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Development of black soldier fly larvae separating machine

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Abstract

The black soldier fly (BSF) is widely recognized as a valuable protein supplement for aquaculture and poultry farming due to its larval composition, which includes 40% crude protein, 33% crude fat, 15% ash, and 12% crude fibre. BSF larvae are highly effective in bio converting organic waste within a short period and can thrive on substrates such as kitchen waste, fruits, and vegetables. Additionally, BSF does not pose any risks as a pest or vector in its adult stage. However, the separation of larvae from waste material presents significant challenges in field applications. To address these issues, a differential separation trommel screener was developed and evaluated. Conventional vibrating screens used for separating BSF larvae often encounter issues with impurity removal and efficiency. This study aimed to develop, and assess the performance of an optimized BSF larvae separation machine. The study focused on key operational parameters, including the rotational speed of the screening cylinder and its angle of inclination, and evaluated their effects on performance metrics such as throughput capacity, output capacity, and screening efficiency. Optimal operational settings were determined to be a screening cylinder rotation speed of 20 rpm and an inclination angle of 9°, resulting in a throughput capacity of 1.02 t/h, an output capacity of 95.3 kg/h, and a screening efficiency of 93.43%. The operating cost was calculated at ₹130 per hour or ₹160 per ton, highlighting the machine's cost-effectiveness. The developed BSF larvae separation machine features a user-friendly design, reliable performance, and the ability for continuous operation. Currently deployed in waste processing plants, it offers an efficient and scalable solution for mechanical waste screening and larvae separation, addressing a critical bottleneck in BSF-based waste management systems.

Keywords: Black soldier fly larvae, waste management, separation efficiency, screening technology, sustainable agriculture

1. Introduction

The Black Soldier Fly (*Hermetia illucens*), native to the Americas, has become widespread globally due to its adaptability to diverse environmental conditions, including variations in light, temperature, and humidity (Barragan-Fonseca *et al.*, 2017) ^[14]. The larvae of this species consume a variety of organic substrates, such as manure, food byproducts, and pre/post-consumer food waste, converting them into valuable biomass suitable for animal feed (Erbland *et al.*, 1997) ^[26]. This bioconversion ability makes BSFL a promising solution for sustainable waste management. Optimal production of BSFL requires maintaining environmental conditions favourable to their growth. Studies indicate that temperatures of 25 °C to 33 °C and substrate moisture levels of 60-70% ensure rapid development and high survival rates (Erbland *et al.*, 1997) ^[26]. The life cycle of BSF includes five main stages: eggs, larvae, prepupae, pupae, and adults. BSFL are particularly efficient at bio converting organic waste, reducing waste mass by 50-95%, and producing a protein-rich biomass with significant nutritional value (Nyakeri *et al.*, 2017) ^[9]. This capability has spurred interest in its application for managing restaurant, municipal, and agricultural waste streams.

However, separating larvae from waste remains a critical bottleneck in scaling BSFL-based systems. Traditional separation methods manual sorting, water flotation, and behavioural migration are inefficient and labour-intensive, particularly for large-scale operations. Addressing these challenges, this research focuses on the development and performance evaluation of a mechanized BSFL separating machine to improve efficiency and scalability.

2. Methodology

2.1 Machine Development and Fabrication

The BSFL separating machine incorporates a dual-cylinder screening system with inner and outer cylinders designed for sequential separation. The inner cylinder separates larger waste particles, while the outer cylinder isolates larvae from smaller waste particles. Key components include:

