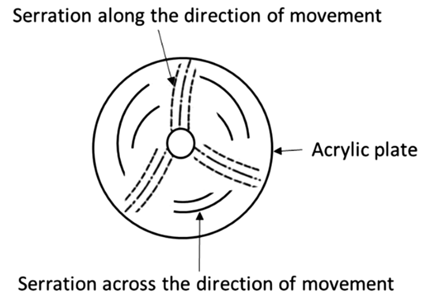

Fig. 2 — Curved serration configuration on rotating lower plate

Step-wise Development Process

1. ***Feeding mechanism:*** A trapezoidal shape hopper (size 300 × 300 mm at top, 180 × 180 mm at the bottom, and 340 mm in length) of 5 kg capacity was fitted above the feeder to load cumin onto the vibratory feeder. A funnel is fitted to channel the cumin falling from the feeder onto the center of the rotating disk. Cumin seed is oblong in shape with ridges and canals, along with stalk and moisture content, restricts the free flow behavior of cumin in the hopper. Considering the flow properties of cumin in bulk, a variable frequency vibratory feeder (460 mm length) was used for continuous and controlled feeding of raw material.

2. ***Plate/disk components:*** The diameter of the circular plate is proportional to centrifugal forces acting on seed dropped from a certain height on the plate surface. Based on preliminary trials conducted, a plate diameter of 760 mm was selected. Considering cost, availability, and ease of machining, acrylic sheet (HDPE) was used for the fabrication of plates. Clearance between the plates can be adjusted in the range of 0.5–25 mm by the screw mechanism provided in the upper plate. For better destalking lower surface of the upper plate is roughened using emery paper. Different grades of emery were tested and 80 grade was selected and glued to the lower surface of the top plate. Further, unique curved serrations (Fig. 2) were provided on the top surface of the lower plate to facilitate the stand-up action of cumin on its travel towards the periphery.

3. ***Motor and drive mechanism:*** The circular plate mechanism was fitted with a torque sensor and handle crank to assess the torque requirement for selecting the motor. Single-phase 1 hp 1440 rpm motor having a torque of 4.94 Nm was selected. Pulley and v-belt

(B49) drive mechanism was used to transmit power from the motor to the plate. A single-phase motor controller was used to regulate the rpm of the lower plate.

4. ***Frame:*** Mild steel angle iron (3.5 × 3.5 cm) and mild steel sheet of 18 gauges were used for fabrication of support frame and other parts such as hopper, side closure of disc and discharge chute.

The developed cumin destalker is shown in Fig. 3. Specification of the developed cumin destalker was presented in following Table 2.

Fig. 3 — Cumin destalker

Table 2 — Specification of the developed prototype

Machine particular	Dimension
Overall dimension (L × B × H)	910 × 760 × 710 mm
Machine capacity	50 kg/h
Power requirement	1 hp 1440 rpm
Power transmission	B49 V belt and pulley
Vibratory feeder	220 v/50 Hz/single phase with controller
Rotating plate	760 mm

Table 3 — Variables of experiment

Variables	Levels
Feed rate, kg/h	30, 50, and 70 kg
Speed, rpm	550, 750 and 950
The gap between plates (mm)	5, 8, and 11 (single pass and multipass)
Performance indicators	Separation efficiency and percent breakage

Performance Test Procedure

Tests were conducted to cover the full combinations of the considered variables under their different levels. This was to determine the performance of the destalking unit, and also to get the best combinations among the variables that lead to maximum destalked cumin with minimum losses. As shown in Table 3, the following performance parameters were determined to evaluate the machine.

The feed rate was controlled by varying the frequency of the vibratory feeder and the rpm of the lower plate was controlled by connecting the variable frequency drive to the motor. Experiments were carried out in two different passes *viz.,* single pass and multi pass. In case of multi pass mode, at a given speed and feed rate the material was destalked at all three clearance settings. Experiments were also conducted at optimum feed rate and speed combinations to check the influence of the pre-drying process (50 °C for 20 min) on performance indices.

