



RESEARCH ARTICLE

# Optimisation of parameters suitable for paddy thresher

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Received: 16 August 2025; Accepted: 29 September 2025; Available online: Version 1.0: 28 November 2025

**Cite this article:** Siprali P, Kavitha R, Surendrakumar A, Senthilkumar T, Sivakumar SD, Thiyagarajan R, Thambidurai S. Optimisation of parameters suitable for paddy thresher. *Plant Science Today*. 2025;12(sp4):01-17. <https://doi.org/10.14719/pst.11306>

## Abstract

Post-harvest processing plays a key role in reducing grain losses and improving overall yield in crops, including paddy. Despite many advancements in agricultural mechanisation, the small and marginal farmers face challenges due to the high cost and limited availability of suitable equipment. This study aims to address this gap by comparing the performance of three types of threshing cylinders: spike tooth, wire loop and rasp bar on two paddy varieties, namely CO 54 and CO 55. The comparative analysis will enable the farmers to select the threshing cylinder best suited for their needs, in maximising output and preserving grain quality. The performance was evaluated across different feed rates (70-126 kg h<sup>-1</sup>) and cylinder speeds (550-950 rpm). The parameters, such as output capacity, threshing efficiency, unthreshed grain loss, broken grain loss and total grain loss were evaluated. Response Surface Methodology (RSM) was used for optimisation. The results showed that feed rate had a stronger effect than cylinder speed on most performance indicators. Among the three, the spike tooth cylinder gave the best results, with a maximum threshing efficiency of 96.81 % and a consistent output of 67.50 kg h<sup>-1</sup> at 650 to 750 rpm and 126 kg h<sup>-1</sup> feed rate. It also had the lowest unthreshed loss (3.19 %), broken grain loss (1.47 %) and total grain loss (4.66 %) under these levels of feed rate and rpm. The wire loop cylinder matched the output for CO 55 but had higher losses under extreme conditions. The rasp bar showed the least broken grain loss (0.88 %) but higher total grain loss (up to 16.16 %). CO 55 performed better than CO 54 across all measures. ANOVA results confirmed the significance of results for the variables such as feed rate and cylinder speed, with strong model fits ( $R^2 > 0.99$ ). The thresher showed optimal results at feed rate of 90 to 105 kg h<sup>-1</sup> and cylinder speed of 650-750 rpm. This study provides valuable insights for improving the efficiency and thereby the sustainability of small-scale paddy threshing by offering optimised operating conditions.

**Keywords:** optimisation; paddy threshing; post-harvest technology; response surface methodology; threshing cylinder performance

## Introduction

Paddy (*Oryza sativa* L.) is an essential cereal crop in the world and has been the staple food for more than half of the world's population. The total rice production of 738 million metric tonnes (MMT) has been reported in the year 2024-25 worldwide. India is ranked second on a global scale with a production of about 137.83 MMT as per the records of the year 2023-24. The major rice-producing states of India are Uttar Pradesh, Telangana and West Bengal (1).

The process of separating grains from the panicles after harvesting is known as threshing. This process has a significant impact on grain quality and accounts for its yield losses. In spite of major advancements in agricultural mechanisation, the small and marginal farmers opt for manual methods of threshing for paddy due to limitations such as the high cost of the equipment and its availability. This dependency on manual threshing methods has led to increased yield losses and reduced grain quality (2). A significant gap in research exists, however, in providing a comprehensive and data-driven comparison of these different small-scale designs, which is essential for enabling farmers to select

the most efficient and cost-effective solution tailored to their specific needs. Therefore, various small-scale threshing equipment, such as axial-flow threshers and mini combine harvesters, have been developed to address this gap (3). In certain agricultural field conditions, such as waterlogged paddy fields, hill farming etc., constraints to mechanisation are noted; therefore, the need for crop or region-specific solutions was realised. Optimisation of threshing components with respect to distinct characteristics of paddy varieties and field conditions is essential (4).

The type of threshing cylinder has a greater influence on determining threshing efficiency, grain quality and power consumption. The spike tooth cylinders are commonly used due to their aggressive threshing action, which leads to high productivity and threshing efficiencies above 95 % at optimal speed, though grain loss increases at high speed (3, 5). The wire loop cylinders are known to provide a smoother threshing operation, resulting in decreased grain damage but slightly reduced output (6, 7). The rasp bar cylinders consume less power for threshing and give minimum broken grains, but the output capacity and threshing efficiency are compromised (8).

The machine and operational parameters, such as cylinder speed, feed rate and crop parameters such as moisture content of the grains, significantly affect the threshing output. The optimal performance is obtained at moderate speed, which is around 700 rpm and feed rates ranging between 1.0-1.4 kg s<sup>-1</sup> (5, 9). The speed of the threshing cylinder and feed rate have a significant effect on threshing efficiency. The increased speed results in broken grains, while steady speed conditions give optimum performance (9, 10). Recent innovations, such as helical-ribbed cylinders, have shown substantial improvements in working efficiency and grain quality (8, 11).

The different paddy varieties exhibit varying physical properties that directly impact threshing performance. This study included two distinct paddy varieties with contrasting grain characteristics for threshing cylinder evaluation. CO 54, developed by Tamil Nadu Agricultural University in 2020, is a short-duration variety (115-120 days) featuring soft, smaller grains (1.9 mm diameter × 5.9 mm length) with taller plant height (115.3 cm). CO 55, derived from ADT 43/GEB 24 parentage, matures in 110-115 days and produces firmer, larger grains (1.7 mm × 6.3 mm) with superior milling recovery of 70.0 % and head rice recovery of 65.0 %. These contrasting grain textures and dimensions enable comparative analysis of threshing cylinder responses across diverse paddy types, strengthening the applicability of optimisation findings.

Identifying the optimal threshing cylinder type and machine parameters is essential for enhancing productivity and sustainability, especially for small-scale farmers. Therefore, this study evaluates the performance of three cylinder types: spike tooth, wire loop and rasp bar under controlled conditions to determine the most efficient and cost-effective design suitable for integration into small-scale mechanised harvesting systems.

## Materials and Methods

### Experimental setup

A laboratory-scale axial-flow paddy thresher was developed for controlled evaluation and optimisation of threshing cylinder performance. The test setup consisted of interchangeable

threshing cylinders (spike tooth, wire loop, rasp bar), concave assembly, feeding chute and grain outlet. A 0.5 hp electric motor powered the cylinders, achieving speeds ranging from 550-950 rpm via pulley combinations. Feed rates (70-126 kg h<sup>-1</sup>) were manually regulated using a calibrated hopper mechanism for uniform feeding. The developed paddy thresher with multiple views has been represented in Fig. 1 and 2. Components used in the thresher are made up of different materials, as shown in Table 1.

### Threshing mechanism

The threshing cylinders developed consisted of three circular mild-steel rings, which were connected by six mild-steel bars. The threshing elements, such as spike tooth or wire loop, were welded onto these bars. The rasp bar cylinder had bars without any elements. The cylinders were supported by bearings on each side on a 35 mm shaft and were powered by a B-type V-belt and pulley arrangement. The harvested paddy cut at 30 cm height was manually fed into the inlet and the grains were collected at the outlet. The structures of the developed threshing cylinders are shown in Fig. 3.

**Table 1.** Materials used in the construction of various parts of the thresher

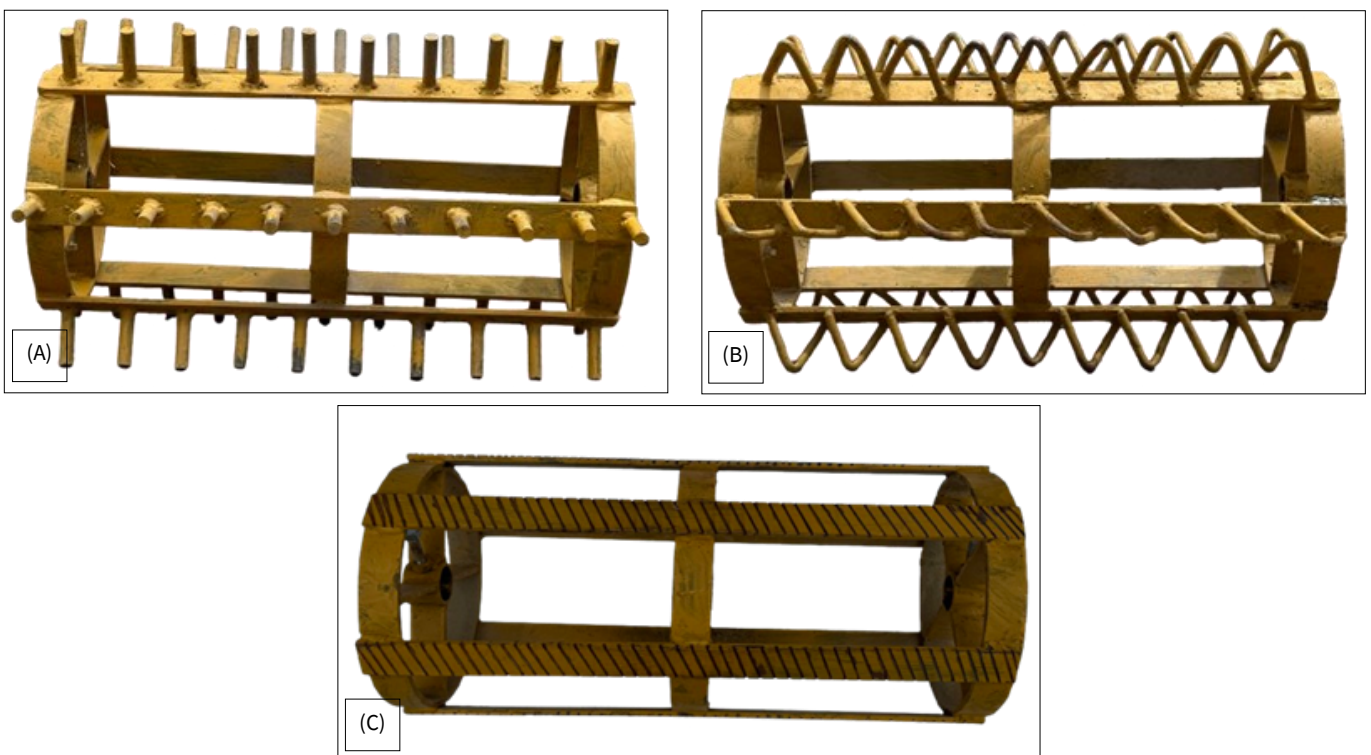
Sl.no.	Components	Materials	Dimensions
1.	Frame	Mild steel	Length: 880 mm, Width: 560 mm, Height: 600 mm
2.	Shaft	Mild steel	Diameter: 35 mm
3.	Feeding inlet	Mild steel	Length: 400 mm, Width: 200 mm
4.	Outlet	Mild steel	Inclined, Length: 900 mm, Width: 120 mm
5.	Threshing cylinder	Mild steel	Length: 515 mm, Diameter: 220 mm
6.	Concave	Mild steel	Concave clearance: 40 mm Spike tooth element: 50 mm
7.	Threshing element	Mild steel	Wire loop element: 50 mm height, 60 mm base width Rasp bars
8.	Pulley	Cast iron	3.5 inch and 2.5 pulley at bottom 6-inch, 8-inch and 5-inch pulleys at the top
9.	Pillow Block Bearing		
10.	V-belt	Rubber	46 B-type, 52 B-type and 44 B-type V-belt



**Fig. 1.** Front and rear view of the paddy thresher.



**Fig. 2.** Side views of the paddy thresher.



**Fig. 3.** Various types of threshing cylinders. A. Spike tooth, B. Wire loop, C. Rasp bar.

### Crop characteristics

The crop parameters, such as variety, grain/straw ratio, moisture content, grain size and crop height, were determined using the standard methods (12).

