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Mechatronic Interventions and Comparative Assessment Between Manual and Automated Chilli Seed Extraction Process

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Abstract

The problem of seed extraction from chilli pods was addressed through a focused study on ergonomic evaluation, automation, and economic assessment of chilli seed extractor. The methodology assessed the impact of variety (03), subjects (03), and amplitude (03) on machine parameters (Extraction efficiency, Separation efficiency, Mechanical damage percentage, Torque), ergonomic parameters (Heart rate, Oxygen consumption rate, Energy expenditure, Blood pressure), and environmental parameters (Noise, PWFS). The probability of occurrence of white finger syndrome (PWFS) in manual chilli seed extractor was observed as 54 years. In order to avoid that, the mechatronics intervention of infra-red sensor, Arduino, DC motor, solar panel, battery was provided to the chilli seed extraction. The results revealed an improvement of 17.13% in extraction efficiency, 2.40% separation efficiency, and increase of 16.0% in mechanical seed damage percentage in comparison to manual chilli seed extractor. The noise measurement in automated chilli seed extractor at 4 ft (1.21 m) distance highlighted a reduction in 13.97%, 2.35%, 8.98%, and 5.74% from front, back, right, and left side. The difference of Rs. 8.02 per hour in operating cost, 1211.8 kg breakeven point, 0.04 benefit-cost ratio, 384 hours payback period, and Rs. 0.5 per kg in unit cost of extraction was recorded with automated chilli seed extractor. The automated chilli seed extractor can be useful for a reduction in drudgery, protection of the operator's health, and improvement in productivity.

Categories: Renewable Energy in Agriculture, Innovation and Technology Management, Embedded Systems and IoT
Keywords: automation, chilli, efficiency, ergonomic, heart rate, sensor

Introduction

Chilli cultivation with multiple nutritional benefits and health rewards [1] is showing tremendous potential for growers, industrialists, and community gardeners [2] prompting a quarter of world's population to consume it on daily basis [3]. Production wise, Asia produces more than 65% of the global share [4] with India accounting 1492.10 ('000) metric tonnes over an area of 774.9 ha ('000) followed by the neighboring nations of China, Thailand, and Pakistan in successive order [5].In Union territory of Jammu and Kashmir, chilli production for 2024 was reported as 558 MT, an increase from 346 MT in 2018 [6]. At a global level, chilli contributes about 17% of the spice trade [7]. The chilli fruit is composed of upper pod and seeds, with later accounting for 20-25% and responsible for survivability of genome and sustainable crop production. Indian vegetable seed industry is known for quality seeds with high vigor, germination, and productivity. The expansion of chilli cultivation area, shifting of agro-climatic conditions, and involvement of farm mechanization has increased the scope for the advancement of chilli seed industry in India. The vegetable seed industry positively influences the Indian economy in terms of revenue, service group, and foreign exchange in the international market. The chilli can ensure economic prosperity, augmentation of family income, and social mobility of small growers [8]. Very often, the extraction of the seed from the chilli pod is carried out manually through hand picking, sun drying, beating, and winnowing. The operation is categorized as "occupational health hazard" as it causes sneezing and body irritation, thereby endangering the health of the labors [9]. Moreover, the manual methods are infested with high time consumption, labor requirement, and low reliability. The seeds obtained have low viability, quality, and germination potential. In fact, the extraction of the seeds and statutory laws are serving as roadblock for the expansion of chilli seed industry [10]. The imported seed extractors are inadequate to fulfil the requirements of chilli varieties endemic to the region of Jammu and Kashmir and India. Most of the equipment's are bulky, costly, and directed to fulfil the requirement of large farmers only. Among them, the manual seed extractors have an inherent prejudice toward the physical dimensions of local chilli varieties and operators/laborers engaged with chilli seed extraction. Also, the majority of the farmers of the union territory of J&K are small and marginal with non-availability of appropriate power sources like tractor, power tiller, or electric motor [11]. Mohiuddin et al. [1] made an attempt and developed a low-cost chilli seed extractor with feeding hopper, cutting rollers, reciprocating

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trays, and tyres. The machine showed improved performance with extraction efficiency, separation efficiency, and mechanical seed damage percentage. However, the machine needs to be operated manually and generates noise during its operation. Khobragade et al. [12] also developed a seed extractor for red chilli. The global trend of reduction in agricultural workforce and emergence of renewable energy sources can serve as panacea for chilli seed extraction and protection of health of operators/laborers. The involvement of mechatronics, sensors [13], and automation technologies [14] can help to improve the performance of the existing machinery and safeguard the health of the operators/laborers [15]. The primary objective of the study was to explore the anomalies in the manual chilli seed extractor that serves as the roadblock for the operator and adversely influence its performance and efficiency. It also focused on the impact of automation technologies in reducing the drudgery and improving the performance parameters of chilli seed extraction process.

