Indian Journal of Agricultural Sciences **92** (12): 1458–1463, December 2022/Article
https://doi.org/10.56093/ijas.v92i12.128786

Development and performance evaluation of garlic (*Allium sativum*) stalk cutter-cum-grader

CHARAN SINGH[1], VIJAY KUMAR SINGH[2], RAVI KUMAR[2*], NEHA[3], MUKESH KUMAR GARG[2], VIKASH KUMAR[4], NIRAV UMESHBHAI JOSHI[1] and CHANDANI POPALIYA[1]

Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana 125 004, India

Received: 6 October 2022; Accepted: 18 October 2022

ABSTRACT

The manual stalk cutting and grading of garlic (*Allium sativum* L.) is inconsistent, inefficient and demands skilled labour. A garlic stalk cutter-cum-grader was developed at the Department of Processing and Food Engineering, CCS Haryana Agricultural University, Hisar, Haryana during 2018–19, along with performance evaluation and optimization of working parameters using response surface methodology. The machine comprises of four major units, viz. cutting unit, grading unit, reciprocating assembly and a transmission system. The performance evaluation indicated that there was a significant effect of feed (2, 3, 4, 5 and 6 stalks) and moisture content (14, 21, 28, 35 and 42 (±1% in all levels, wet bulb) of the stalk on the performance parameters. The capacity of the machine increased with moisture content and feed rate. The grading efficiency first increased and then decreased with moisture content, whereas it decreased with an increase in feed rate. The bulb damage increased with a decrease in moisture content, whereas the effect of feed was minimal. The cutting efficiency decreased with an increase in the stalk feed rate and moisture content. A moisture content of 30.98% and feed of 3.75 stalks were found optimal, close to the moisture content of 31% and feed of 4 stalks and recommended for the best performance of the machine.

Keywords: Capacity, Cutting efficiency, Garlic, Grading efficiency, Optimization, Stalk cutter-cum-grader

Garlic (*Allium sativum* L.) belongs to the Amaryllis family (Amaryllidaceous), a bulbous and perennial plant is native to central Asia (Morales-González *et al*. 2019). India is the second largest producer of garlic after China, with a production of 3.1 million tonnes during 2020–2021 (Anonymous 2022). Garlic bulb separation is the primary and most important unit operation among the different post-harvest operations for selling, transport and value addition of garlic followed by grading, which enhances the market demand of the product.

In India, traditionally garlic stalk cutting and grading are often done using manual cutting tools and hands, which is time-consuming as well as cost-ineffective process (Barman *et al.* 2015). Similarly, in Egypt, the garlic roots and stems are majorly removed by hand labour (Ibrahim and Athai 2018). The manual stalk cutting requires proper attention and can lead to hand injuries too. The size of the garlic bulb (clove size) directly affects the design and performance of the garlic peeling machine (Manjunatha *et al.* 2014) hence, is an important factor in garlic processing. There is also a direct relationship between garlic clove which is being used as seed and the resulting size of garlic bulb. The manual grading process is also time-consuming, uninteresting and demands skilled labour. The existing machines in the market either cut the stalk or grade the product or have lower capacity, simultaneously working machines are obscure. Barman *et al.* (2015) developed power-operated garlic stem and root cutter with a capacity of 32.52 kg/h and a cutting efficiency of 99.08%. In addition, Ibrahim and Athai (2018) developed a garlic root and stem cutting machine, which had 1.5 times the capacity of the manual root and stalk cutting. Keeping the above problem into consideration, the objective of the current study was the development, performance evaluation and optimization of the garlic stalk cutter-cum-grader.

[1]College of Agricultural Engineering and Technology, Junagadh Agricultural University, Gujarat; [2]College of Agricultural Engineering and Technology, CCS Haryana Agricultural University, Hisar, Haryana; [3]Indira Chakravarty College of Home Science, CCS Haryana Agricultural University, Hisar, Haryana; [4]Maharana Pratap Horticulture University, Regional Mushroom Research Center, Murthal, Haryana. *Corresponding author email: ravisangwan11@gmail.com

MATERIALS AND METHODS

The drawing of the machine was first prepared in AutoCAD (Trial version 2018) software. The fabrication and experimental runs were carried out at the Department of Processing and Food Engineering, CCS Haryana

Agricultural University, Hisar, Haryana during 2018–19 to evaluate the performance and optimize the operational parameters of the machine.