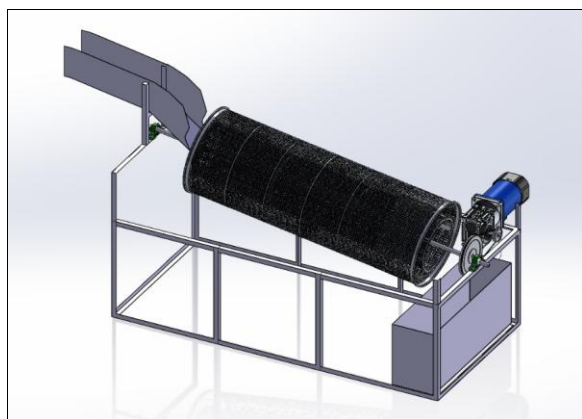


Fig 1: Isometric View of BSFL Separating Machine

2.1.1 Length and Diameter of the Rotating Cylinders

To maximize the exposure of material to the screening surface, it is essential to ensure a large surface area within the screen cylinder. According to Brentwood (2016), increasing the length and diameter of the screen cylinder enhances the surface area, thereby improving the material's interaction with the screen.

In the developed machine, two concentric cylinders with distinct screen designs are used. This dual-cylinder arrangement allows the material to pass through two separate screening processes, effectively increasing screening efficiency and simplifying the separation of waste and larvae. As noted by Yung Heng (1996), at the start of the screening process, undersized particles quickly pass through the sieve due to their smaller size compared to the mesh openings. Toward the end of the cylinder, most of these undersized particles have already been screened, leaving behind near-mesh or oversized particles, which reduces the screening rate, noted by Gatade (2023) ^[11]. Considering these factors, and keeping it in view the length of both cylinders was set at 1800 mm to optimize the screening process.

2.1.2 Outer screening cylinder (for larva separation from kitchen waste)

Previously, the separation of larvae from waste was performed manually by placing the waste on a mesh with a 25 mm² sieve size. In this method, larvae would move through the mesh, separating from the waste. However, this process had a significant drawback: unwanted waste particles often passed through along with the larvae. Based on these observations, the sieve size was increased to 10 mm², as it was readily available in the market. Another trial was conducted using the same quantity of waste. The results showed a significant improvement, with an efficiency of 85–90%. Most larvae were successfully separated from the compost, though small-sized compost particles and sticks were still present among the separated larvae. This size was chosen to optimize the separation of larvae and waste while minimizing contamination with smaller waste particles.

2.1.3 Inner screening cylinder (for large kitchen waste separation)

The inner screening cylinder was primarily designed to separate

larger waste particles and clods from the compost. Following this initial separation, the remaining waste, along with the larvae, is processed by the outer screening cylinder for further refinement.

As noted by Yung Heng (1996), In the traditional separation method, a 25 mm² sieve was used, which allowed larger unwanted waste particles to pass through, resulting in inefficient separation. To reassess its effectiveness, a trial was conducted using a cylinder fitted with a 25 mm² sieve. The trial revealed that the openings of the sieve were too large, allowing most of the unwanted particles to fall through. Consequently, this sieve size was deemed unsuitable for separating larger waste particles. To address this issue, and based on market availability, the sieve size was replaced with a 10 mm² sieve. A subsequent trial using this sieve demonstrated significant improvement, with effective separation of larger clods and waste particles. The remaining compost containing larvae passed through to the next stage of separation. However, to achieve even better results, the sieve size was finalized at 15 mm² for the inner screening cylinder. This size was found to effectively separate large compost particles, again after some small trials taken at campus ensuring that only manageable waste and larvae moved to the next cylinder for further processing.

2.1.4 Electric motor

The selection of the motor was based on the torque requirements, taking into consideration the availability of suitable motors in the market. For torque calculation, the radius of the outer cylinder. The weight of the screening system, including both concentric cylinders and the waste on the inner cylinder, was also factored into the calculation. These weights are as follows:

Weight of the inner cylinder (W_1)

Weight of the outer cylinder (W_2)

Weight of waste on the inner screen (W_3)

The torque (T) was calculated using the equation:

$$T = 9.81 \times (W_1 + W_2 + W_3) \times R \quad (1)$$

Thus, the required torque for the motor was determined to be 458.16 Nm, ensuring that the motor selected could adequately drive the screening system under operational conditions.