Materials And Methods

This section follows a chronological order from procurement of chilli, selection of subjects, integration of sensors, and comparative evaluation between manual and automated chilli seed extraction process.

Procurement of chilli varieties

Three local chilli varieties (Shalimar 1, Shalimar 2, and Shalimar 3) were procured from open market and tri-axial dimensions of each variety were measured with the help of digital Vernier Caliper, Table *1*.

Variety	Length	Width	Thickness	Eccentricity index	Sphericity
Shalimar 1	3.88	3.13	0.53	1.23	0.47
	3.95	3.06	0.52	1.30	0.44
	3.74	2.94	0.61	1.27	0.50
	3.82	2.91	0.76	1.32	0.51
	3.44	2.67	0.73	1.28	0.50
Mean	3.76	2.94	0.63	1.27	0.48
Shalimar 2	3.55	2.71	0.77	1.30	0.51
	3.42	2.46	0.74	1.40	0.45
	3.37	2.18	0.60	1.54	0.43
	3.53	2.83	0.70	1.25	0.50
	3.41	2.56	0.67	1.33	0.45
Mean	3.45	2.54	0.69	1.35	0.46
Shalimar 3	4.09	3.29	0.80	1.24	0.89
	3.95	3.42	0.85	1.15	0.85
	3.93	3.13	0.81	1.25	0.82
	4.01	3.13	0.75	1.30	0.76
	3.75	3.18	0.74	1.18	0.78
Mean	3.950	2.59	1.0	1.52	1.0

*Each value represents an average of five values

TABLE 1: Physical characteristics of chilli varieties used for ergonomic evaluation

Selection of subjects

Three subjects (A, B, and C) of different age groups were selected on the basis of physical condition, experience, and availability for ergonomic evaluation of chilli seed extractor, Table *2*. The manual chilli seed extractor was evaluated in terms of ergonomic, machine, and environmental parameters, Table *3*.

Parameter	A	B	C
Sex	Male	Male	Male
Age, years	21	25	44
Stature, mm	1706.88	1828.8	1645.92
Eye height, mm	1584.96	1766.64	1252.72
Acromion to Dactylion, mm	731.52	854.64	762
Elbow height, mm	426.72	518.16	1097.28
Shoulder width, mm	457.2	457.2	426.72
Hand length, mm	177.8	203.2	177.8
Hand width, mm	88.9	101.6	88.9
Grip diameter, mm	127	129.54	127
Palm length, mm	91.44	114.3	101.6
Shoulder height, mm	1371.6	1524	1371.6
Arm length, mm	426.72	548.64	457.2
Weight, kg	65	78	59.5

TABLE 2: Physical attributes of the subjects selected for the study

Type	Parameter	Level	Response
Ergonomic Evaluation of manual Chilli seed extractor	Chilli variety	3 (Shalimar 1, Shalimar 2, and Shalimar 3)	Ergonomic parameters; Heart rate monitor: Blood pressure; Oxygen consumption rate: Energy expenditure; Machine parameters; Extraction efficiency: Separation efficiency: Mechanical damage percentage: Torque; Environmental parameters: Noise PWFS
	Subject	3 (A, B and C)	
	Amplitude	3 (4, 8, and 10 cm)	
Evaluation of Automated Chilli seed extractor	Variety	3 (Shalimar 1, Shalimar 2, and Shalimar 3)	Machine parameters; Extraction efficiency: Separation efficiency: Mechanical damage percentage: Environmental parameters: Noise
	Amplitude	3 (4, 8 and 10 cm)	
Cost assessment	-	Operating cost, Rs. h^{-1}; Breakeven point, kg; Benefit cost ratio; Payback period, years; Unit cost of seed extraction, Rs. kg^{-1}	Comparative evaluation between manual and automated chilli seed extractor