Design consideration: The machine was designed by considering several important points, such as the cost of the machine, power requirement, capacity and number of workers working on the machine (Kumar *et al*. 2017). The main parts of the garlic stalk cutter-cum-grader was the reciprocating assembly, grading unit, cutting unit and transmission unit. All the units were first designed in a 3-D line diagram (Fig 1).

Major components of machine

Main frame: The main frame of the machine was made up of mild steel angle bars and hollow bars of 5 mm thickness. The height of the machine was 1070 mm, which was considered based on the height of the machine for precision work (1050–1100 mm) as suggested by Gasic (1979). The overall dimensions (Length×Width×Height) of the machine were 1350 mm × 790 mm × 1070 mm (Table 1).

Reciprocating assembly: The reciprocating assembly served as the frame for the grading unit, the outlet for different grades and transferring reciprocating motion to the cutting blade. The assembly was given reciprocating motion by an electric motor via a set of pulleys, v-belt and slider-crank mechanism. The rpm of the assembly was 177 and the stroke length was kept at 36 mm with a slope of 36° (Table 1). The slope of the machine was decided based on the maximum bulb frictional coefficient (35°) given by Ibrahim (2013).

Cutting and feeding unit: The stalk cutting was performed by a reciprocating serrated blade of stainless steel (SS 304). The serrated cutting blade was used as it has lower specific cutting energy compared to a flat blade (Liu *et al*. 2012). The blade was designed based on the studies of Tuck *et al*. (1991), according to which, the blade with 0° rake angle, 30° clearance angle and 6 mm pitch had the lowest critical speed. The overall length of the blade was 75 cm with 115 serrations. The thickness of the blade was selected 2 mm. The rpm of the blade was decided based on the preliminary experiments during the development of the machine. The blade was connected with the reciprocating unit with the help of a set of levers and links so that with each stroke of the reciprocating assembly there will be one stroke of the cutting blade.

The guide for the blade was welded on the front top side of the main frame, which also served as feeding slits (Fig 1). Four slits (25 mm clearance) for two workers were provided. To avoid any contact of the hand with the blade, a smooth metal sheet (safety cover) with its slope away from the blade was installed. To keep the length of the remaining stalk constant, metal guides of 13 mm were installed behind feeding slits which were selected based on market demand of 10–20 mm leftover stalk.

Grading unit: A detachable type grading unit was fabricated and placed on the reciprocating assembly with its axis parallel to the reciprocating assembly (Fig 1). The grading unit was a step diverging type, consisting of four