Power required is calculated with the torque obtained by calculated as below

$$P = T \times \omega \quad \dots (2)$$

$$P = T \times \frac{2\pi N}{60} \quad \dots (3)$$

Substituting the values we get T from equation 3.1 and N is Maximum Speed of rotation will be 30 rpm.

$$P = 458.16 \times \frac{2\pi 30}{60}$$

Hence, a single-phase electric motor of 2 hp was selected.

2.1.5 Shaft for screening cylinders

The shaft in this application is designed to support the weight of the screening cylinders and the waste while operating at a maximum rotational speed of 30 RPM. To determine the required shaft diameter, the torsion equation (Strength of Materials by R. K. Bansal) is used, which relates the applied

torque, material properties, and shaft dimensions.

The torsion equation is expressed as:

$$T = \frac{\pi \tau d^3}{16} \quad \dots (4)$$

Where,

T is the applied torque (in Nm).

τ is the allowable shear stress of the shaft material (in N/m²).

d is the diameter of the shaft (in meters).

Rearranging the equation to solve for the shaft diameter (d):

$$d = \left\{ \frac{16T}{\pi \tau} \right\}^{1/3} \quad \dots (5)$$

The calculated diameter of the shaft is approximately 38.78 mm. to ensure safety and accommodate additional factors like wear and fatigue we selected the shaft of 40mm diameter.

2.1.6 Support frame structure

The machine's supporting structure is a durable frame designed to accommodate the entire assembly, including the screen cylinders, shaft, bearings, pulleys, electric motor, and hopper. The frame was fabricated using 30 × 3 mm L-angles and 25 × 2 mm square pipes, with overall dimensions of 2400 × 900 × 1000 mm (L × W × H). To ensure stability and balance during operation, additional weight was incorporated into the frame, enhancing its overall performance and reliability.

2.1.7 Hopper (Feeder)

The angle of repose for vermicompost material was recorded as 34° (Amin *et al.*, 2022) [31], and this value was referenced in the absence of specific data for BSFL material. To overcome the angle of repose, a G.I. sheet was installed at a 45° inclination on the inner screening cylinder. This configuration was designed to ensure smooth and efficient feeding of material into the system. Additionally, the height of the feed hopper was set at 402 mm from support frame to facilitate proper and effortless feeding of the material into the machine.

2.1.8 Collection Unit

The collection unit is constructed using a G.I. (galvanized iron) sheet with a thickness of 1 mm. The unit is designed as a box with dimensions of 820 × 320 × 500 mm (L × B × H). It is positioned at the sloped end of the machine, where the separated waste exits from both cylinders. The collected waste can be utilized as compost. Meanwhile, the larvae, which pass through the screen during the separation process, are directly collected on the ground beneath the machine. This design ensures efficient segregation and collection of both compost and larvae.

2.2 Performance Evaluation of Machine

2.2.1 Throughput capacity

Throughput Capacity is capability of screening machine to handle the input material and throwing it out as oversize or under-size material without holding it inside the machine. (Gatade, 2023) [11]

Equation for it as given below

$$Q_t = \frac{W_4}{t} \quad \dots (3.6)$$

Where,

Q_t = Throughput capacity, kg/h;

W_4 = Total weight of waste (kg); and

t = Duration of screening operation (h).

2.1.2 Output Capacity

Output capacity of the machine can be calculated by taking ratio of Weight of waste passed through screen to the screen recorded productive time of screening. (Includes time for loading, Unloading, Repair and maintenance) (Anyanwu *et al.*, 2021) [4]

Equation for it as given below,

$$Q_D = \frac{W_5}{T_p} \quad \dots (3.7)$$

Where,

Q_D = Design output capacity, kg/h;

W_5 = Weight of larvae separated through screen, Kg; and

T_p = Productive time of operation (time excluding the time required for loading, unloading, cleaning, repair, maintenance etc.) (h)

2.1.3 Screening Efficiency

Screening efficiency of the machine can be calculated by ratio of weight of waste passed from screen cylinder to the sum of the waste passed from cylinder and weight of larva separated from screen. (Gatade, 2023) [11]