Destalking Efficiency (η_d)

A sample of about 5 g is randomly collected and the weight of cumin with and without stalk is recorded. Separation efficiency is calculated by the equation:

$$\text{Destalking efficiency} = \frac{\text{Weight of sample with stalk}}{\text{Total weight of sample}} \times 100$$

Percent Broken (%)

Percent broken was calculated based on the weight of broken in a known weight of sample using following formula

$$\text{broke broken} = \frac{\text{Weight of brokens}}{\text{Total weight of sample}} \times 100$$

Machine Capacity (kg/h)

Capacity of machine was determined by the following equation:

$$Machine\ capacity = \frac{Mass\ of\ sample}{\text{time consumed in destalking operation}}, kg/h$$

Cost Analysis

The cost analysis of the cumin destalker prototype was calculated based on manufacturing cost, fixed cost, variable cost, B: C ratio, and pay-back period.[16,17]

Statistical Analysis

Three-factor completely randomized design was followed to determine the effect of varying feed rate, rpm, and clearance between plates on the dependent

Table 4 — Statistical analysis of the performance tests (single pass)

Factors	F-value		SE(m)		CD	
	η_d	$B_{\%}$	η_d	$B_{\%}$	η_d	$B_{\%}$
Feed rate (A)	49.89 (<0.0001)	119.14 (<0.0001)	0.236	0.093	0.669	0.264
Speed in rpm (B)	207.50 (<0.0001	121.97(<0.0001	0.236	0.093	0.669	0.264
Clearance between the plate (C)	220.23 (<0.0001)	434.68 (<0.0001)	0.236	0.093	0.669	0.264
A × B	3.646 (0.011)	1.877 (0.128)	0.408	0.161	1.159	NS
A × C	2.673 (0.042)	2.967 (0.027)	0.408	0.161	1.159	0.456
B × C	11.753 (<0.0001)	9.391 (<0.001)	0.408	0.161	1.159	0.456
A × B × C	1.799 (0.098)	0.442 (0.890)	0.707	0.279	NS	NS

η_d – destalking efficiency; $B_{\%}$ - per cent broken; NS – non-significance

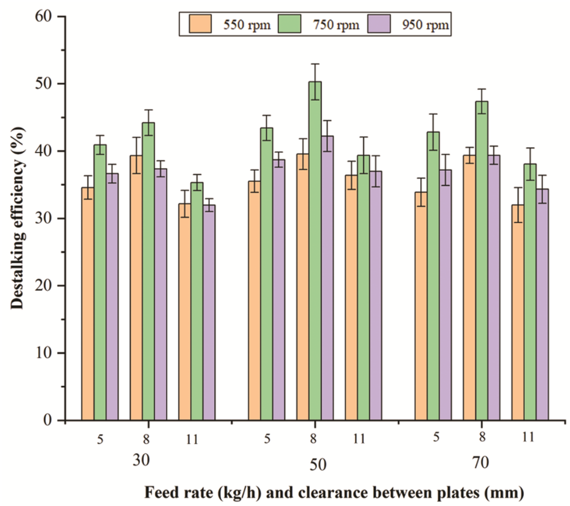

Fig. 4 — Effect of feed rate, rpm, and clearance between plates (single pass) on destalking efficiency

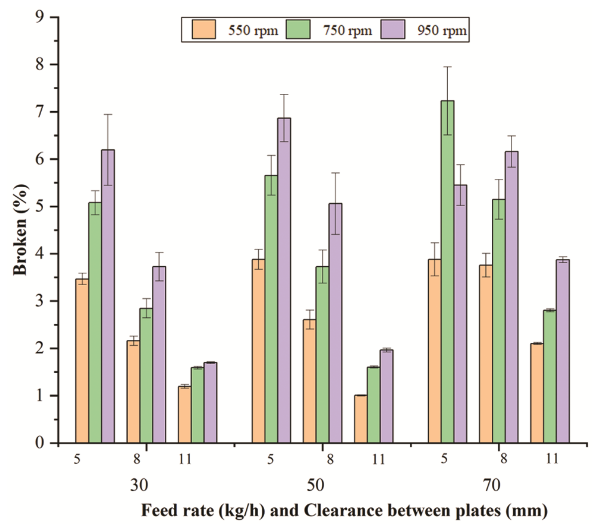

Fig.5 — Effect of feed rate, rpm, and clearance between plates (single pass) on a broken percentage

parameters. Analysis of variance was performed using SAS Version 9.3 (Proc GLM) available at ICAR-IARI, New Delhi.

Results and Discussion

Effect of Single-pass on Performance Indices

The developed cumin destalker was tested at varying feed rates, clearance between plates, and rpm to check its performance in terms of separation efficiency and percent breakage. Tests were carried out to optimize the operational parameters of the developed unit. Statistical parameters were shown in Table 4.