TABLE 3: Plan of experiment for ergonomic evaluation of chilli seed extractor

Chilli seed extractor

The chilli seed extractor composes of feeding hopper, cutting section, oscillating screen, handle, collection tray, and tyres, Figure *1*. The feeding hopper was trapezoidal in shape to provide an easy access to the chilli pods toward the cutting section. The cutting section contains two rollers with corrugated blades mounted on their periphery and a gear setup at the end of the rollers for opposite motion. The opposite motion of the blades generates centrifugal force and impact action that results in the cutting of the chilli pods. The blades were arranged in such a manner so as to ensure at least four cuts in chilli pods for the separation of seeds. The chilli pods then pass through the oscillating screen operated by the handle. The oscillation of the screen allows the seeds to pass through the sieve and chilli pods to get collected in the collection tray. The chilli seed extractor was light in weight and portable with the help of four tyres.

A laser beam infrared sensor (3-5 V, 2-10 cm range, and 35 degree detection angle) was attached at the feeding hopper in order to provide the signals to the motor. The system was programmed in such a manner that the motor starts working only at the time of feeding of chilli through the feeding hopper. The motor is connected with an Arduino and relay assembly powered by a 75 W solar panel and a 12-volt battery system, Figure *2*. A DC motor with a chain and sprocket system was attached to the power cutting system of the chilli seed hopper. The cut chilli passes through the reciprocating screen, allowing the seeds to pass through the sieve and pods to fall in the collection tray.

Instrumentation in manual chilli seed extractor

A series of sensors and instruments were used on the operator and chilli seed extractor, Figure *1*. A digital heart rate (HR) monitor (Polar RS 400) with a strip attached to the operator served as the basis of HR measurement. The readings were recorded at the start of the experiment and after the experiment for comparative evaluation. Similarly, a digital blood pressure apparatus (HEM-75156-A) was used to assess the variation in the blood pressure of the operation during chilli seed extractor operation. The readings were recorded after every 10-minute interval in both the HR monitor and blood pressure apparatus.

FIGURE 1: Instrumentation and automation in chilli seed extractor

A torque sensor of 1000 Nm capacity was also attached on the handle to assess the variation in torque consumption pattern. The noise level of the chilli seed extractor was recorded with noise meter (Larson Davis Model LxT 831). The noise was measured at different distances to assess the impact on the operator and bystanders. The vibration was measured using an accelerometer (SEN041F model). The sensor of the accelerometer was attached to the handle of the chilli seed extractor. The Larson Davis human vibration meter (HVM 200) and G4 LD utility software were used for the investigation of data.

The oxygen consumption rate and energy expenditure of the operator of the manual chilli seed extractor were obtained from HR. Oxygen serves as the basic ingredient for the oxidation of food and generation of energy in the human body. It was measured indirectly to assess the amount of oxygen consumed by the operator during the chilli seed operation.

Oxygen Consumption Rate, $lmin^{-1} = 0.114 \times HR - 0.68 - - - - (1)$

Energy Expenditure, $kJmin^{-1} = 0.159 \times HR - 8.72 - - - (2)$

Where:

HR is the heart rate

Measurement of performance parameters

The parameters representing the performance of machine were measured with standard procedures. The extraction efficiency defined the percentage of seeds extracted from the chilli pods [1]. Some of the seeds not detached from the chilli pods were extracted manually. The seeds were also separated by oscillating screen, represented by separation efficiency. The seeds collected in the collecting tray were checked for damage, disease, and cracking through manual inspection. The damage of the seed beyond 50% was considered as damaged and unsuitable for seed germination.

Extraction Efficiency =
$$\frac{WeightOfSeedsOnCollectingTray}{WeightofSeedsOnCollectingTray + WeightOfSeedsExtractedManuallyFromChilliPods} ---- (3)$$

Separation Efficiency = $$1 - \frac{MassofFleshInSeedSample}{MassOfSeedSample} ---- (4)$$

Automation of chilli seed extractor

Afterwards, the chilli seed extractor was automated with the help of Arduino, infrared sensor, and solar panel system through Integrated development environment (IDE), Figure *2*. The ergonomic, machine, and environmental parameters were again measured in automated chilli seed extractor for comparative evaluation.