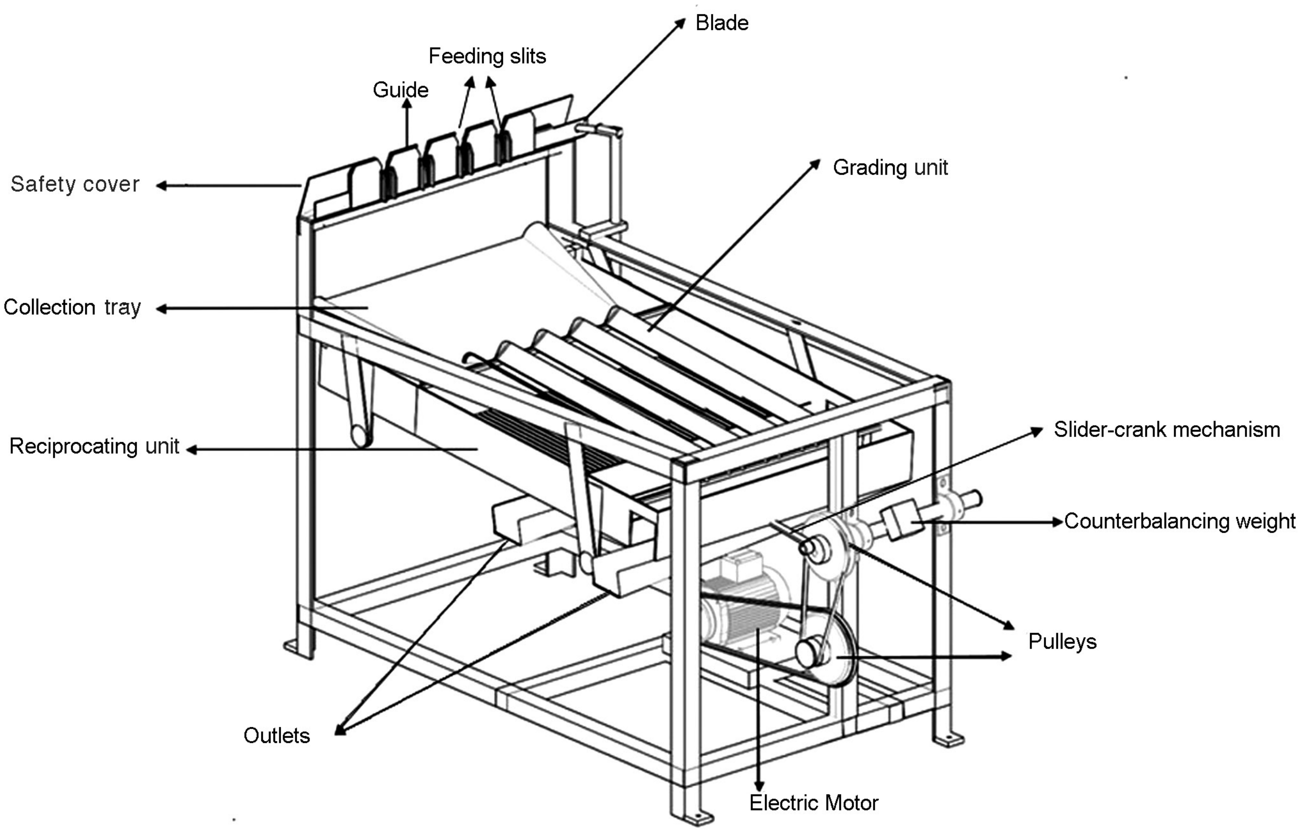

Fig 1 Angle view of AutoCAD 3-D line diagram of machine.

Table 1 Materials used and specification of different units

Part	Materials used and specification
Main frame	
Angle/Hollow square bar	Angle bars MS (length 1070, 1350, 790 mm) of 5 mm
Motor stand	Hollow square column MS of cross-section 48 mm × 48 mm (length 1350, 790 mm each) A wooden square plank of 280 mm × 230 mm of thickness 30 mm
Feeding unit	
Blade Guide	10 MS (4 mm) Plates of size 100 mm × 90 mm
Guide for leftover stalk length	8 MS Plates of size (4 mm thickness, 100 mm height, 13 mm wide)
Cutting unit	
Cutting blade	SS (SAE 304) length 750 mm Serration per meter- 164 Rake angle- 0° Clearance angle- 30° Width of blade- 45 mm Thickness of blade- 2 mm
Reciprocating unit	
Frame	MS (3 mm) Length - 1260 mm, Breadth - 760 mm Height - 120 mm
Bearing	Four bearings of 50 mm diameter each

MS, Mild Steel; SS, Stainless Steel.

trapezoidal lanes with a step increase in clearance according to grade size. The grader was divided into three classes with a step increase in clearance along with the length of the unit starting from the smallest size Class I (<30 mm) then a section for Class II (30–45 mm) and then for Extra class (>45 mm) (Prasad 2012). The length of grader for Class I and Class II was 475 mm and 255 mm, respectively. The length of the grader for class I was kept longer than the grader for class II which was selected based on the pre-trials.