Destalking Efficiency

Destalking efficiency is ranged between 31.98% and 50.27% (Fig. 4). Statistical analysis showed that feed rate, rpm, and clearance between the plate had significant (p <0.01) individual influence on destalking efficiency. However their interaction effect was found non-significant (p >0.01) as shown in Table 4. Destalking efficiency first increased with an increase in selected variables and then decreased with further increase. Reduced efficiency at high rpm could be due to shorter residence time; whereas, at increased clearance, the tip of the cumin might not encounter the upper plate consequently reducing the destalking effect. On the other hand, at low rpm and clearance, there could not be enough centrifugal force and clearance to enable the cumin seed to stand on its tip. The highest destalking efficiency (50.27%) was observed when the clearance between the plates was 8 mm and operated at 50 kg/h and 750 rpm.

Percent Broken

The results of the statistical analysis show that the three independent variables had a significant (p <0.01) effect on percent broken, however, their interaction effect was found non-significant (p >0.01), except interaction of rpm and clearance (Table 4). Broken percent varied from 1.01% to 7.23% (Fig. 5) and was observed to increase with the increase in feed rate, speed, and decrease in clearance. More percent breakage at high feed rate and low clearance could be due to increased abrasion between cumin seeds and

Table 5 — Statistical analysis of the performance tests (multi-pass)

Factors	F-value		SE(m)		CD	
	η_d	$B_{\%}$	η_d	$B_{\%}$	η_d	$B_{\%}$
Feed rate (A)	164.62 (<0.0001)	208.64 (<0.0001)	0.478	0.232	1.431	0.695
Speed in rpm (B)	151.72 (<0.0001)	52.94 (<0.0001)	0.478	0.232	1.431	0.695
A × B	12.80 (0.011)	2.783 (0.058)	0.828	0.402	2.478	NS

η_d – destalking efficiency; $B_{\%}$ - per cent broken; NS – non-significanc

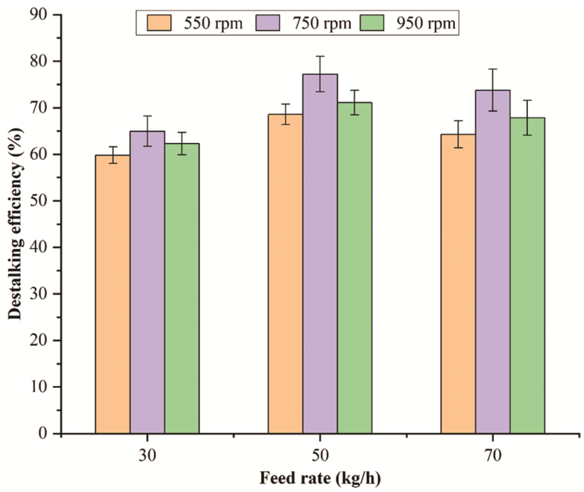

Fig. 6 — Effect of feed rate and speed on destalking efficiency (multi-pass)

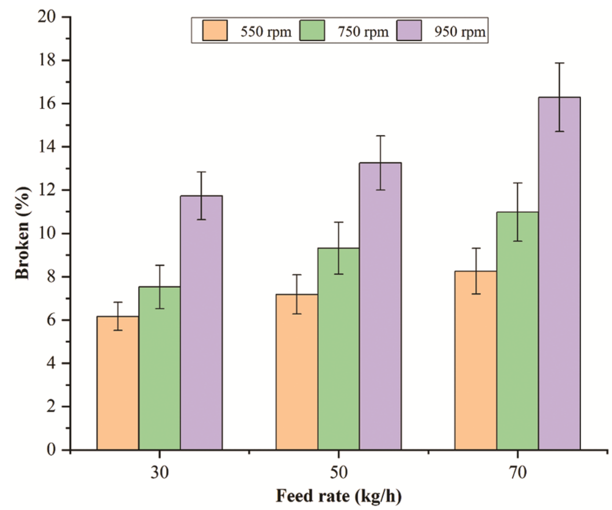

Fig. 7 — Effect of feed rate and speed on percent broken (multi-pass)

between cumin seeds and plates. The highest value of the tested parameter (7.23%) was observed when the machine was operated at 950 rpm, with 5 mm clearance and 70 kg/h feed rate.

Effect of Multi-pass on Performance Indices

Based on the performance parameters observed during single-pass experiments, trials were conducted to destalk the material by passing through all three clearances (multi-pass) by varying feed rate and plate rpm. Experimental data analyzed for different statistical parameters were presented in Table 5.