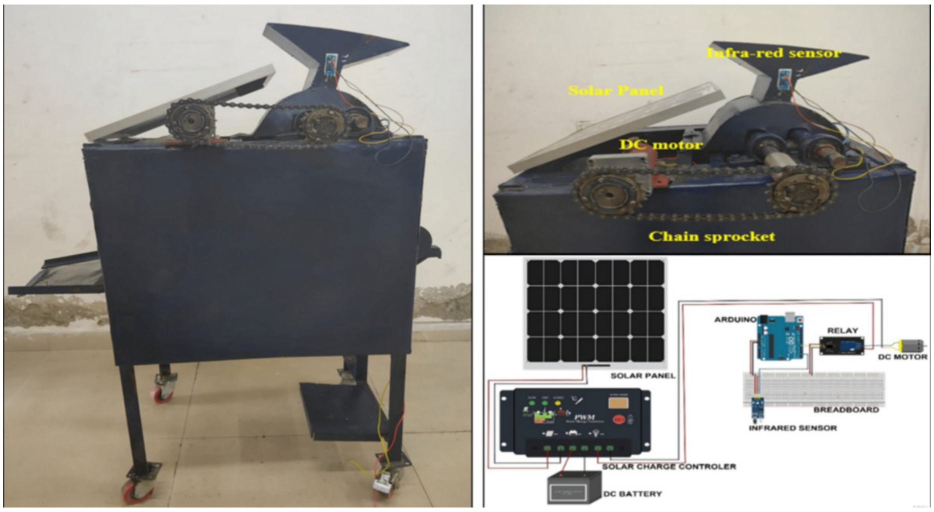

FIGURE 2: Arduino-based infrared sensor module for automation of chilli seed extractor

Cost assessment

The viability of the technology and commercial potential was judged through operating cost, benefit-cost ratio, break-even point, and payback period. The economic parameters of automated chilli seed extractors were measured for comparative evaluation with manual chilli seed extractor.

Results

Variation in machine parameters in chilli seed extractor (manual and automated)

The results revealed that 10 cm amplitude of oscillating screen provided more acceleration to the chilli pods and seeds and increases their ability to get segregated. Consequently, the highest extraction efficiency of 59.17% was observed with subject C for Shalimar 1 and 56.3% with subject B for Shalimar 3 at 10 cm amplitude of oscillating screen, Figure *3*. This may be attributed to the similar length of the chilli pods in Shalimar 1 (3.76 mm) and Shalimar 2 (3.95 mm), Table *1*. Mohiuddin et al. [1] also observed that the extraction efficiency increased with an increase in amplitude of oscillating screens. A separation efficiency of 86.91% was observed with subject C at 4 cm amplitude for Shalimar 2. The eccentricity index of 1.35 and sphericity 0.46 might have created a cumulative effect and allowed the seeds to pass through the oscillating screen. The mechanical seed damage varied from 0.51% with subject B at 8 cm amplitude to 1.12 % with subject C at 10 cm amplitude of oscillating screen for Shalimar 2 variety. It was observed that the thicker upper layer of Shalimar 2 created an obstruction for the seeds to flow easily.