Transmission drive: The transmission drive consisted of an electric motor, v-belts, pulleys and a slider-crank mechanism. Three pulleys namely P_1 (Motor pulley), P_2 (Intermediate step cone pulley) and P_3 (Pulley attached to the slider-crank) were used to transmit the power to the reciprocating assembly (Fig 1). The diameter of P_1 and P_3 was 100 and 170 mm, respectively. The diameter of the step cone pulley P_3 was 200 and 40 mm. The pulley P_3 was connected to a slider crank of length 205 mm.

Motor power analysis: The power required by the machine was noted using an energy meter. The maximum energy consumed by the motor was 0.6 kWh. Based on this, a 1 hp motor (0.7457 kW) was selected for the machine.

Fabrication of machine: The main frame was welded to bear the weight and vibrations of the machine. The reciprocating unit was welded in an open rectangular box type arrangement to accommodate a removable type grader on top without any fasteners and the open box worked as an outlet for different grades which was provided with adequate slopes. The ball bearings were used to suspend the reciprocating unit in the middle of the main frame. The reciprocating unit was connected with the transmission drive with the help of a slider-crank mechanism which was used to convert rotary motion into reciprocating motion. The electric motor was placed at the bottom and was fastened with the help of nuts and bolts. The open belt drive mechanism was used to transmit energy to the desired point. The cutting unit was not in direct contact with the transmission drive, instead, it receives energy from the reciprocating unit with the help of the lever and links.

Performance evaluation

Raw material and experimental design

The garlic variety GS17 was procured from the Department of Vegetable Sciences, CCS Haryana Agricultural University, Hisar, Haryana. The experiment was designed using response surface methodology (RSM) with central composite rotatable design (CCRD) for two independent variables (Kumar *et al*. 2017). The performance evaluation of the machine was carried out at different stalk moisture content levels (14, 21, 28, 35 and 42 (±1% with all levels, wet bulb)) and different feed (2, 3, 4, 5 and 6). A total of 150 kg of garlic plants were used for the experiment. The experimental design and optimization of the independent variables were carried out using statistical software Design Expert 11.80. The machine was tested for the following parameters.

Capacity (kg/h): The capacity of the machine was calculated by measuring the weight of the bulbs de-topped by the machine in a given time.

$$\text{Capacity (kg/h)} = \frac{\text{Weight of bulb after cutting stalk (kg)}}{\text{Time taken (h)}} \tag{3}$$

Grading efficiency (%): The grading efficiency was calculated (Eq. 4) by checking whether the particular bulb belongs to the respective outlet or not (Dress and Ibrahim 2013).

$$\text{Grading efficiency (\%)} = \frac{M1 + M2 + M3}{M} \times 100 \tag{4}$$

Where, M1, M2, M3 are mass of classified bulbs received at the outlet of class I, class II and extra class in kg respectively; M is total mass of garlic bulb in kg.

Bulb damaged (%): The bulbs whose cloves get separated or get bruised or have any physical damage was considered damaged bulb and separated by visual inspection (Ibrahim and Athai 2018).

$$\text{Bulb damage (\%)} = \frac{\text{Weight of the damaged bulb (kg)}}{\text{Total bulb output (kg)}} \times 100 \tag{5}$$

Cutting efficiency (%): Bulbs with the leftover stalk of length more than 2 cm after cutting were considered uncut

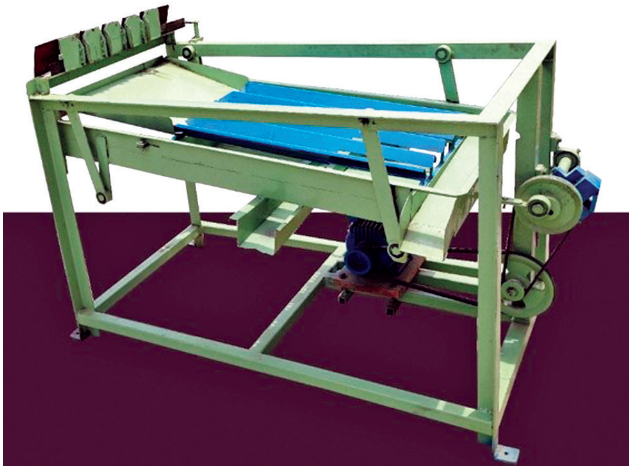

Fig 2 Isometric view of the developed machine after fabrication.

and weighed, then used for calculating cutting efficiency (Eq. 6).

$$\text{Cutting efficiency (\%)} = \frac{\text{Weight of the uncut stalk (kg)}}{\text{Total weight of feed stalk (kg)}} \times 100 \quad (6)$$

RESULTS AND DISCUSSION

The machine was tested for its performance evaluation following standard procedure (Fig 2).