Moisture content (%) =

$$\frac{\text{Weight of wet sample} + \text{Weight of dry sample}}{\text{Weight of dry sample}} \times 100 \quad (\text{Eqn. 1})$$

The grain moisture content was determined by drying five random samples (~0.5 kg each) at 130 °C for 15 hr (13).

$$\text{Grain/straw ratio} = \frac{\text{Weight of dry grain}}{\text{Weight of dry straw}} \quad (\text{Eqn. 2})$$

From a representative sample, grain and straw were separated by hand and the size (grain diameter and length) of 50 grains was measured. The length of the grains and average diameter were measured by a digital Vernier calliper with an accuracy of 0.02 mm (13).

### Experimental procedure

The trials were conducted at the Wetlands (11.0031° N, 76.9249° E) and Paddy Breeding Station (11° N, 77° E), Tamil Nadu Agricultural University, Coimbatore. Two paddy varieties (CO 54 and CO 55) were evaluated. Variety CO 54 bear soft and small grains, while variety CO 55 has large, firm grains. Each cylinder type was tested across five feed rates, i.e. 70, 84, 98, 112, 126 kg h<sup>-1</sup> and four-cylinder speeds, i.e. 550-650, 650-750, 750-850, 850-950 rpm, with each condition replicated four times. After each trial, grains were manually collected and separated, with key parameters (output capacity, threshing efficiency) determined using standard methods (12, 14).

$$\text{Output capacity, kg/h} = \frac{\text{Threshed grains at the outlet, kg}}{\text{Duration of test run, min}} \times 60 \quad (\text{Eqn. 3})$$

$$\text{Threshing efficiency, \%} = 100 - \frac{\text{Unthreshed grains collected at the outlet per unit time, kg}}{\text{Total grain input, kg}} \quad (\text{Eqn. 4})$$

### Design of experiments

A factorial design was employed with three cylinder types, two paddy varieties, five feed rates and four cylinder speed ranges. The experimental layout has been summarised in Table 2.

### Statistical analysis

The data obtained from the performance evaluation of three different kinds of threshing cylinders were subjected to statistical analysis to validate the findings obtained and to determine the significance of independent parameters. Analysis of Variance (ANOVA) was used to determine the effects of independent parameters such as, cylinder type, paddy variety, feed rate and cylinder speed on the dependent parameters, including output capacity, threshing efficiency and various grain losses (9, 10). In addition to ANOVA, Response Surface Methodology (RSM) was used for the optimisation of machine parameters.

### Response surface methodology (RSM)

RSM is a combination of statistical and mathematical tools used for the development, improvement and optimisation of systems where the response or the dependent factor is influenced by many variables. It is essentially useful for the analysis of a system where the primary goal is to optimise the output by investigating the relationships between multiple independent parameters and key performance or dependent parameters (7). In the present study, RSM was used to analyse the interaction between the independent parameters, such as feed rate and cylinder speed and the dependent parameters, such as output capacity, threshing efficiency and grain losses. By analysing the performance evaluation data, it was possible to identify the optimal combination of these parameters that would maximise the desired output, thereby reducing losses (7, 9).

**Table 2.** Design of experiments for evaluating the performance of the threshing cylinders

Independent variables			
Parameters	Levels	Values	Dependent variables
Paddy variety	2	CO 54	Output capacity (kg h <sup>-1</sup> ) Threshing efficiency (%) Unthreshed grain loss (%) Broken grain loss (%) Total grain loss (%)
		CO 55	
Cylinder type	3	Spike tooth	
		Wire loop	
		Rasp bar	
Feed rate (kg h <sup>-1</sup> )	5	70	
		84	
		98	
		112	
		126	
Cylinder speed (rpm)	4	550-650	
		650-750	
		750-850	
		850-950	

Design of experiment: 4 Factorial Completely Randomised Design

## Results and Discussion

### Crop condition

Details of crop condition for CO 54 and CO 55 paddy varieties before manual threshing operations are given in Table 3.

### Performance evaluation

#### Output capacity

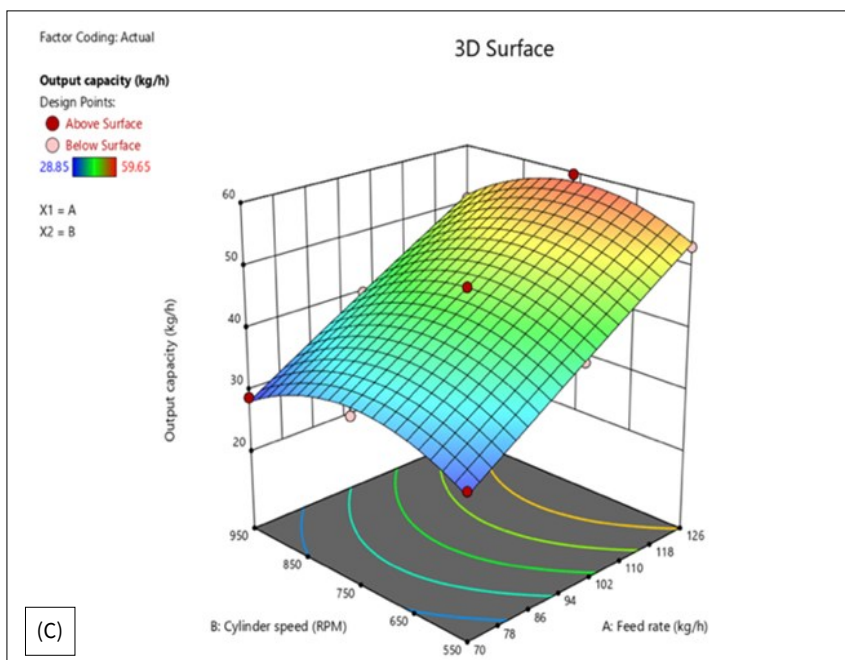
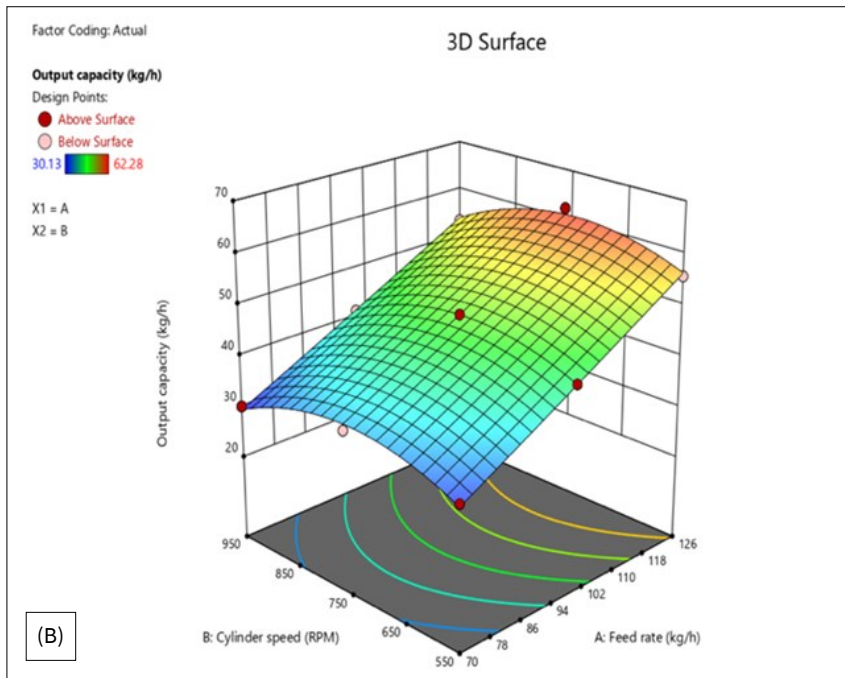
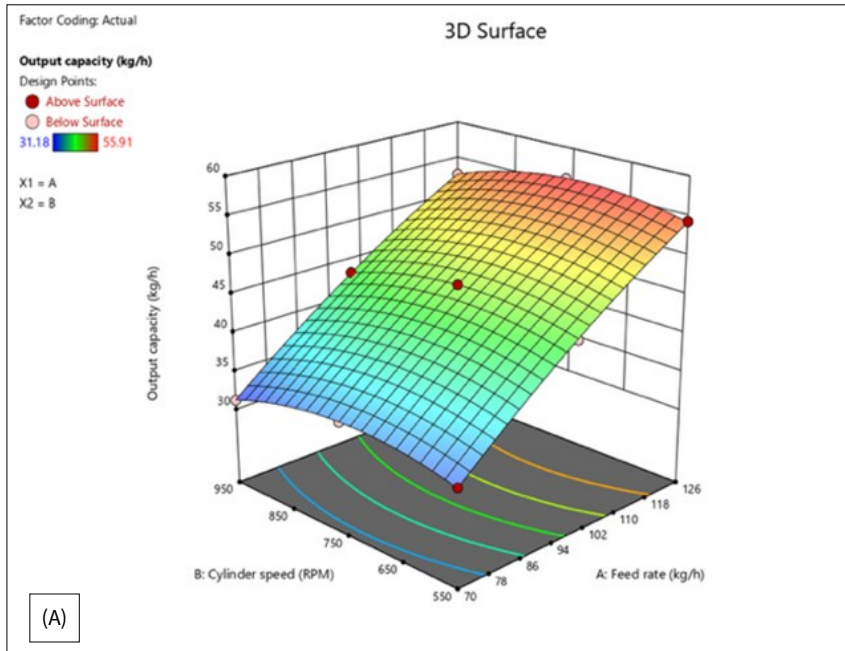
The output capacity of the thresher with three-cylinder types (spike tooth, wire loop and rasp bar) on paddy varieties (CO 54 and CO 55) was determined at five different levels of feed rate i.e. 70, 84, 98, 112 and 126 kg h<sup>-1</sup> and four speed ranges: i.e. 550-650, 650-750, 750-850 and 850-950 rpm. The observed output capacity of CO 54 and CO 55 varieties is shown in Fig. 4.