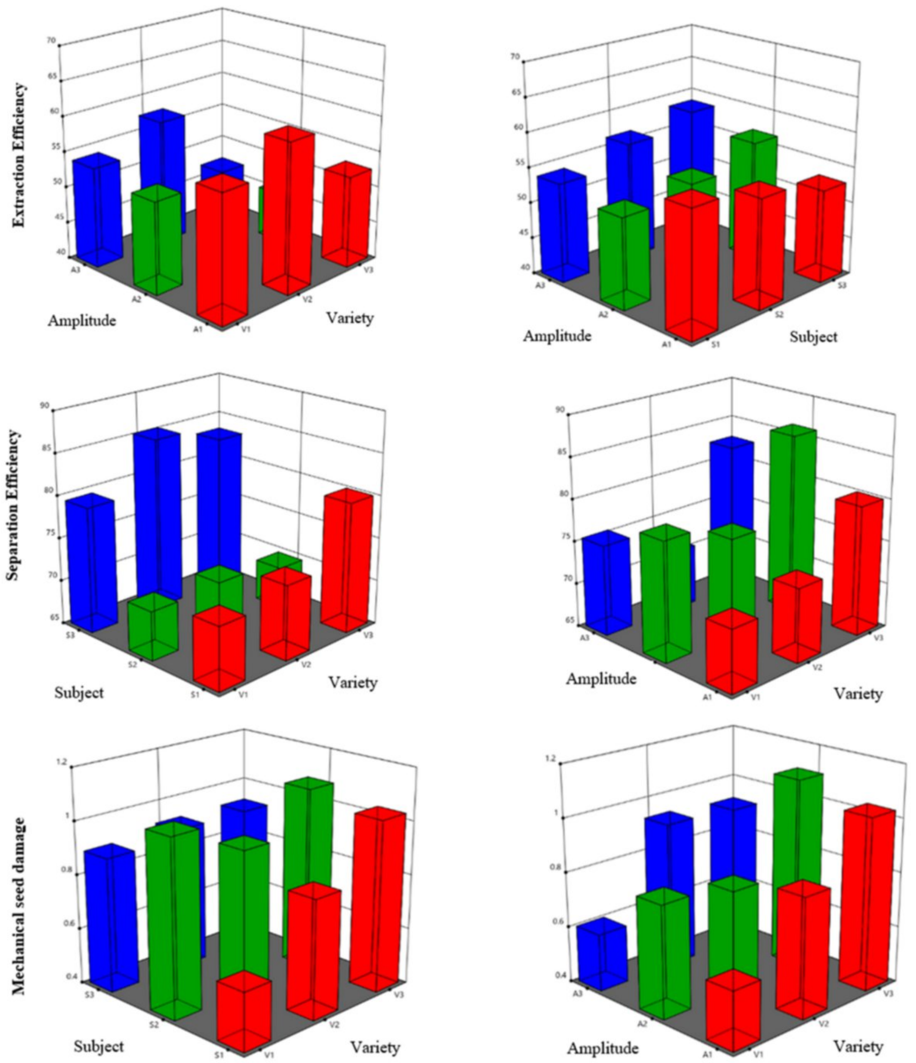

FIGURE 3: Variation in extraction efficiency, separation efficiency, and mechanical seed damage percentage in manual and automated chilli seed extractor

In automated chilli seed extractor, an extraction efficiency of 73% at 10 cm amplitude with Shalimar 1 was recorded, Figure 3. Similarly, the extraction efficiency for Shalimar 2 and Shalimar 3 was recorded as 72% at same amplitude of oscillating screen. This highlights an increase in 17.13% in extraction efficiency between manual and automated chilli seed extractor. In the same manner, the maximum separation efficiency of 89% was observed for Shalimar 2 variety, an increase of 2.40% from manual chilli seed extractor. The mechanical seed damage of 0.6-1.3% was comparable between manual and automated chilli seed extractor.

Change in ergonomic parameters in manual and automated chilli seed extractor

The rise in the HR can be treated as the indicator of exertion and fatigue of the operator. It was observed the average HR increased with an increase in amplitude of the oscillating screen for all the three varieties of chilli. The HR witnessed an increase of 14.13%, 23.07%, and 6.12% for Shalimar 1, Shalimar 2, and Shalimar 3, Figure 4. In case of blood pressure, an increase of 7.03%/8.53%, 13.22%/5.88%, and 16.23%/12.65% in systolic/diastolic blood pressure for Shalimar 1, Shalimar 2, and Shalimar 3 was recorded. It was observed that Subject A and subject B operated chilli seed extractor without any obstruction. However, the subject C with comparatively higher age faced breathlessness and obstructions during the experimental trials.