Performance evaluation and model building: The data of different experiment runs of operational parameters and their corresponding response parameters are given in Table 2.

Capacity of stalk cutter-cum-grader: The maximum capacity of the machine was found 195.28 kg/h at the moisture content (28%) and feed (6 stalks), which was better than the existing machine developed by Barman *et al*. (2015) and Ibrahim and Athai (2018) with a maximum capacity of 35.52 kg/h and 45.54 kg/h (728 pieces×Mean bulb weight), respectively. Also, Ibrahim and Athai (2018) stated that the average capacity of a single worker was around 485 pieces per hour and the mean weight of garlic bulb was 62.5 g which makes a capacity of 30.3 kg/h per worker. It was observed from ANOVA that quadratic terms of independent parameters were significantly ($P<0.0001$) affecting the capacity. The significant quadratic model (R^2=0.99) to assess the approximate effect of independent variables on the capacity of the machine is given in Eq.7. It can be seen from Fig 3A that with the increase in the number of stalks the capacity of the machine increases. A slight decrease in capacity can be seen with the decrease in moisture, which can be justified by bulb moisture loss as well as the increase in cutting strength required, which ultimately affects the capacity of the machine. In addition, Ibrahim and Athai (2018) stated that loss of moisture content increases the cutting strength of the garlic stalk, hence ultimately decreasing the capacity of the machine.

$$\text{Capacity (kg/h)} = 62.36 + 39.93 \times A - 0.05 \times B + 0.003\, A \times B - 3.20 \times A^2 - 0.005 \times B^2 \quad (7)$$

where A and B, the actual value of feed and moisture content respectively. The same notations will be used in further models.

Grading efficiency: The grading efficiency varied from 86.20–91.66% and was comparable with a small cylinder-type grading machine developed by Abd El-Rahman (2011) whose grading efficiency was 94.34%. The grading efficiency was found to maximum (91.66%) when the feed was 2 stalks and moisture content was 28%. It was observed from ANOVA that quadratic terms of independent parameters had a significant ($P<0.05$) (R^2=0.78) effect on grading efficiency Eq.8. It can be interpreted from Fig 3B that the grading efficiency first increased with an increase in moisture

Table 2 Data of various independent and dependent parameters

Experimental run	Independent parameter (Coded)		Independent parameter (Actual)		Dependent parameter			
	F	MC	F	MC	C (kg/h)	GE (%)	BD (%)	CE (%)
1	1	-1	5	21	184.90	88.60	3.20	93.71
2	1	1	5	35	190.50	87.40	2.50	92.86
3	-1	1	3	35	159.74	88.47	2.29	98.72
4	-1	-1	3	21	155.04	89.47	3.16	98.75
5	-2	0	2	28	134.60	91.66	2.37	99.37
6	0	-2	4	14	173.64	88.26	3.83	96.32
7	2	0	6	28	195.28	90.30	2.87	91.42
8	0	2	4	42	183.91	86.20	2.08	96.40
9	0	0	4	28	178.10	91.10	2.65	96.00
10	0	0	4	28	177.20	91.60	2.60	96.60
11	0	0	4	28	178.20	91.20	2.65	96.00
12	0	0	4	28	177.10	91.60	2.61	96.70
13	0	0	4	28	177.50	91.50	2.64	96.30

F, Feed (no. of stalks); MC, Moisture content (%); C, Capacity; GE, Grading efficiency; BD, Bulb damage; CE, Cutting efficiency.