Screening efficiency is capability of screening machine to get desired fraction of under-size with maximum possible accuracy. equation for it as given below

$$\eta_s = \frac{W_5}{W_6} \quad \dots (3.8)$$

Where,

η_s = Screening efficiency, %;

W_5 = Weight of larvae separated through screen, Kg;

W_6 = Weight of waste passed through screen including larvae, Kg

3. Results and Discussion

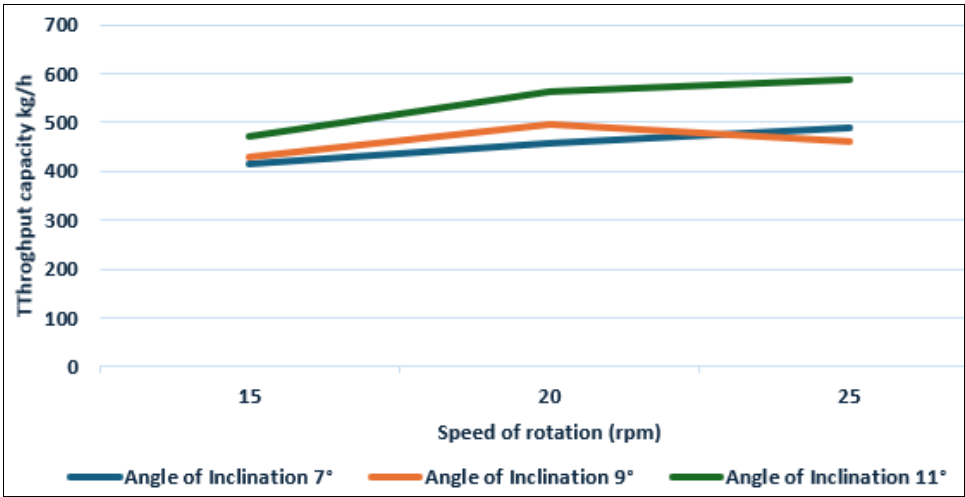
3.1 Effect of Operational Parameter on Performance Evaluation of BSFL Separator Machine

The influence of key operational parameters, including the rotational speed of the screening cylinder and the inclination of the screen cylinder, was systematically evaluated to assess the machine's performance. The experimental design and parameter levels, as outlined in Table 1, served as the basis for this analysis. The stepwise evaluation of the effects of these parameters on throughput capacity, output capacity, and screening efficiency is presented in the following sections.

3.1.1 Effect of Operational Parameters on Throughput Capacity of BSFL Separator Machine

Graph 1 illustrates the relationship between throughput capacity (kg/h), rotational speed (RPM), and inclination angle (7°, 9°, and 11°). At 15 RPM, throughput is lowest across all angles, ranging from 416 kg/h at 7° to 470 kg/h at 11°, reflecting improved material flow at steeper angles. At 20 RPM, capacity increases significantly, with 11° achieving the highest throughput of 563 kg/h due to optimal centrifugal and gravitational force balance. At 25 RPM, throughput rises further, peaking at 588 kg/h for 11°, though the improvement rate diminishes, likely due to excessive centrifugal forces disrupting

material retention. Overall, the highest throughput occurs at 25 RPM and 11°, emphasizing the need to optimize both speed and angle for efficient screening systems. These findings highlight that 25 RPM and 11° provide the best performance conditions, offering practical guidance for enhancing screening efficiency.



Graph 1: Effect of speed of rotation and inclination angle of the screening cylinder on the throughput capacity

Table 2: ANOVA for the effect of operational parameters on Throughput Capacity

Source	df	Sum of Square	Mean Square	F- Cal	Result
Replication	2	0.85	0.42	0.00	NS
Speed of Cylinders (A)	2	4531.67	2265.84	0.69	NS
Angle of Inclination(B)	2	46174.70	23087.35	7.07	S**
AB	4	52276.68	13069.17	4.00	S**
Error	16	52276.68	3267.29		
Total	26	102988.1			

S*- Significant effect at 1% of level, S**- Significant effect at 5% of level, NS - Non- significant effect