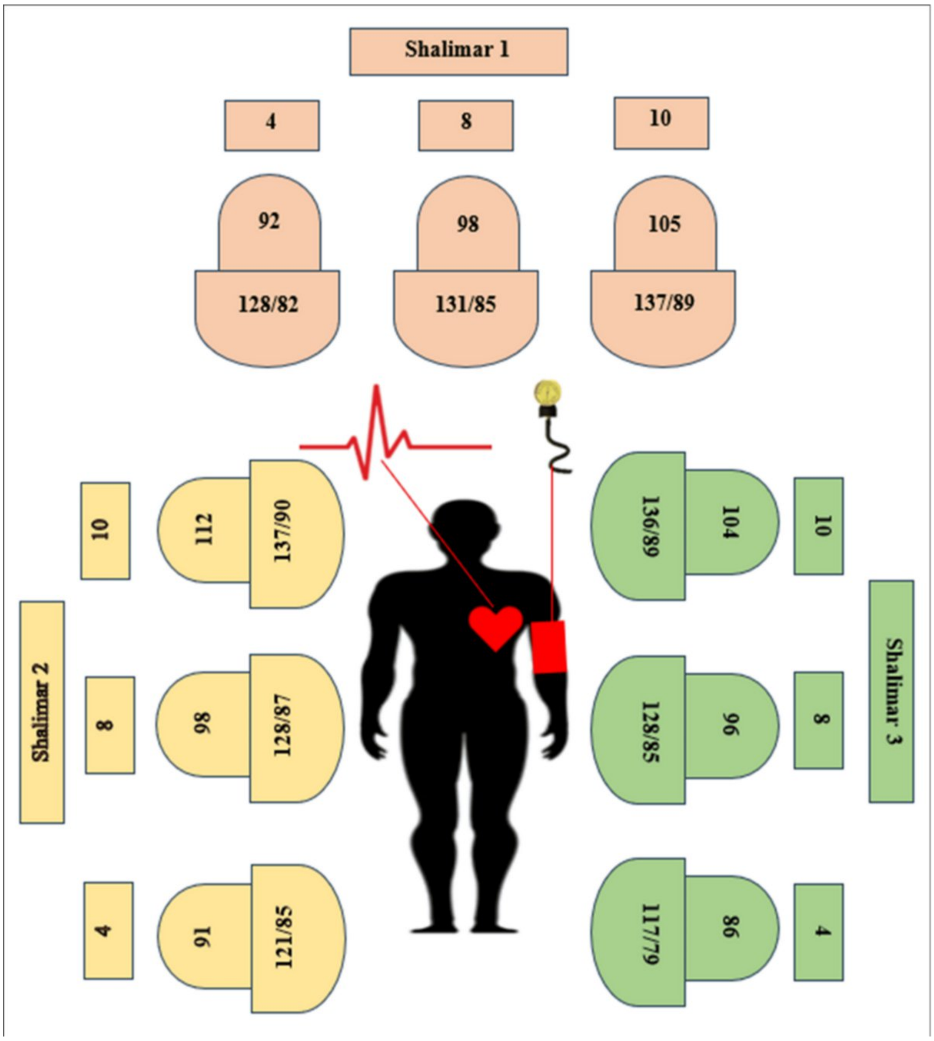

FIGURE 4: Variation in heart rate and blood pressure during operation

The oxygen consumption and energy expenditure are inter-related to highlight the drudgery and fatigue of the operator. The highest oxygen consumption of 0.37 lpm was observed with subject A at 4 cm amplitude for Shalimar 1, Figure *5*. At lower amplitude of 4 cm, the chilli pods and seeds were unable to gain momentum to get segregated on oscillating screens. This prompted the operator to exert higher force to turn the screen and separate the chilli pods from seeds. In general, it was observed that higher amplitude causes lower drudgery due to higher surface area and acceleration force, Figure *5*. The oxygen consumption was correlated with energy expenditure. The energy expenditure varied from 1.77 kJ min^{-1} to 6.22 kJ min^{-1} during different treatment combinations. The lower amplitude causes higher energy expenditure in comparison to 8 cm and 10 cm amplitude of the oscillating screen.