content (up to 28%) then decreased with a further increase in moisture content. The higher moisture content leads to higher adhesion forces between the surface and garlic bulb, which leads to less bulb jump hence lesser grading efficiency. A similar justification for the effect of moisture on cohesion forces was given by various researchers in kenaf seeds (Izli 2015), barley (Sologubik *et al*. 2013) and cucurbit seeds (Milani *et al*. 2007). A slight decrease in grading efficiency with an increase in the feed (no. of the stalk) was observed which can be interpreted as a result of blockage and increased mutual collision of bulbs. Similar findings were also observed by Abd El-Rahman (2004) in the testing of a portable shaker type grading machine for onion and Muhammad *et al*. (2007) in apple grading.

$$\text{Grading efficiency (\%)} = 74.44+0.90\times A+1.18\times B-0.007\times A\times B - 0.14\times A^2 -0.022\times B^2 \tag{8}$$

Bulb damage: The bulb damage varied from 2.08–3.83%, which was comparable with the garlic stalk cutter developed by Yu *et al*. (2016) and Ibrahim and Athai (2018) whose bulb damage was 2.39% and 3.0–4.8%, respectively. It was observed from ANOVA that quadratic terms of independent parameter had a significant ($P<0.0001$) ($R^2=0.99$) bulb damage (Eq. 9). It can be interpreted from the Fig 3C that the bulb damage increased with a decrease in moisture content, whereas the effect of feed was very little. The bulb damage was obtained maximum with 4 stalks at 14% stalk moisture content. At a higher moisture content of the bulb, the cloves are more adhesively attached to the bulb, whereas with a decrease in moisture, cloves get less adhered to the bulb (Ibrahim 2013). Hence, at low moisture content due to mutual collision and impact with the machine, there is a higher tendency for bulb breakage. With the increase in fees, the mutual collision of bulbs increases, which can be attributed to the increase in bulb damage with the increase in feed. Similarly, on the performance evaluation of on-farm onion grader, an increase in bulb damage with the increase in feed was also reported by Karthik (2015).

$$\text{Bulb damage (\%)} = 5.91 - 0.057\times A - 0.18\times B + 0.006\times A\times B - 0.0011\times A^2 + 0.0017\times B^2 \tag{9}$$