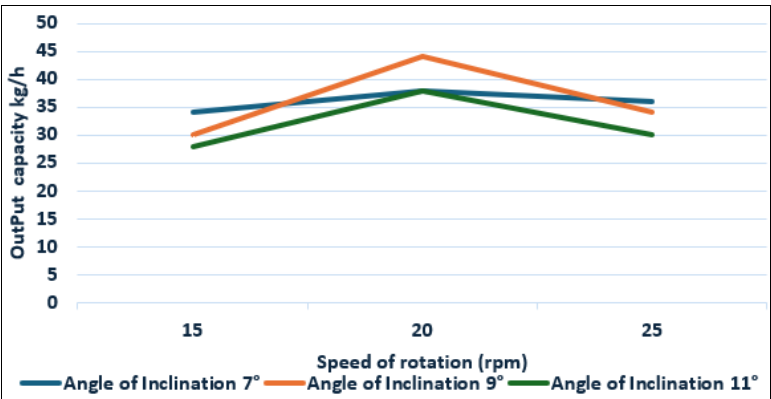
The two-way ANOVA results in Table 4.2 confirm experimental consistency, as Replication shows no significant variability (SS = 0.85, F = 0.00). The Speed of Cylinders (SS = 4531.67, F = 0.69) has no significant effect. In contrast, the Angle of Inclination (SS = 46174.70, F = 7.07) demonstrates a highly significant impact. The interaction between Speed of Cylinders and Angle of Inclination (SS = 52276.68, F = 4.00) is also significant, emphasizing the combined influence of these factors. The total

variance was 102,988.1, with an error MS of 3267.29. These results highlight that the Angle of Inclination and its interaction with Speed of Cylinders are critical determinants of the response, while Speed alone is not significant. Graph 2 illustrates the relationship between output capacity (kg/h) in larvae separation and the operational parameters of rotational speed and inclination angle (7°, 9°, and 11°). At 15 RPM, output capacity is low for all angles, with 7° yielding the highest (34 kg/h) and 11° the lowest (28 kg/h), reflecting reduced efficiency due to limited material movement and shorter retention times at steeper angles. At 20 RPM, output capacity peaks at 44 kg/h for a 9° angle, demonstrating optimal force balance for efficient larvae separation. However, at 25 RPM, output capacity declines across all angles, with 7° achieving 36 kg/h and 11° the lowest at 30 kg/h, due to excessive centrifugal forces reducing contact time with the screening surface. The results show that the optimal separation efficiency is achieved at 20 RPM and a 9° inclination angle, emphasizing the importance of balancing rotational speed and angle to maximize larvae separation.

Table 1: Effect of operational parameters on performance of the Black Soldier Fly Larvae separating Machine

Sr. No.	Speed of rotation, RPM	Angle of inclination, (°)	Throughput capacity(kg/h)	Output capacity (kg/h)		Screening Efficiency (%)
				Larvae	Compost	
1	15	7	416	34	190	82.9
2	15	9	428	30	140	71.4
3	15	11	470	28	120	60.5
4	20	7	457	38	160	84.4
5	20	9	495	44	120	89.7
6	20	11	563	38	100	68.5
7	25	7	490	36	110	73.4
8	25	9	462	34	120	71.7
9	25	11	588	30	165	57.9

3.1.2 Effect of Operational Parameters on Output Capacity of BSFL Separator Machine



Graph 2: Effect of speed of rotation and inclination angle of the screening cylinder on the output capacity