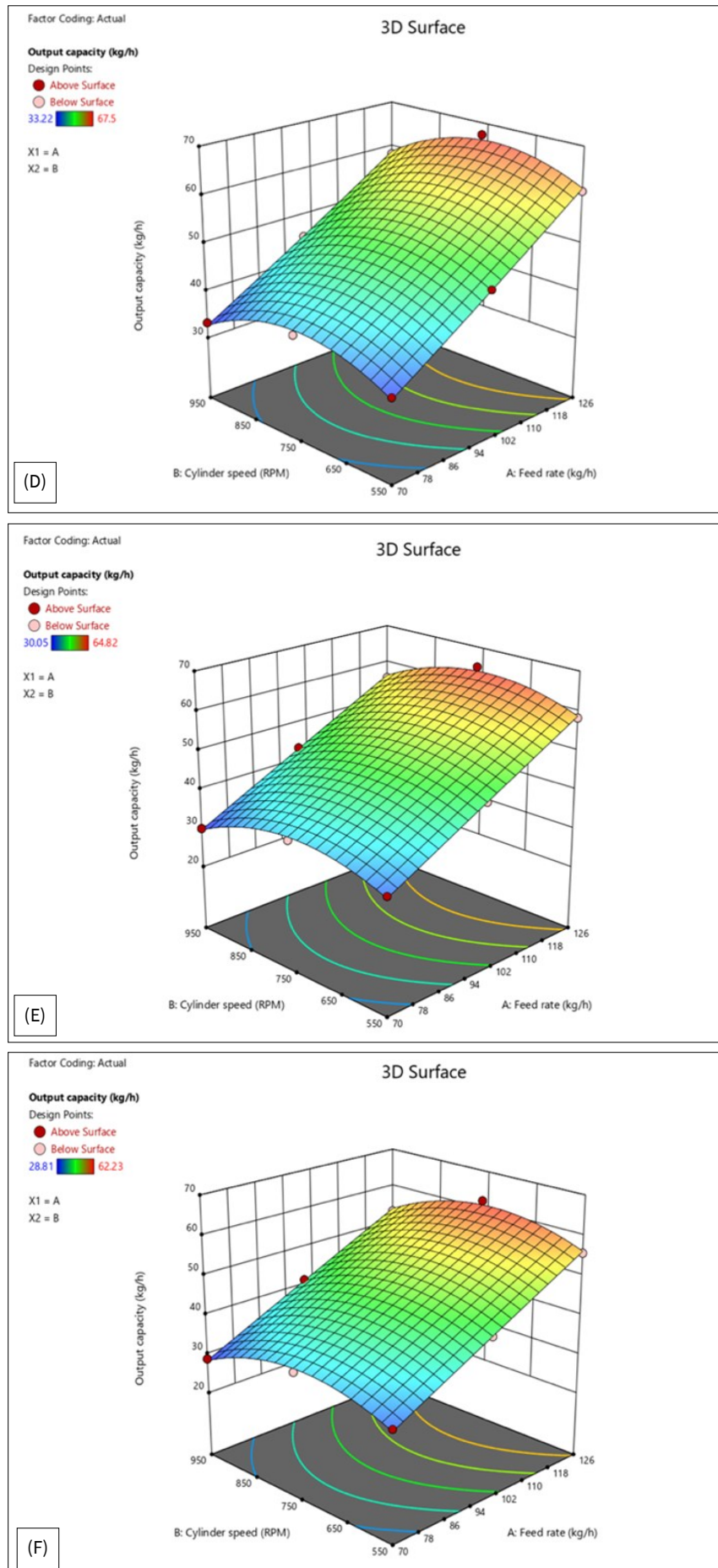
The 3D surface plots demonstrate that feed rate and cylinder speed influenced output capacity for paddy varieties CO 54 and CO 55, using spike tooth, wire loop and rasp bar threshing cylinders. Output capacity consistently increased with feed rate, underscoring its dominant role across both varieties and cylinder types. Cylinder speed showed moderate influence, with optimal performance generally observed around 750 rpm. The spike tooth cylinder delivered the highest output for both varieties (CO 54: 57.87 kg h<sup>-1</sup>; CO 55: 67.5 kg h<sup>-1</sup>), attributed to its aggressive threshing action. This aligns with other studies that have found that increasing the thresher's feed rate and cylinder speed improves productivity and this interaction of the parameters significantly affects threshing efficiency (7, 9). The wire loop cylinder closely followed, achieving peak outputs (CO 54: 62.28 kg h<sup>-1</sup>; CO 55: 64.82 kg h<sup>-1</sup>) due to smoother grain flow and reduced clogging. The rasp bar cylinder consistently yielded the lowest outputs (CO 54: 59.65 kg h<sup>-1</sup>, CO 55: 62.23 kg h<sup>-1</sup>), reflecting its gentler threshing mechanism. Overall, variety CO 55 consistently showed superior output capacities, likely because of its firmer grain structure and improved threshability compared to CO 54. These findings align with other studies that have found that physical properties of the plant are important for the performance of the machine (8).

Statistical analysis indicated strong model reliability for both varieties, with spike tooth cylinder models exhibiting the highest accuracy (R<sup>2</sup> = 0.9999). Feed rate had the most significant impact across all conditions (p < 0.0001), with cylinder speed also significant but to a lesser extent (p < 0.05). Quadratic terms for cylinder speed were highly significant, indicating non-linear relationships. The spike tooth cylinder was optimal for maximising output capacity, particularly for the CO 55 variety, under controlled operational conditions.

**Table 3.** Various characteristics of paddy varieties and paddy grain at threshing

Parameters/ Paddy variety	CO 54	CO 55
Grain moisture content (% w.b.)	19.42	18.67
Straw moisture content (% w.b.)	56.71	51.92
Grain/straw ratio	1:1.1	1:1.2
Grain diameter (mm)	1.9	1.7
Grain length (mm)	5.9	6.3
Crop height (cm)	90	80
Panicle length (cm)	24	22





**Fig. 4.** Three-dimensional response surface showing output capacity ( $\text{kg h}^{-1}$ , z-axis) as a function of feed rate ( $70\text{--}126 \text{ kg h}^{-1}$ , x-axis) and cylinder speed ( $550\text{--}950 \text{ rpm}$ , y-axis) for CO 54 and CO 55 variety; (A): Spike tooth cylinder (CO 54), (B): Wire loop cylinder (CO 54), (C): Rasp bar cylinder (CO 54), (D): Spike tooth cylinder (CO 55), (E): Wire loop cylinder (CO 55), (F): Rasp bar cylinder (CO 55). The colour gradient from blue (lowest capacity) through green and yellow to red (highest capacity) highlights peak throughput at high feed rates and speeds. Black dots mark the actual data points.

### Threshing efficiency

The efficiency of the thresher with three cylinder types (spike tooth, wire loop and rasp bar) on paddy crop (CO 54 and CO 55 variety) was checked at five different feed rate levels, i.e. 70, 84, 98, 112 and 126 kg h<sup>-1</sup> and four speed ranges, viz. 550-650, 650-750, 750-850 and 850-950 rpm. The data for threshing efficiency for the CO 54 and CO 55 varieties is shown in Fig. 5. The 3D surface plots illustrate the combined effects of feed rate and cylinder speed on threshing efficiency for paddy varieties CO 54 and CO 55, using spike tooth, wire loop and rasp bar cylinders. In both varieties, feed rate and speed significantly influenced efficiency, with optimal performance typically occurring at moderate speeds (around 750 rpm) and higher feed rates (100-110 kg h<sup>-1</sup>). This finding aligns with other studies that have shown cylinder speed of the thresher and crop feeding rate to have a significant and positive effect on threshing efficiency and productivity (7, 9).

For CO 54, the spike tooth cylinder showed a linear increase in efficiency, peaking at 95.55 %. The wire loop cylinder achieved a slightly higher maximum efficiency (95.83 %) but was more sensitive to excessive speed and feed rate, indicating a narrow optimal range. The rasp bar cylinder had the lowest efficiency (93.6 %) but demonstrated stable performance across a broad range of conditions. In CO 55, all cylinders performed better. The spike tooth achieved the highest efficiency (96.23 %), followed closely by the wire loop (96.08 %) and the rasp bar (94.06 %). This improvement in CO 55 can be attributed to its firmer grains and better threshability. These findings align with other studies that have found that physical properties of the plant are important for the performance of the machine (8).

Statistical analysis confirmed the significant influence of feed rate and cylinder speed on all cylinders for both varieties ( $p < 0.0001$ ). Interaction effects (AB) and quadratic terms ( $A^2$ ,  $B^2$ ) varied by cylinder: spike tooth showed significant AB interaction for both varieties, while wire loop displayed significant non-linear responses across all parameters.  $R^2$  values indicated strong model fits-highest in spike tooth (0.9987-0.9999), followed by wire loop (up to 0.9995) and rasp bar, slightly lower but still reliable. The spike tooth cylinder consistently delivered the most effective and reliable threshing efficiency for both varieties, especially CO 55. Wire loop cylinders offered high peak efficiency but were more sensitive to variation, while rasp bar designs provided stable but comparatively lower performance.