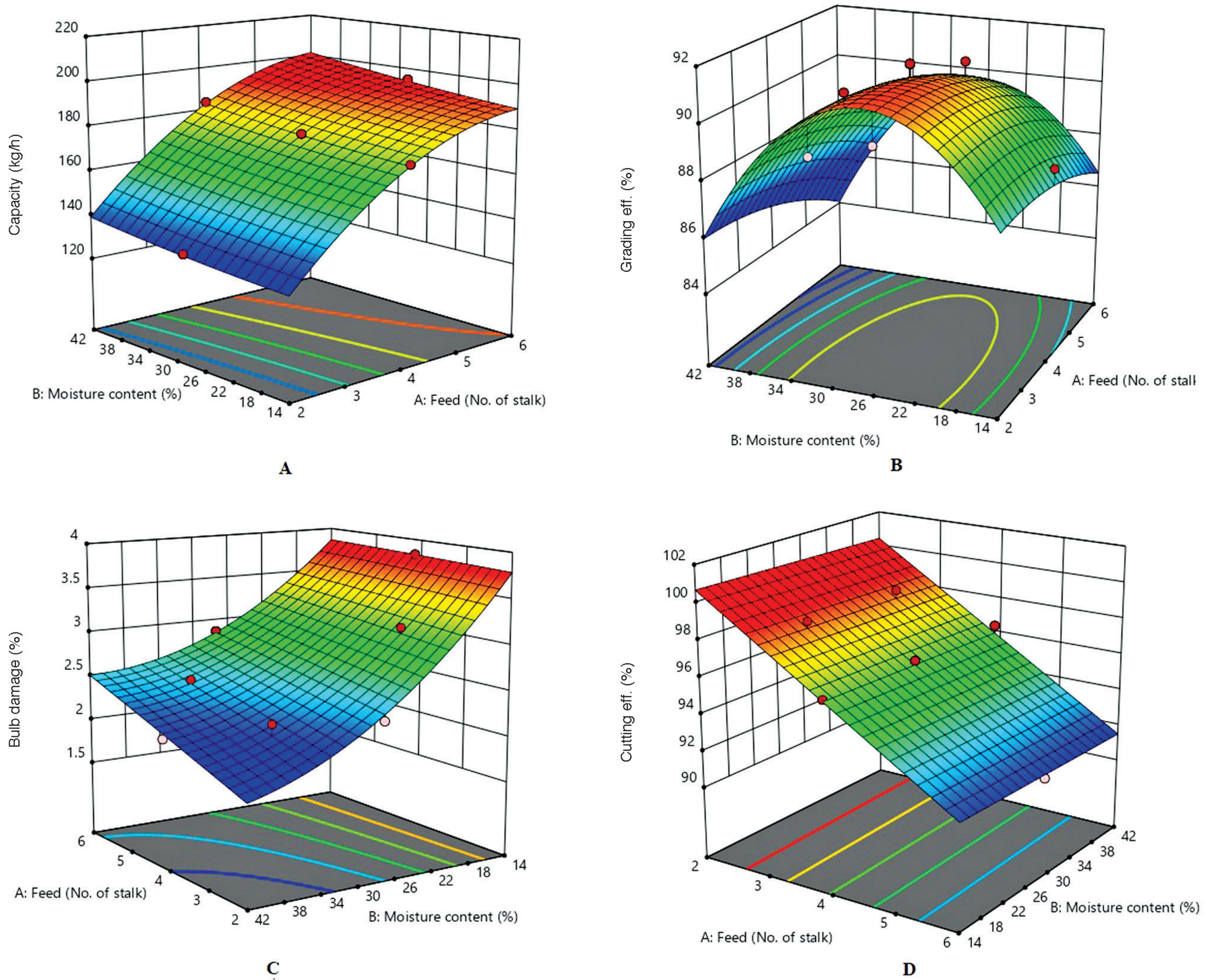

Fig 3 Response surface diagram showing the effect of independent variables on A) Capacity, B) Grading efficiency, C) Bulb damage, D) Cutting efficiency.

Cutting efficiency: The cutting efficiency (%) varied from 91.42–99.37%, which was comparable with the cutting efficiency (99.08%) of power-operated garlic stem and root cutter developed by Barman *et al*. (2015). A linear significant (P<0.0001) model (R^2=0.94) to assess the approximate effect of independent variables on cutting efficiency is given in Eq.10. As it is clear from Fig 3D that the cutting efficiency is in direct relationship with feed, whereas moisture content has only a minor effect. The slight rise in cutting efficiency (%) with moisture content can be attributed to a decrease in the required cutting strength of garlic stalks at higher moisture content. Moreover, Ibrahim and Athai (2018) mentioned that at a lower moisture content, the cutting strength was higher as compared to a higher moisture content of garlic stalk. The effect of feed was attributed to the reason of difficult handling of garlic stalks with an increase in the number of stalks in the operator's hand, which ultimately result in uneven cutting off the stalk hence lower cutting efficiency.

$$\text{Cutting efficiency (\%)} = 105.26 - 2.23\times A - 0.0085\times B \quad (10)$$

Optimization of operational parameters using response surface methodology (RSM): The feed of 3.75 stalks and moisture content of 30.98% were found optimal for machine operation. At this optimized condition, the machine capacity, grading efficiency, bulb damage and cutting efficiency were 174.17 kg/h, 90.6%, 2.46% and 96.62%, respectively. The machine was operated again at 4 stalks and 31% moisture content (close to optimal parameters) to validate the optimized values and was recommended. A significant reduction in labour was accompanied by the lower capacity of human workers in stalk cutting and grading.

The optimization of process parameters resulted in 3.75 stalks and moisture content of 30.98%, which had the machine capacity, grading efficiency, bulb damage and cutting efficiency 174.17 kg/ha, 90.6%, 2.46% and 96.62%, respectively. The optimized parameters were close to 4 stalks and 31% moisture content, hence were recommended for the best performance of the development machine to the farmers as well as small entrepreneurs.