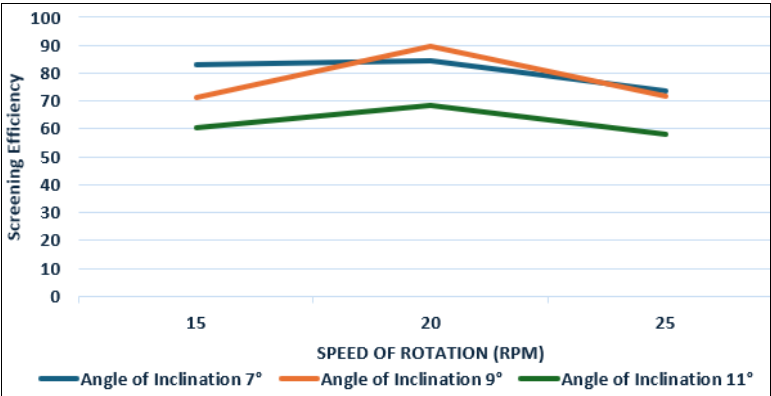
These findings provide practical guidance for optimizing screening systems. The two-way ANOVA results (Table 4.3) confirm experimental consistency, with Replication showing negligible variability (SS = 0.17, F = 0.00). The Speed of Cylinders (SS = 387.86, MS = 193.93, F = 4.74) had a highly significant effect, whereas the Angle of Inclination (SS = 263.01, MS = 131.50, F = 3.22) was not significant, indicating its lesser individual impact. The interaction between Speed and Angle (SS = 654.29, MS = 163.57, F = 4.00) was significant, highlighting their combined influence. These findings demonstrate that the Speed of Cylinders and its interaction with Angle are key factors, while the Angle alone has a minimal effect on the response.

Table 3: ANOVA for the effect of operational parameters on Output Capacity

Source	df	Sum of Square	Mean Square	F- Cal	Result
Replication	2	0.17	0.08	0.00	NS
Speed of Cylinders (A)	2	387.86	193.93	4.74	S**
Angle of Inclination(B)	2	263.01	131.50	3.22	NS
AB	4	654.29	163.57	4.00	S**
Errorr	16	654.29	40.89		
Total	26	1306.7			

S*- Significant effect at 1% of level, S**- Significant effect at 5% of level, NS - Non- significant effect

3.1.3 Effect of Operational Parameters on Screening Efficiency of BSFL Separator Machine



Graph 3: Effect of speed of rotation and inclination angle of the screening cylinder

Graph 3 illustrates the combined impact of rotational speed (15, 20, and 25 RPM) and inclination angle (7°, 9°, and 11°) on screening efficiency during system evaluation. Screening efficiency is influenced by both parameters, with the highest efficiency (89.7%) observed at 20 RPM and a 9° angle. At 15 RPM, efficiency is highest at 7° and declines with steeper angles due to reduced retention time. Similarly, at 25 RPM, efficiency decreases across all angles as excessive centrifugal

force accelerates material flow, reducing interaction with the screen. The 7° angle generally yields higher efficiency across speeds but still declines with increasing rotation. The optimal configuration of 20 RPM and 9° achieves a balance between material movement and retention, ensuring effective separation. These results highlight the importance of optimizing speed and angle for maximizing separation accuracy in screening systems.

Table 4: ANOVA for the effect of operational parameters on Screening Efficiency

Source	df	Sum of Square	Mean Square	F- Cal	Result
Replication	2	0.17	0.08	0.00	NS
Speed of Cylinders (A)	2	387.86	193.93	4.74	S**
Angle of Inclination(B)	2	263.01	131.50	3.22	NS
AB	4	654.29	163.57	4.00	S**
Errorr	16	654.29	40.89		
Total	26	1306.7			

S*- Significant effect at 1% of level, S**- Significant effect at 5% of level, NS - Non- significant effect

The two-way ANOVA results (Table 4.4) reveal that Replication (SS = 0.17, F = 0.00) was not significant, confirming experimental consistency. The Speed of Cylinders (SS = 387.86, MS = 193.93, F = 4.74) had a significant effect, highlighting its critical influence on the response. In contrast, the Angle of Inclination (SS = 263.01, MS = 131.50, F = 3.22) was not significant, suggesting its limited individual impact.

The interaction between Speed and Angle (SS = 654.29, MS = 163.57, F = 4.00) was significant, emphasizing the importance of their combined effects. These findings indicate that the Speed of Cylinders and its interaction with Angle are key contributors to the response, while the Angle alone has minimal influence.