### Unthreshed grain loss

The unthreshed grain loss of the thresher with three cylinder types (spike tooth, wire loop and rasp bar) on paddy crop (CO 54 and CO 55 variety) was determined at five different levels of feed rate (70, 84, 98, 112 and 126 kg h<sup>-1</sup>) and four speed ranges: (550-650, 650-750, 750-850 and 850-950 rpm). The observed unthreshed grain loss for CO 54 and CO 55 varieties is shown in Fig. 6. The 3D surface plots show how feed rate and cylinder speed affected unthreshed grain loss for both CO 54 and CO 55 paddy varieties across spike tooth, wire loop and rasp bar cylinders. In general, unthreshed grain loss decreased at moderate speeds (650-750 rpm) and feed rates (90-110 kg h<sup>-1</sup>), indicating an optimal zone for effective threshing. This behaviour, where an optimal zone exists, is supported by other research studies that found a significant interaction between cylinder speed and feed rate on threshing efficiency, with higher speeds generally increasing efficiency and therefore, reducing unthreshed losses (7, 9).

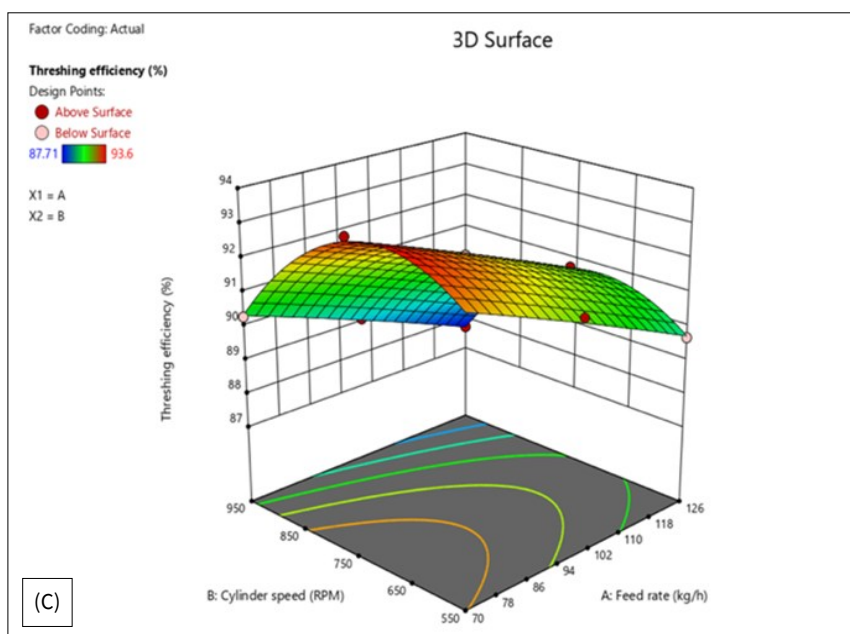
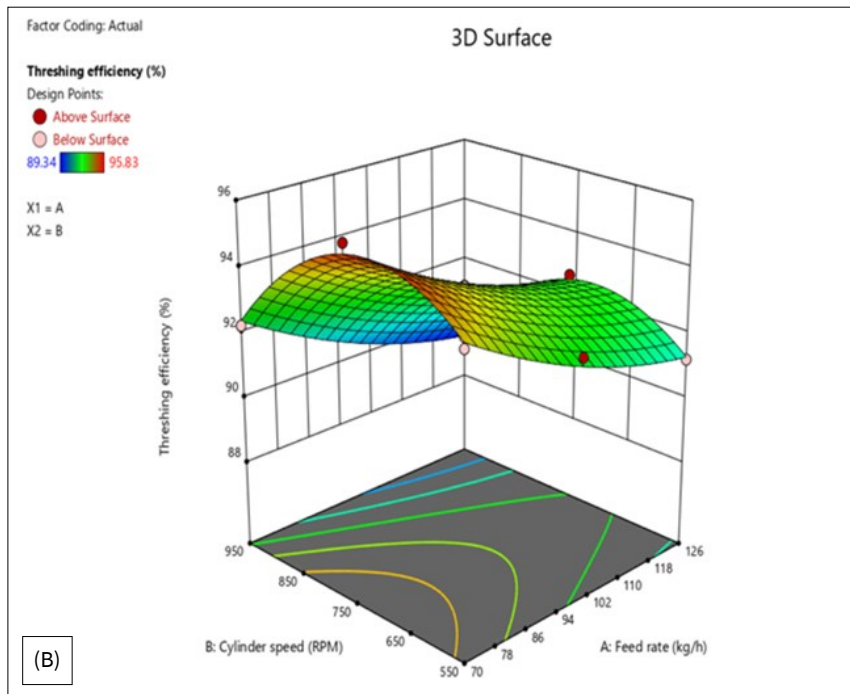
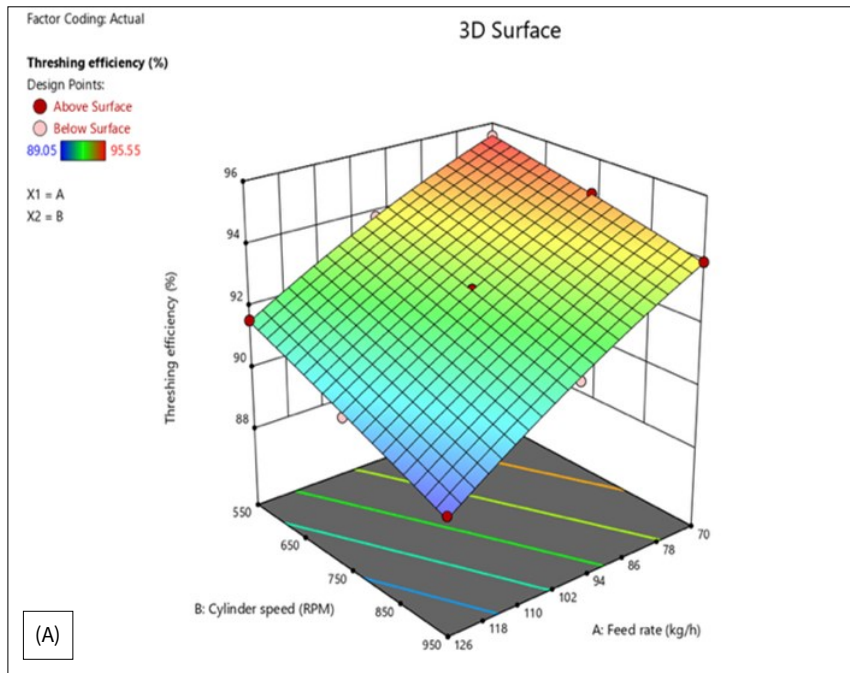
For CO 54, the spike tooth cylinder exhibited a clear reduction in unthreshed grain loss under optimal settings, reaching a minimum of 3.19 %. The wire loop cylinder required precise control of conditions to achieve minimal loss (~4.23 %), showing high sensitivity to speed and feed variations. The rasp bar showed a broader but higher loss range (~6.10 %), demonstrating stable but less efficient performance. In CO 55, overall unthreshed grain loss was lower across all cylinders, attributed to the variety's better threshability (8). The wire loop cylinder achieved the lowest loss (~2.85 %), followed by spike tooth (~3.07 %) and rasp bar (~3.86 %). ANOVA confirmed that feed rate and cylinder speed significantly impacted unthreshed grain loss across both varieties ( $p < 0.0001$ ). Spike tooth and wire loop cylinders showed significant quadratic effects ( $A^2$ ,  $B^2$ ), reflecting non-linear trends, while AB interactions were significant primarily for spike tooth. Model fits were strong: wire loop showed the highest predictive accuracy ( $R^2 = 0.9995$ , predicted  $R^2 = 0.9949$ ), followed by spike tooth ( $R^2 = 0.9986$ ) and rasp bar ( $R^2 = 0.9973$ ). Overall, CO 55 outperformed CO 54 in minimising unthreshed grain loss. Among cylinders, the wire loop provided the lowest losses and highest prediction reliability, while the spike tooth offered balanced performance across a range of conditions. The rasp bar, though less efficient, showed stable results across both varieties.