REFERENCES

Abd El-Rahman M M. 2004. Improving the field performance of a portable bulbs grader. *Misr Journal of Agricultural Engineering* **21**(2): 199–11.

Abd El-Rahman M M. 2011. Development and performance evaluation of a simple grading machine suitable for onion sets. *Journal of Soil Science and Agricultural Engineering* **2**(2): 213–26.

Anonymous. 2022. Statista Research Department. Production volume of garlic in India FY 2022, by leading state. https://www.statista.com/statistics/744339/india-garlic-production-bystate/#:~:text=The%20country%20produced%20over%203.1,of%20the%20garlic%20in%202021.

Barman C, Bhatt Y C, Jain H K and Vyas S S. 2015. Performance evaluation of power operated garlic stem and root cutter. *Agricultural Engineering Today* **39**(3): 57–61.

Dress A and Ibrahim M. 2013. Development of a garlic bulb separator: Grading unit. *Misr Journal of Agricultural Engineering* **30**(1): 57–78.

Gasic M. 1979. Anthropometric dimensions and the height of the working surface for work in a standing position. *Archives of Industrial Hygiene and Toxicology* **30**(3): 1253–57.

Ibrahim M M and Athai M S. 2018. Development of a garlic root and stem cutting machine. *Misr Journal of Agricultural Engineering* **35**(3): 807–26.

Ibrahim M M. 2013. Development of a garlic bulb separator: Separating unit. *Misr Journal of Agricultural Engineering* **30**(1): 1–27.

Izli N. 2015. Effect of moisture on the physical properties of three varieties of kenaf seeds. *Journal of Food Science and Technology* **52**(6): 3254–63.

Karthik S K. 2015. 'Development of on-farm onion grader'. PhD Thesis, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru, Karnataka.

Kumar N, Sharma D K and Garg M K. 2017. Ergonomic intervention in design and development of pedal operated aonla pricking machine. *Agricultural Engineering Today* **41**(2): 40–47.

Liu Q, Mathanker S K, Zhang Q and Hansen A C. 2012. Biomechanical properties of miscanthus stems. *Transactions of the American Society of Agricultural and Biological Engineers* **55**(4): 1125–31.

Manjunatha M, Samuel D V K, Anurag R K and Gaikwad N. 2014. Development and performance evaluation of a garlic peeler. *Journal of Food Science and Technology* **51**(11): 3083–93.

Milani E, Seyed M, Razavi A, Koocheki A, Nikzadeh V, Vahedi N, Fard M M and Pour A G. 2007. Moisture dependent physical properties of cucurbit seeds. *Journal of International Agrophysics* **21**: 157–68.

Morales-González J A, Madrigal-Bujaidar E, Sánchez-Gutiérrez M, Izquierdo-Vega J A, Valadez-Vega M D C, Álvarez-González I, Morales-González A and Madrigal-Santillán E. 2019. Garlic (*Allium sativum* L.): A brief review of its antigenotoxic effects. *Foods* **8**(8): 343–50.

Muhammad A, Muhammad S S, Manzoor A and Muhammad Y. 2007. Design, development and performance evaluation of fruit and vegetable grader. *Pakistan Journal of Agriculture Science* **44**(4): 704–13.

Prasad R. 2012. A Technology Package of garlic processing for value addition. Centre for Rural Development and technology, IIT, Delhi, India.

Sologubik C A, Campanone L A, Pagano A M and Gely M C. 2013. Effect of moisture content on some physical properties of barley. *International Journal of Industrial Crops and Product* **43**: 762–67.

Tuck C R, O'Dogherty M J, Baker D E and Gale G E. 1991. Laboratory studies of the performance characteristics of mowing mechanisms. *Journal of Agricultural Engineering Research* **50**: 61–80.

Yu Z, Hu Z, Yang K, Peng B, Wu F and Xie H. 2016. Design and experiment of root cutting device in garlic combine harvesting. *Transactions of the Chinese Society of Agricultural Engineering* **32**(22): 77–85.