3.2 Optimization of Operating Parameters of BSF Larvae Separating Machine

The experiment evaluated the effects of rotational speed (15, 20, 25 RPM) and cylinder inclination angle (7°, 9°, 11°) on throughput capacity, output capacity, and screening efficiency of a BSFL separating machine.

At 15 RPM, throughput increased with angle, peaking at 470 kg/h at 11°, while screening efficiency declined from 82.9% at 7° to 60.5% at 11° due to limited material dispersion. At 20

RPM, throughput reached 563 kg/h at 11°, and screening efficiency peaked at 89.7% at 9°, indicating optimal operation. At 25 RPM, the highest throughput was 588 kg/h at 11°, but screening efficiency dropped to 57.9% at the same angle due to reduced retention time and excessive centrifugal force.

Inclination angles showed varying effects: 7° provided lower throughput and moderate efficiency, 9° balanced throughput (495 kg/h) and maximum screening efficiency (89.7%), while 11° achieved the highest throughput but diminished efficiency. The optimal configuration was identified as 20 RPM and 9°, delivering 495 kg/h throughput, 44 kg/h output capacity, and a peak efficiency of 89.7%. These parameters ensure effective separation, energy efficiency, and minimal operational challenges, providing the best performance for BSFL separation.

3.3 Validation of Developed BSFL Separator Machine Performed at Optimized Parameters

The BSFL separator was validated using optimized parameters: a 9° inclination angle and a 20 RPM rotational speed. Trials were conducted with waste material (40–45% moisture content), assisted by two labours, and replicated three times.

Table 5: Performance of Developed BSFL Separator Machine at Optimized Parameters

Sr. No.	Parameters	Test-1	Test-2	Test-3	Average
1	Duration of Operation, Sec	1800	1800	1800	1800
2	Time required for filling the collection trough (sec.)	1200	1200	1200	1200
3	Time required for unloading the collection trough (sec.)	135	140	130	135
4	Weight of waste material passed through the screen (W_4) (kg)	510	515	505	510
5	Weight of waste material received at outlet (W_5) (kg)	405	397	381	394.3
6	Weight of larvae received from waste (W_6) (kg)	48	48	47	47.66
7	Weight of compost received from waste (W_7) (kg)	57	70	77	66.66
8	Throughput capacity (t/h)	1.02	1.03	1.01	1.02
9	Output capacity (t/h)	96	96	94	95.3
10	Screening efficiency (%)	94.11	93.20	93	93.43

The average results were 1.02 t/h throughput capacity, 95.3 kg/h output capacity, and 93.43% screening efficiency. The waste material passed through the screen averaged 510 kg, with 47.66 kg of larvae and 394.3 kg of material collected at the outlet, reflecting high separation efficiency.

Each trial lasted 1800 seconds, including 1200 seconds for filling and 1013.33 seconds for unloading, demonstrating consistent processing times. The optimized design ensured efficient feeding, screening, and collection, enabling continuous operation with minimal interruptions. These findings confirm the effectiveness of the optimized parameters in achieving high throughput, output capacity, and screening efficiency.

4. Conclusion

The performance evaluation of the BSFL separator machine led to the following conclusions:

- Optimal operational parameters were identified as a rotational speed of 20 RPM and an inclination angle of 9°.
- At these settings, the machine achieved a throughput capacity of 1.02 t/h, an output capacity of 95.3 kg/h, and a screening efficiency of 93.43 %.
- Operating costs were calculated at ₹130/hour and ₹160/ton, confirming its cost-effectiveness.
- The machine effectively separated waste and larvae with waste moisture content of 40–45%, reducing manual labour requirements.
- Waste was efficiently directed to the collection unit for easy handling.

- The absence of a dedicated larvae collection unit led to minor larvae escape, suggesting a scope for design improvement.
- The machine supports continuous operation with reliable performance and is currently in use at a waste processing plant, offering an efficient and scalable solution for mechanical waste screening and larvae separation.

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