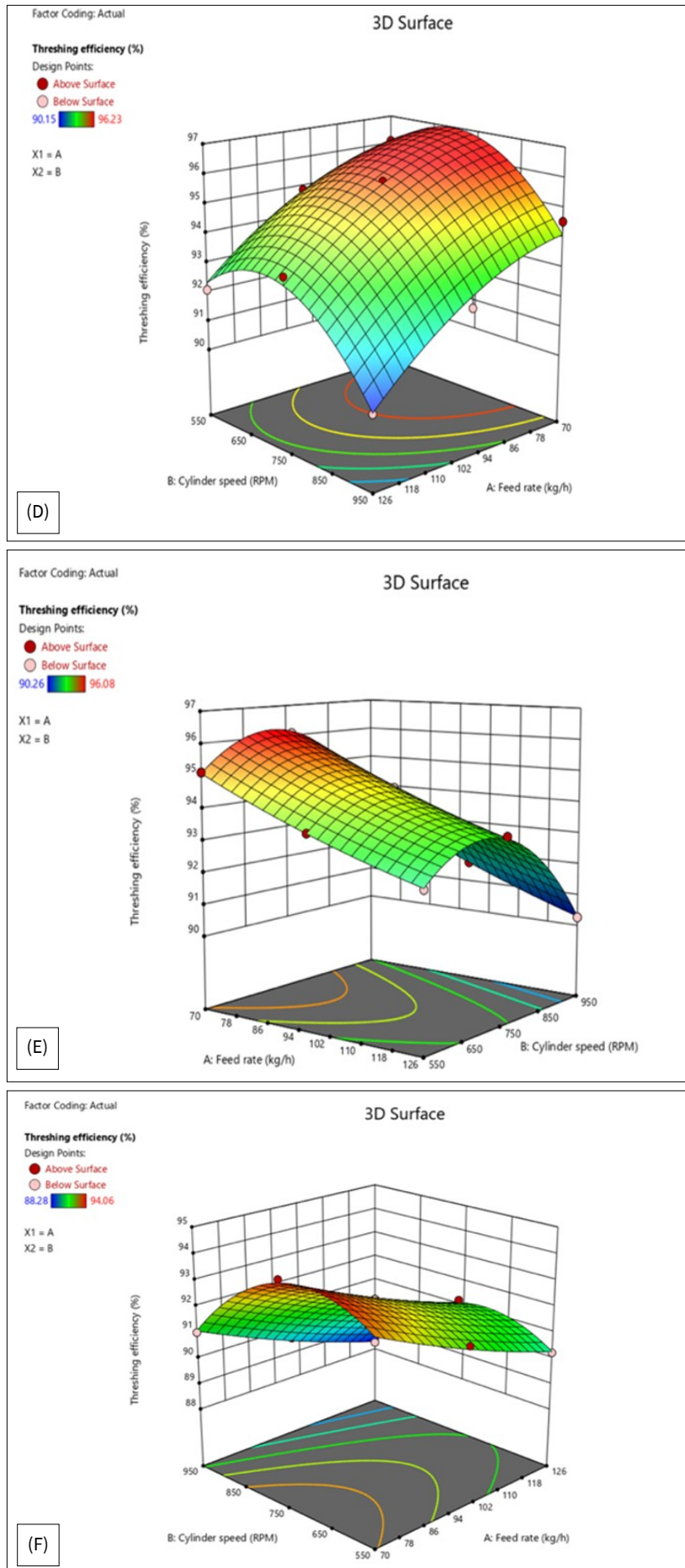
### Broken grain loss

The broken grain loss of the thresher with three cylinder types (spike tooth, wire loop and rasp bar) on paddy crop (CO 54 and CO 55 variety) was determined at five different levels of feed rate (70, 84, 98, 112 and 126 kg h<sup>-1</sup>) and four speed ranges: (550-650, 650-750, 750-850 and 850-950 rpm). The observed broken grain loss for the CO 54 variety is shown in Fig. 7. The 3D surface plots illustrate the effect of feed rate and cylinder speed on broken grain loss for both CO 54 and CO 55 paddy varieties using spike tooth, wire loop and rasp bar cylinders. In both varieties, grain breakage increased with higher speeds and feed rates, especially beyond 850 rpm and 110 kg h<sup>-1</sup>, highlighting the need to optimise operational conditions to minimise mechanical damage.

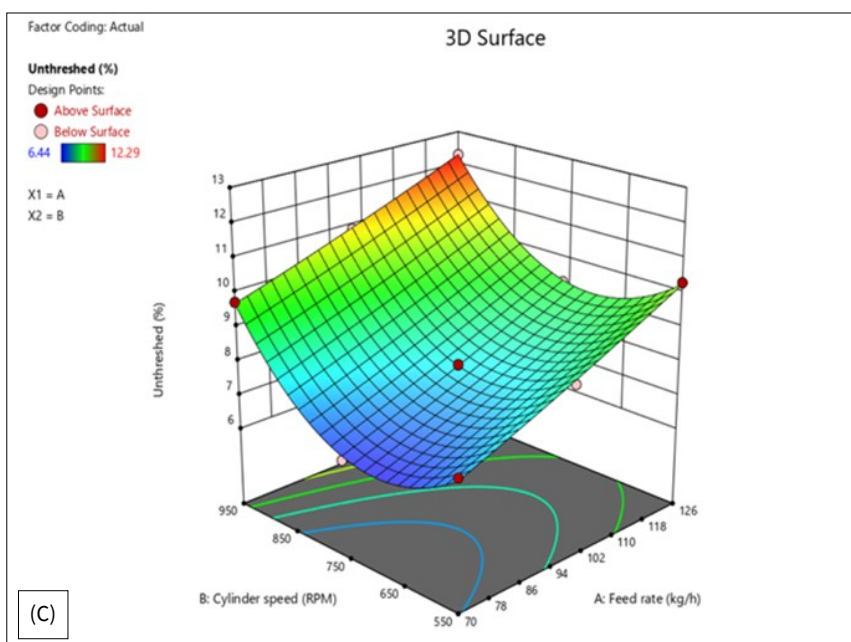
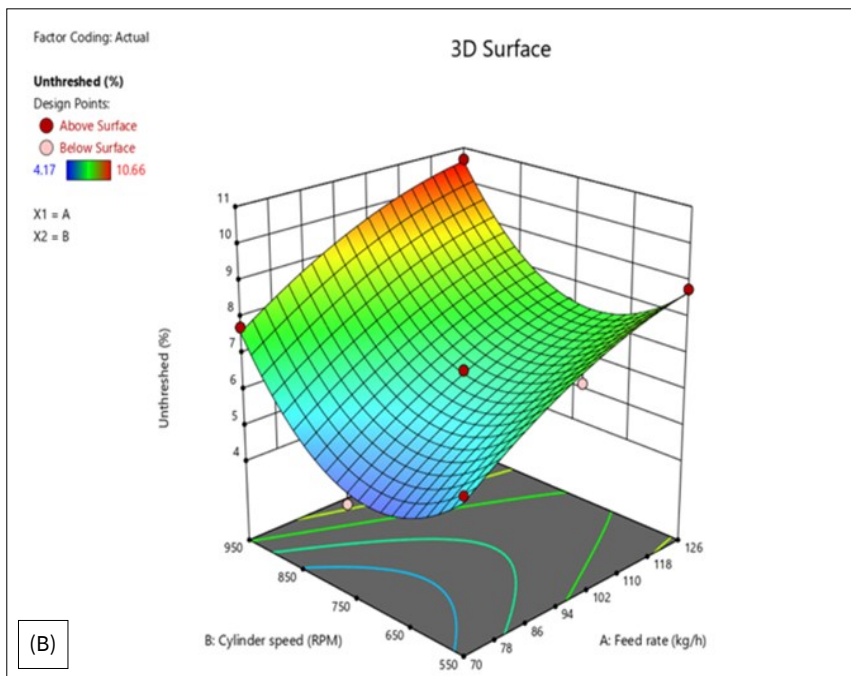
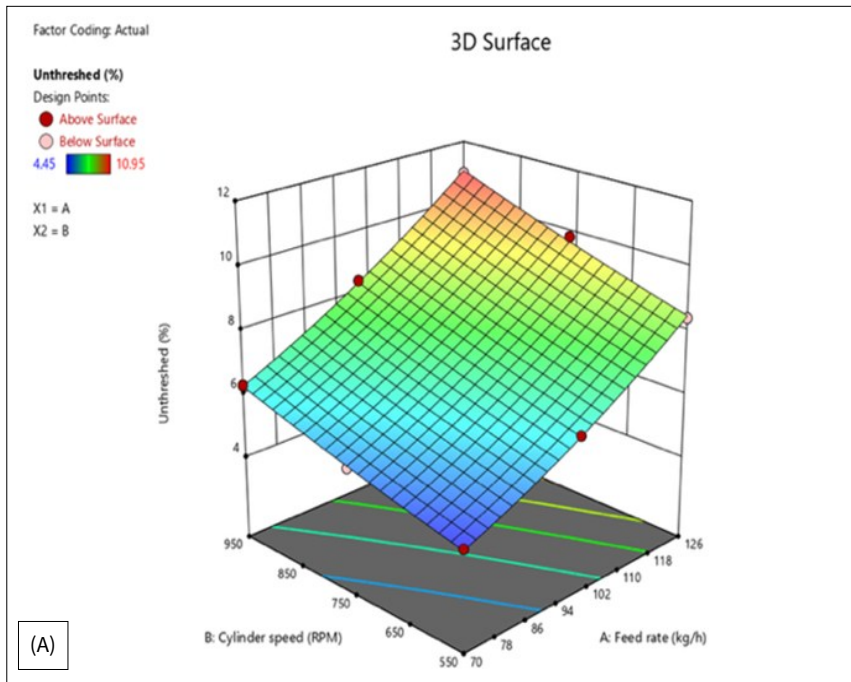
For CO 54, the spike tooth cylinder showed a linear rise in breakage from 1.8 % at low settings to a peak of 4.66 % at aggressive speeds and feed rates. This finding aligns with the studies that found an increase in broken grain as cylinder speed increased, indicating that excessive impact force from spikes can cause significant grain breakage (7, 9). The wire loop exhibited a curved response, with breakage rising steeply beyond 800 rpm and a peak of 4.23 %, indicating sensitivity to excessive speed. The rasp bar offered the lowest breakage range (~0.86 %-3.87 %), confirming its gentle operation. In CO 55, breakage was generally lower. The rasp bar performed best (max ~3.88 %), followed by wire loop (~4.41 %) and spike tooth (~4.47 %), though all showed similar trends with breakage rising at extreme conditions.