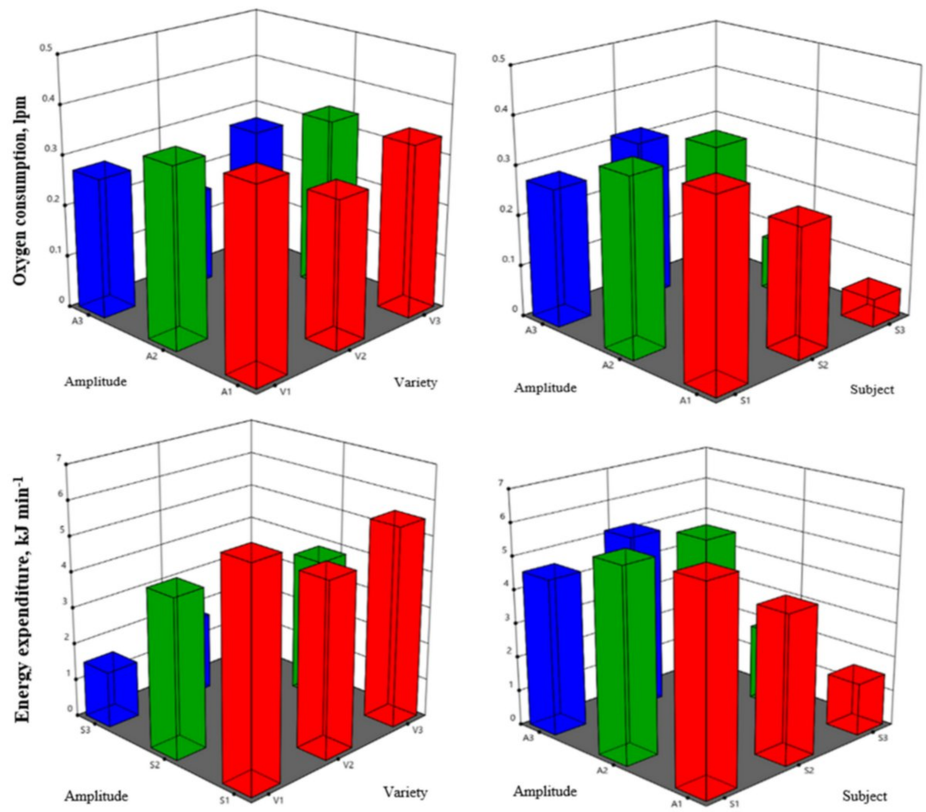

FIGURE 5: Change in oxygen consumption, energy expenditure, and occurrence of PWFS

The torque showed an increasing trend with an increase in amplitude of oscillating screen from 4 cm to 10 cm. The torque consumption increased from 1.2 Nm to 1.7 Nm for all the treatment combinations. However, it was observed that the motion of the cutting section was obstructed due to jamming of chilli pods in the cutting blades. The highest torque consumption of 1.7 Nm was observed with subject B at 8 cm amplitude of operation, Figure 6.

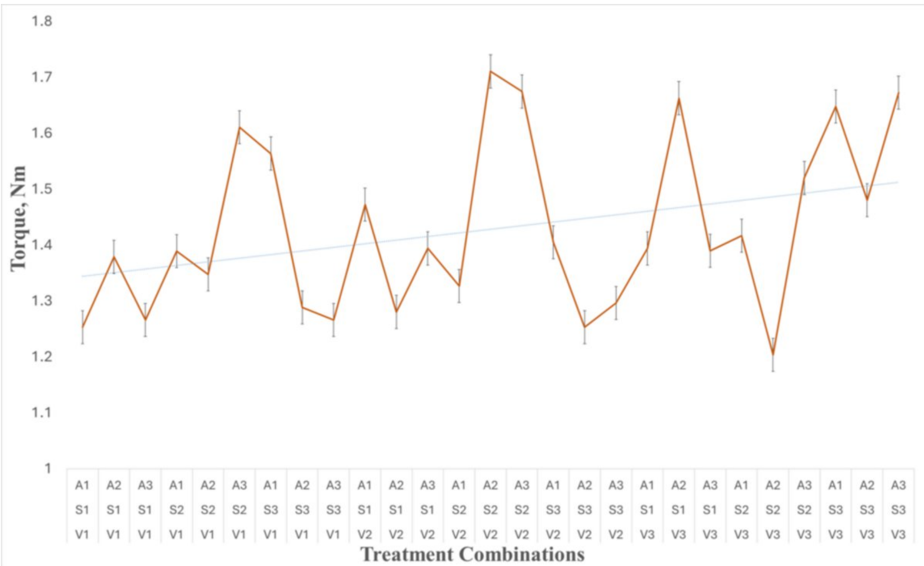

FIGURE 6: Change in torque consumption with treatment combinations

Change in environmental parameters

The noise level of the manual chilli seed extractor was recorded at different positions to understand the variation at operator's position and bystander's position at different heights. It was observed that noise level lowered with an increase in distance from 2 ft. (0.6 m) to 6 ft. (1.82 m) from all sides and increased with the height from 1.5 ft. (0.45 m) to 4.5 ft. (1.37) at a particular position, respectively. A decrease in noise level of 13.13%, 14.58%, 10.86%, and 9.67% from the front, back, right, and left was recorded. At a particular position, a variation of 4.5-6.0% in the noise level was also observed, Figure 7. The probability of white finger syndrome (PWFS) was comparatively lower due to low amplitude vibrations induced through the handle of chilli seed extractor. The data highlighted that a minimum of 54 years is required for the emergence of PWFS in subject B at an 8 cm amplitude for Shalimar 3 variety, Figure 7. This implies that the operator working with the manual chilli seed extractor can face PWFS in the working age. The revelation demands the introduction of interventions to protect the operator and improve productivity.