Destalking Efficiency

Destalking efficiency during multi-pass ranged between 59.81%–77.22% (Fig. 6), which is considerably higher than the efficiency observed during single-pass experiments. Better efficiencies observed during multi-pass trial could be due to differences in length of cumin in a given lot viz., non-graded raw material. The highest destalking efficiency was found at 750 rpm and 50 kg/h feed rate. Statistical analysis of the data obtained revealed that feed rate and rpm had a significant ($p < 0.01$) as shown in Table 5 influence on destalking efficiency; however, their interaction effect was non-significant ($p > 0.01$) on the tested parameter. Further, the influence of feed rate and rpm on destalking efficiency followed the same trend as in the case of a single pass.

Percent Broken

Broken percentage considerably increased during a multi-pass as compared to single pass. Values of percentage broken ranged from 6.17% to 16.29% (Fig. 7). Feed rate and rpm had a positive significant ($p < 0.01$) influence on percent broken, the highest damage (16.29%) was observed at 950 rpm and 70 kg/h feed rate. Increased damage in the multi-stage and at a high feed rate may be due to the cumulative effect of residence of cumin and abrasion between cumin and plates.

Effect of Pre-drying on Performance Indices

The experiment was conducted to check the effect of the pre-drying process on destalking performance and revealed that pretreatment significantly improves efficiency with a slight increase in broken percentage. About 5% higher destalking efficiency and 1.5% more damage were observed (Fig. 8) when the material is dried in a tray dryer and immediately destalked at a disc speed of 750 rpm and 50 kg/h feed rate. Improved destalking efficiency and increased

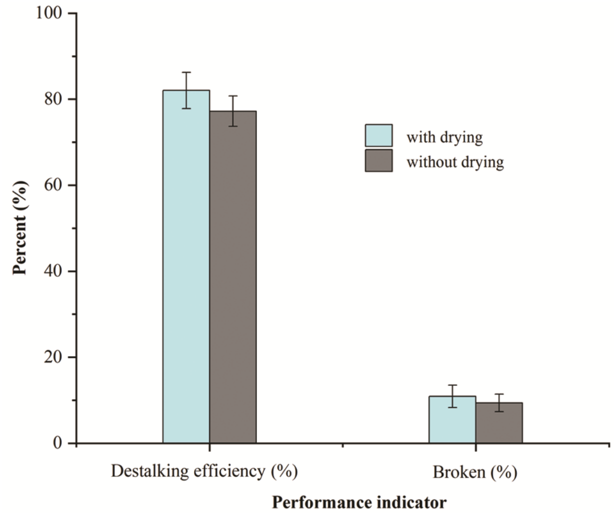

Fig. 8 — Effect of pre-drying on performance parameters (multi-pass)

Table 6 — Cost analysis of developed cumin destalking prototype

S.N	Component	Cost (Rs.)
1	Manufacturing cost	45,000
2	Salvage value	4,500/year
3	Depreciation	4,050/year
4	Total fixed cost	9,850/year
5	Labour cost @ Rs. 250/day of 8 h	31.25/h
6	Total variable cost	44.5/day
7	Capacity of machine	50 kg/h
8	Cost of destalking operation	910 t/h
9	The average net annual profit	15400/year
10	B/C ratio	0.96
11	Payback period	2.92 years

breakage could be due to the high brittleness of stalk at low moisture content.

Cost Analysis

Cost evaluation of the developed cumin destalking unit is presented in Table 6. The cost of the destalking unit as calculated based on the materials used and fabrication charges was found to be Rs. 45000 per unit. Cost estimates of destalking unit were calculated using 50 kg/h capacity obtained at the optimized condition of various parameters. The cost of destalking of cumin seed was calculated to be Rs. 910 t/h. The manual destalking is not a feasible operation in cumin seeds. The payback period of the developed prototype is 2.92 years with 0.92 B/C ratio.

Conclusions

Centrifugal type destalker unit was developed and tested for cumin. The results of the study showed that, feed rate, clearance between plate, and rpm of the plate affected the destalking efficiency and percent broken. Clearance of 8 mm, 950 rpm, and 50 kg/h feed rate showed maximum destalking efficiency of 50.72%. The highest destalking efficiency of about 77.22% was observed when cumin was passed through all clearance (multi-pass) at 750 rpm and 50 kg/h. The efficiency was further increased to 82.03% when the material was dried before destalking. Breakage of material up to 10% was observed when destalking was performed at optimum conditions with pre-drying treatment. The rated capacity and estimated cost of the developed machine were 50 kg/h and Rs. 45,000.00 per unit, respectively. The developed cumin-destalking machine is suitable for small and marginal farmers and could be adopted successfully to add value to threshed cumin and improve its quality.

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