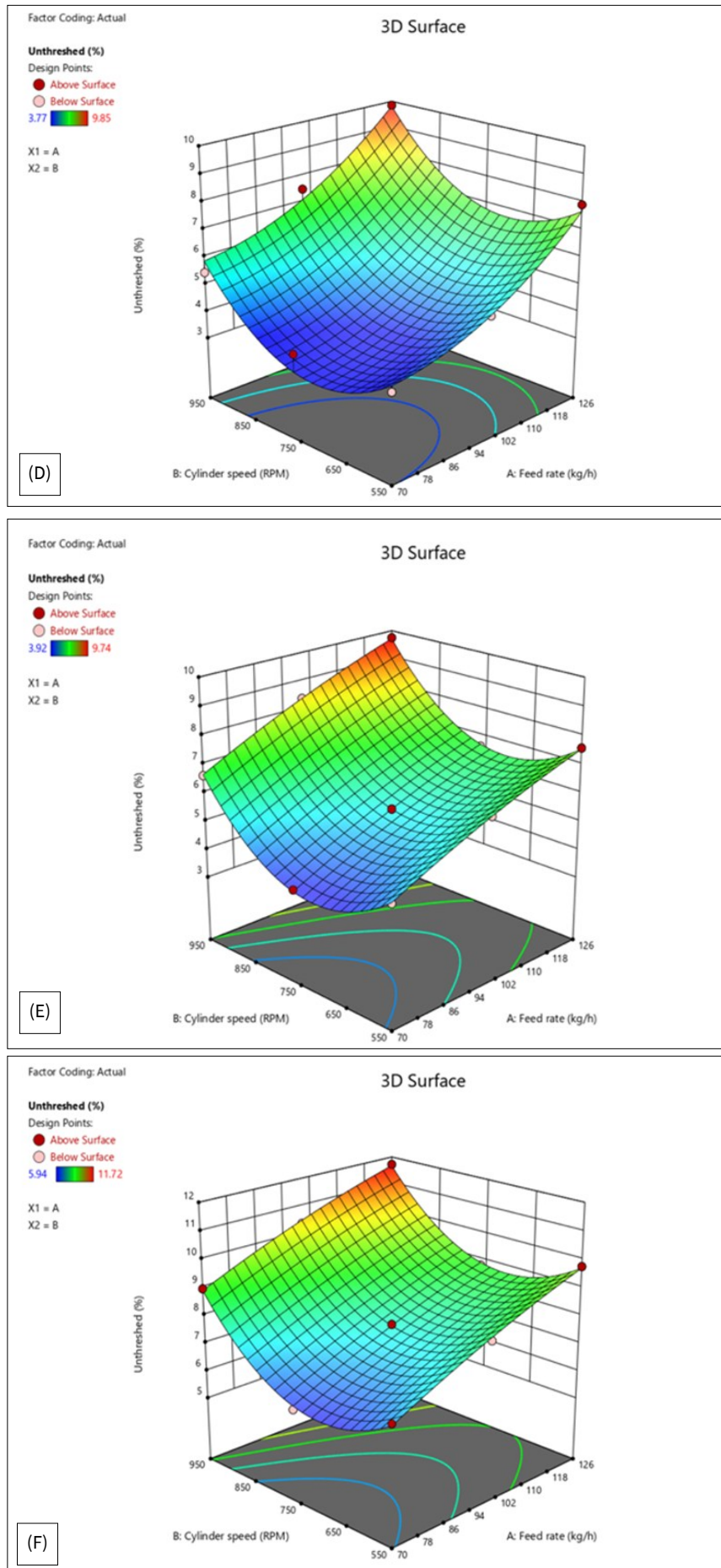
Statistical analysis confirmed feed rate and cylinder speed as significant factors ( $p < 0.0001$ ). Spike tooth and wire loop models showed strong fits ( $R^2 > 0.99$ ), with the wire loop achieving the highest predictive accuracy ( $R^2 = 0.9973$  for CO 54;  $R^2 = 0.9942$  for CO 55). The rasp bar, while less predictive (CO 55 predicted  $R^2 = 0.7407$ ), maintained consistent results due to its softer threshing action. Overall, CO 55 showed marginally lower broken grain losses across cylinders. Among designs, the rasp bar consistently minimised breakage, while the wire loop provided reliable modelling with moderate losses. The spike tooth, though effective, resulted in higher breakage under aggressive conditions.



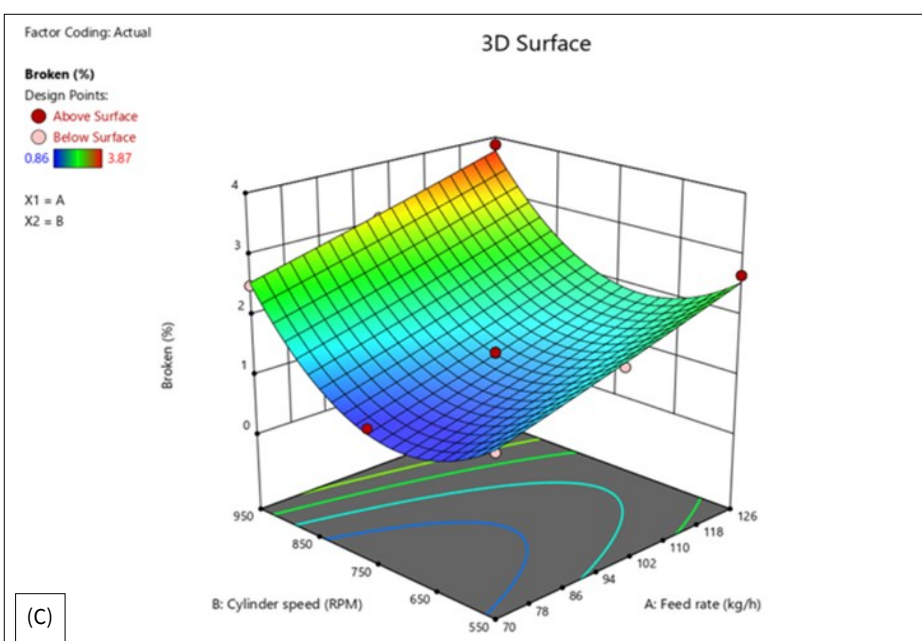
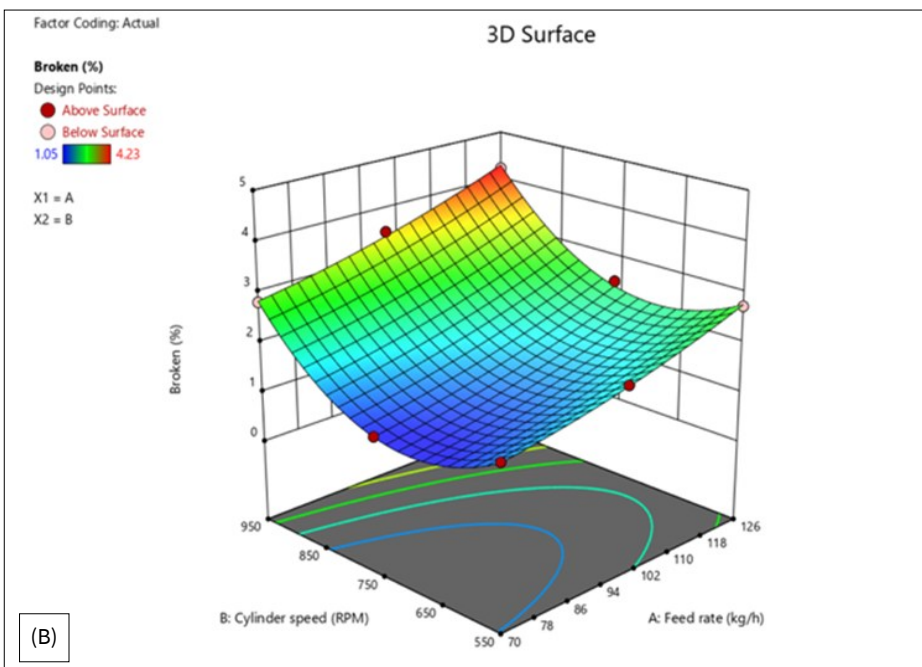
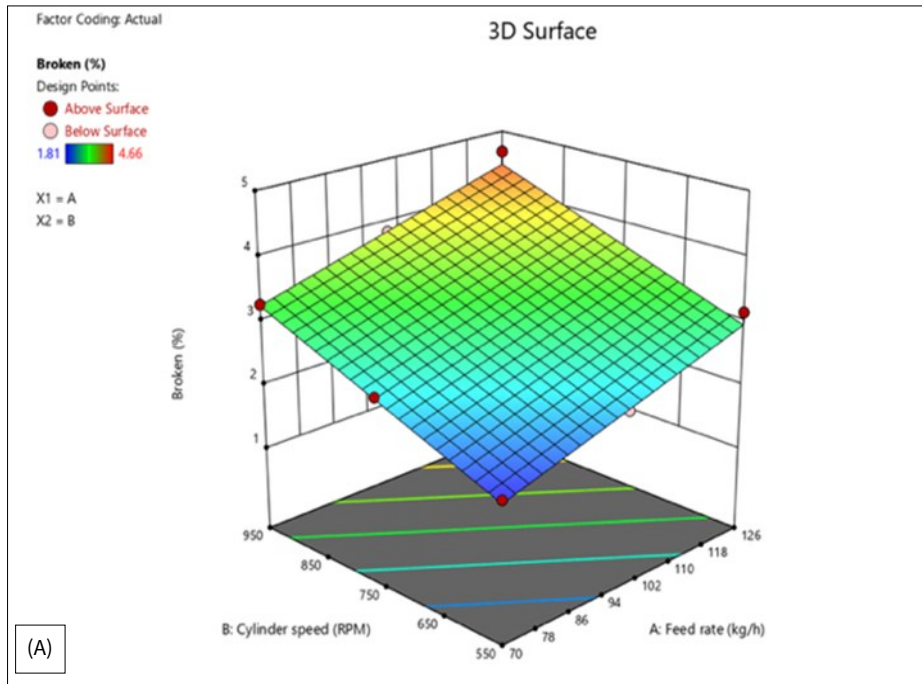


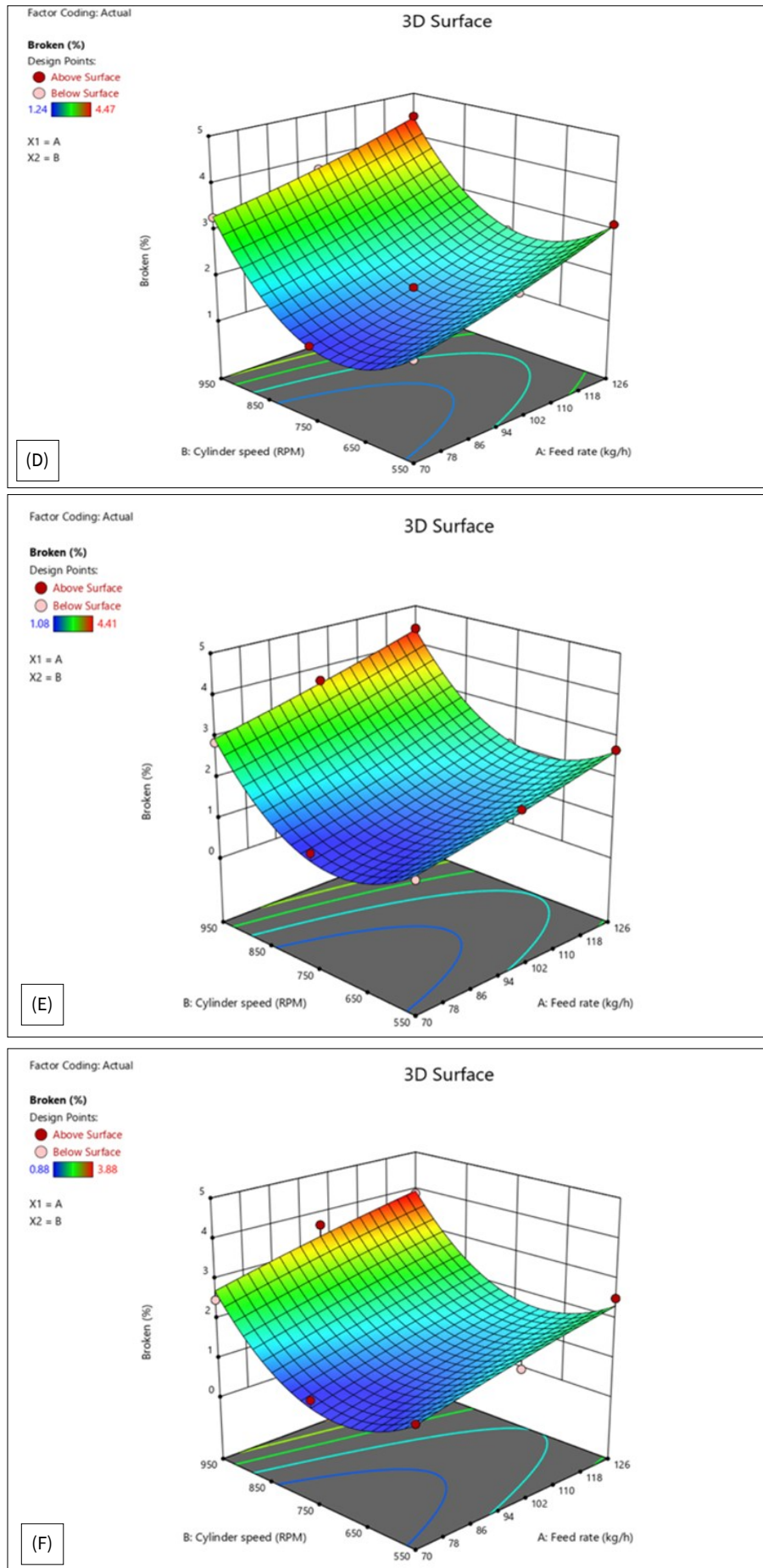
**Fig. 5.** Three-dimensional response surface showing threshing efficiency ( %, z-axis) as a function of feed rate (70-126 kg h<sup>-1</sup>, x-axis) and cylinder speed (550-950 rpm, y-axis) for CO 54 and CO 55 variety; (A): Spike tooth cylinder (CO 54), (B): Wire loop cylinder (CO 54), (C): Rasp bar cylinder (CO 54), (D): Spike tooth cylinder (CO 55), (E): Wire loop cylinder (CO 55), (F): Rasp bar cylinder (CO 55). The colour gradient from blue (lowest efficiency) through green and yellow to red (highest efficiency) shows how efficiency improves most when both feed rate and speed are high. Black dots mark the actual experimental runs.





**Fig. 6.** Three-dimensional response surface showing unthreshed grain loss (% , z-axis) as a function of feed rate (70-126 kg h<sup>-1</sup>, x-axis) and cylinder speed (550-950 rpm, y-axis) for CO 54 and CO 55 variety; (A): Spike tooth cylinder (CO 54), (B): Wire loop cylinder (CO 54), (C): Rasp bar cylinder (CO 54), (D): Spike tooth cylinder (CO 55), (E): Wire loop cylinder (CO 55), (F): Rasp bar cylinder (CO 55). The colour gradient from blue (lowest loss) through green and yellow to red (highest loss) indicates that unthreshed loss decreases with higher cylinder speeds, especially at moderate feed rates. Black dots denote experimental data points.





**Fig. 7.** Three-dimensional response surface depicting broken grain loss (% , z-axis) versus feed rate (70-126 kg h<sup>-1</sup>, x-axis) and cylinder speed (550-950 rpm, y-axis) for CO 54 and CO 55 variety; (A): Spike tooth cylinder (CO 54), (B): Wire loop cylinder (CO 54), (C): Rasp bar cylinder (CO 54), (D): Spike tooth cylinder (CO 55), (E): Wire loop cylinder (CO 55), (F): Rasp bar cylinder (CO 55). The colour gradient from blue (lowest breakage) through green and yellow to red (highest breakage) reveals that breakage is minimised at lower feed rates and intermediate speeds. Black dots represent actual measurements.

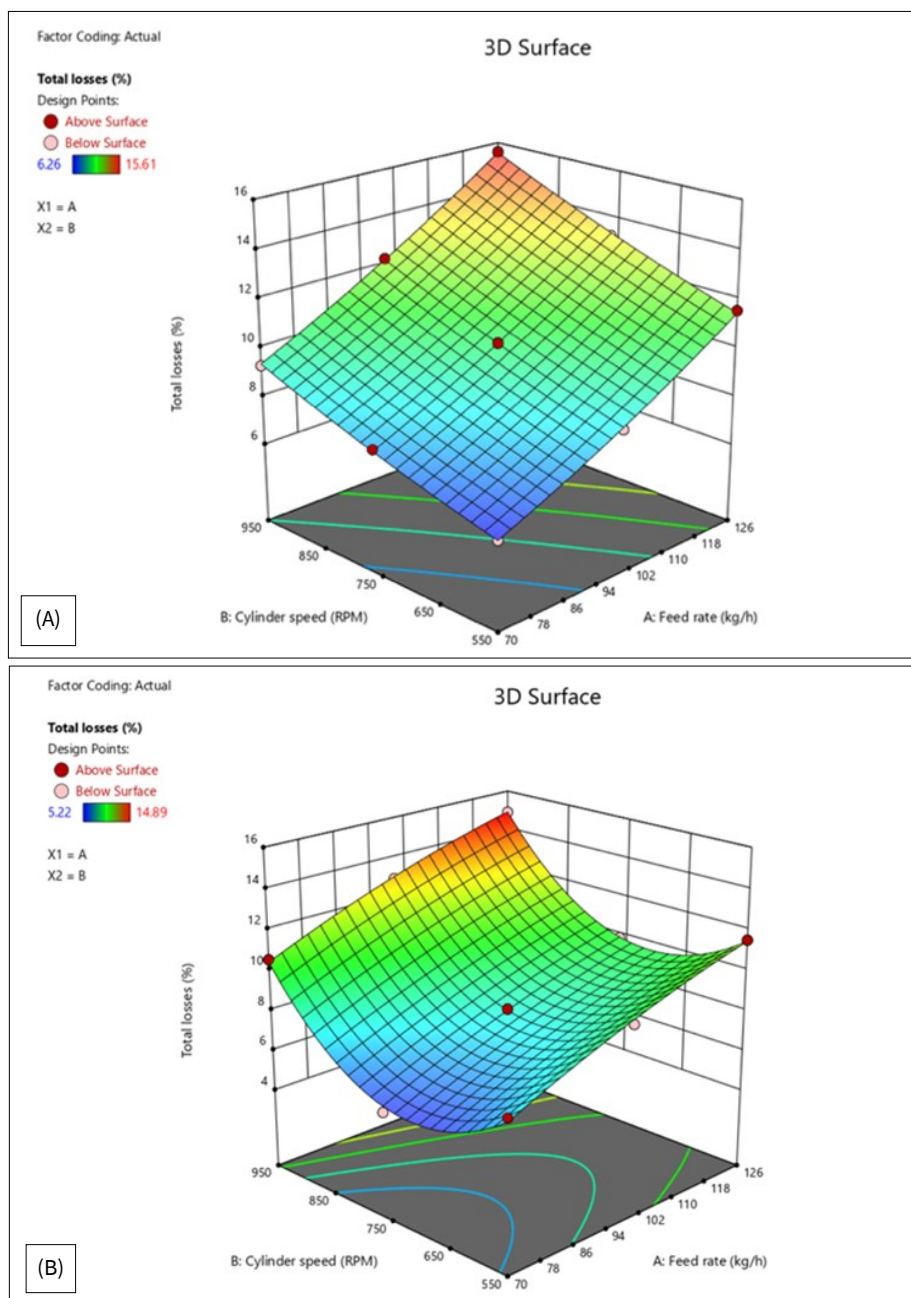
### Total loss

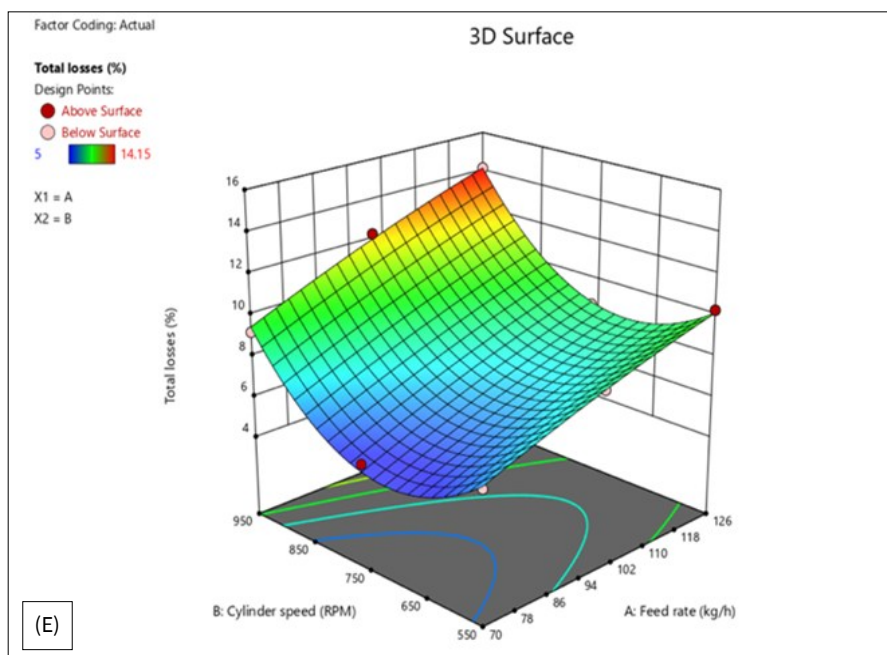
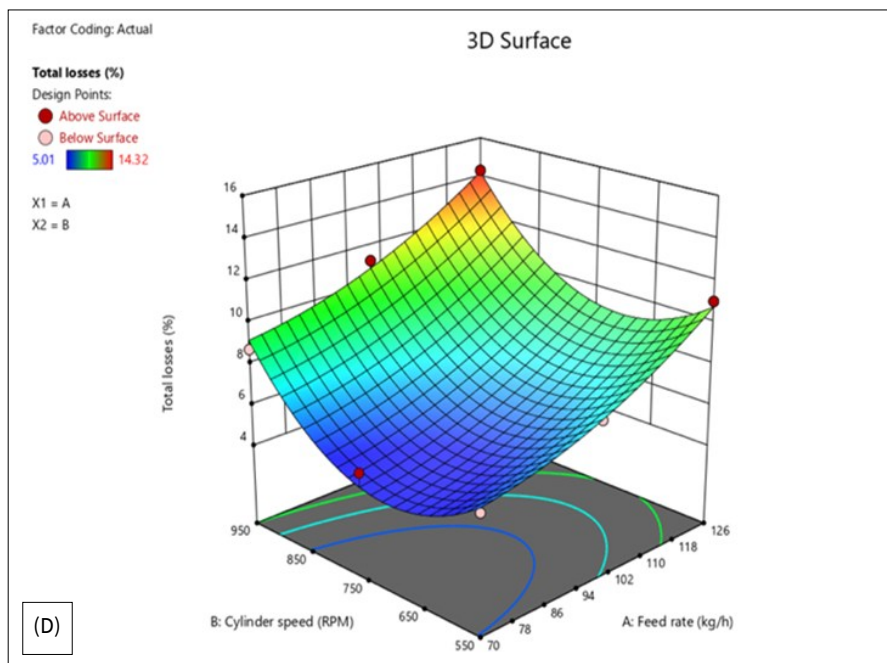
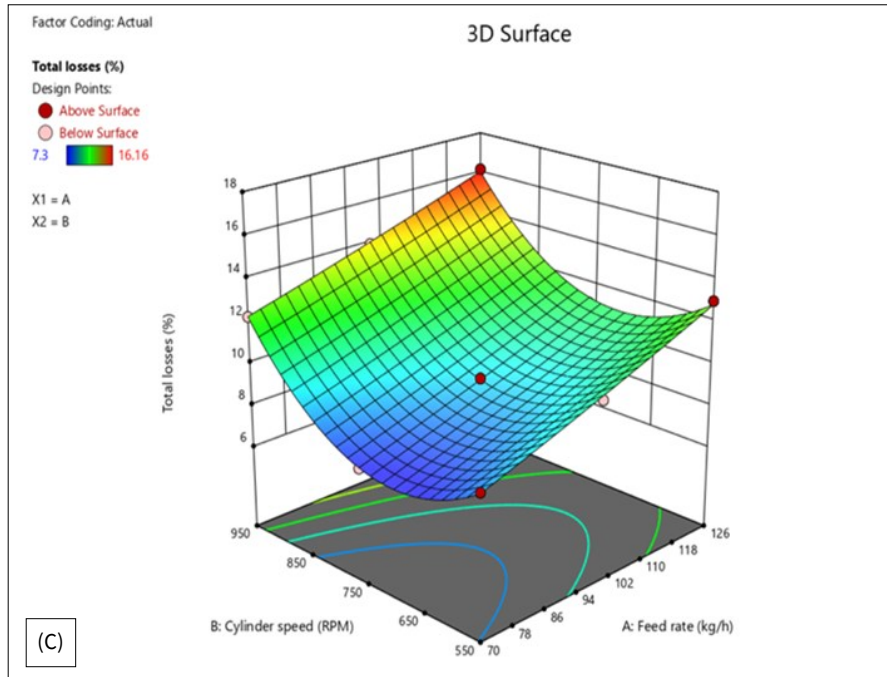
The total grain loss of the thresher with three cylinder types (spike tooth, wire loop and rasp bar) on paddy crop (CO 54 and CO 55 variety) was determined at five different levels of feed rate (70, 84, 98, 112 and 126 kg h<sup>-1</sup>) and four speed ranges: (550-650, 650-750, 750-850 and 850-950 rpm). The observed total grain loss for CO 54 and CO 55 varieties is shown in Fig. 8. The 3D surface plots illustrate the effect of feed rate and cylinder speed on total grain loss for both CO 54 and CO 55 varieties using spike tooth, wire loop and rasp bar cylinders. In both varieties, total grain loss increased at higher speeds and feed rates, emphasising the need for balanced operational conditions to minimise losses. This need for balanced operational conditions is also supported by other research studies, which indicate that while higher feed rates and speeds can increase productivity, a higher cylinder speed can also increase damaged grain, highlighting a fundamental necessity that requires careful optimisation (7, 9).

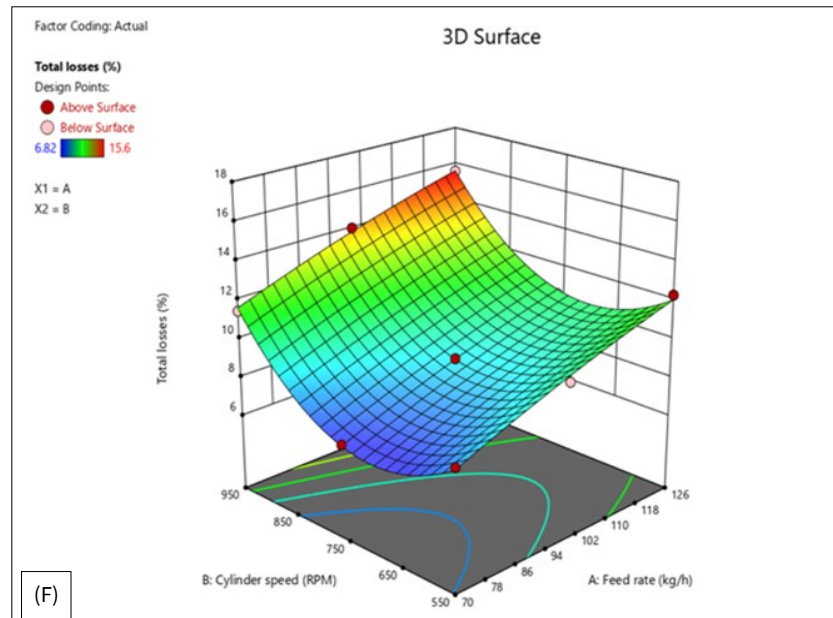
In CO 54, the spike tooth cylinder showed the highest total loss (up to 15.61 %) due to its aggressive action at high speeds and feed rates. The wire loop displayed a pronounced

curved response, peaking at 14.89 %, with minimal losses near 750 rpm and 95-105 kg h<sup>-1</sup>. The rasp bar had the highest peak loss (16.16 %), indicating limited control at extreme conditions. For CO 55, grain loss was generally lower across all cylinders. The spike tooth ranged from 5.01 % to 14.32 %, the wire loop from 5.00 % to 14.15 % and the rasp bar from 6.82 % to 15.60 %, showing improved control due to CO 55's firmer grains and better threshability. These findings align with other studies that have found that physical properties of the plant are important for the performance of the machine (8).

ANOVA results confirmed significant effects of feed rate and cylinder speed on all cylinders ( $p < 0.0001$ ). The spike tooth showed strong interaction and quadratic effects ( $R^2 = 0.9993$ ), indicating high sensitivity. The wire loop and rasp bar also showed reliable model fits. ( $R^2 \approx 0.996-0.997$ ), Though with simpler, mostly independent parameter effects. Overall, CO 55 performed better than CO 54 in minimising total grain loss. The wire loop provided efficient loss control across moderate conditions, while the spike tooth was highly responsive to settings. The rasp bar, though stable, had higher losses at extremes due to its gentler but less forceful action.







**Fig. 8.** Three-dimensional response surface of total grain loss (% , z-axis) plotted against feed rate (70-126 kg h<sup>-1</sup>, x-axis) and cylinder speed (550-950 rpm, y-axis) for CO 54 and CO 55 variety; (A): Spike tooth cylinder (CO 54), (B): Wire loop cylinder (CO 54), (C): Rasp bar cylinder (CO 54), (D): Spike tooth cylinder (CO 55), (E): Wire loop cylinder (CO 55), (F): Rasp bar cylinder (CO 55). The colour gradient from blue (lowest total loss) through green and yellow to red (highest total loss) demonstrates that total loss is minimised when feed rate and speed are balanced. Black dots indicate experimental runs.

The study produced the following key findings:

- The spike tooth cylinder achieved the highest threshing efficiency (up to 96.23 %) and output capacity (67.5 kg h<sup>-1</sup> for CO 55), making it the most effective among the tested designs.
- The wire loop cylinder demonstrated better performance in minimising grain breakage (< 4.5 %) while maintaining moderate output levels.
- The rasp bar cylinder offered smoother material handling and the lowest total grain loss in CO 55, but showed reduced throughput and threshing efficiency.
- Optimal operating parameters were identified at cylinder speeds of 650-750 rpm and feed rates between 84-112 kg h<sup>-1</sup>, where performance was maximised and losses minimised.
- Increased cylinder speed and feed rate beyond these limits led to a rise in broken grains and unthreshed losses, particularly in the spike tooth and wire loop cylinders.
- Statistical models developed for performance prediction showed high reliability with R<sup>2</sup> values exceeding 0.99 for most configurations, validating the consistency and robustness of the experimental results.

## Conclusion

The evaluation of spike tooth, wire loop and rasp bar threshing cylinders was carried out for two paddy varieties, CO 54 and CO 55, under controlled laboratory conditions. The spike tooth cylinder was found to be most suitable for high-output threshing applications, while the use of a wire loop provides gentle handling and reduces grain breakage. The rasp bar cylinder, though less efficient, offers consistent performance with minimal losses in specific conditions. This study highlights the importance of a data-driven approach to small-scale mechanisation, where optimising the

balance between machine parameters and crop characteristics is necessary for improving efficiency and profitability.

To extend this research, future studies should be focused on optimising parameters (650-750 rpm, Spike tooth cylinder) through field trials under real-world conditions. Further optimisation of cylinder design and multi-objective analysis could enhance efficiency while minimising grain loss.

## Acknowledgements

The authors are thankful to Tamil Nadu Agricultural University for funding and facilities provided for carrying out this research. All the experts' participation for brainstorming were acknowledged herewith. The authors gratefully acknowledge the fellowship support from the Department of Science and Technology (DST), Government of India, under the INSPIRE program. This research work was also financially supported by the Indian Council of Agricultural Research (ICAR).

## Authors' contributions

This work was carried out in collaboration among all authors. SP planned the experiment, performed the experimental work, conducted the data analysis and wrote the first draft of the manuscript. RK helped in framing the overall experiment, providing critical ideas and assisted with manuscript correction. TS also helped with the manuscript correction and reviewing the manuscript. AS, SDS, RT and ST contributed valuable ideas for the experiment and reviewed the manuscript. All authors read and approved the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interest to declare.

**Ethical issues:** None

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