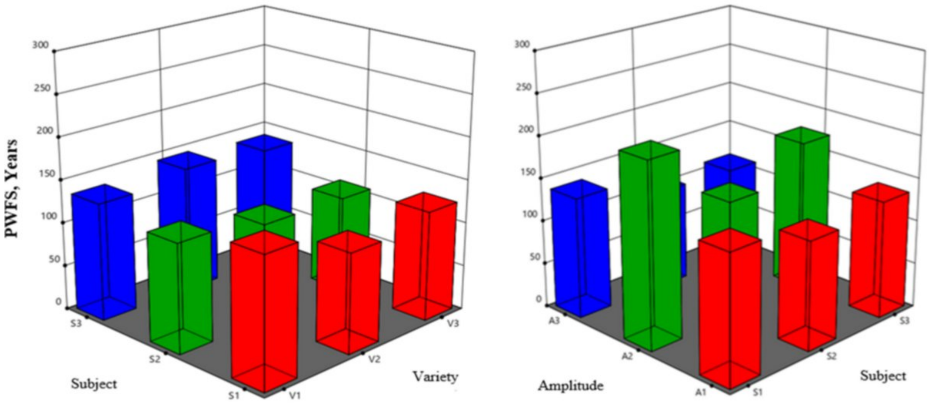

FIGURE 7: Variation in the noise level at different positions and heights and occurrence of PWFS

The noise measurement in automated chilli seed extractor at 4 ft. (1.21 m) distance highlighted a reduction in 13.97%, 2.35%, 8.98%, and 5.74% from the front, back, right, and left side, Figure 8 and Figure 9. The reduction was mainly due to the removal of the handle and the involvement of an infra-red sensor to operate the DC motor of the cutting section at the time of detection of chilli pods in the feeding hopper.

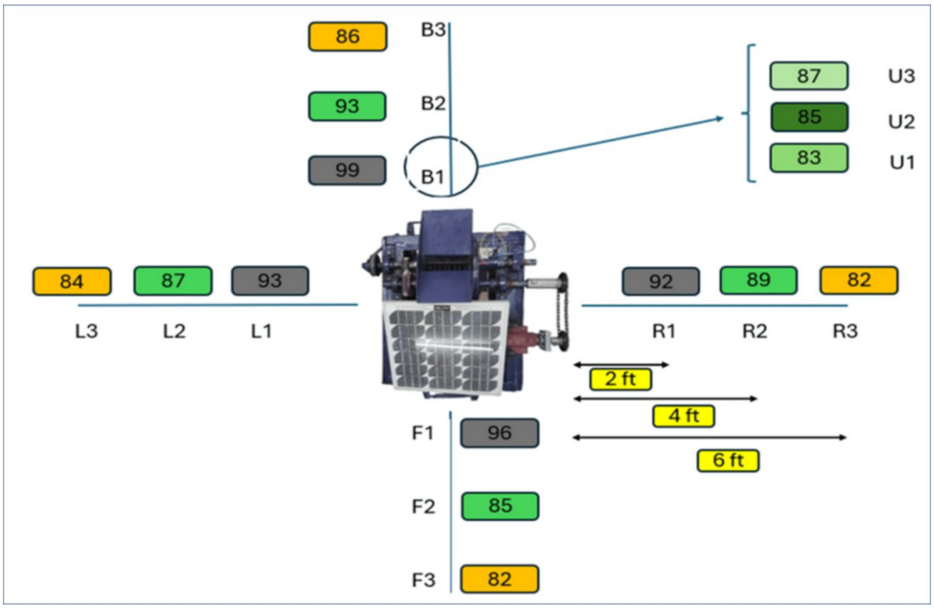

FIGURE 8: Variation in the noise level at different positions and heights

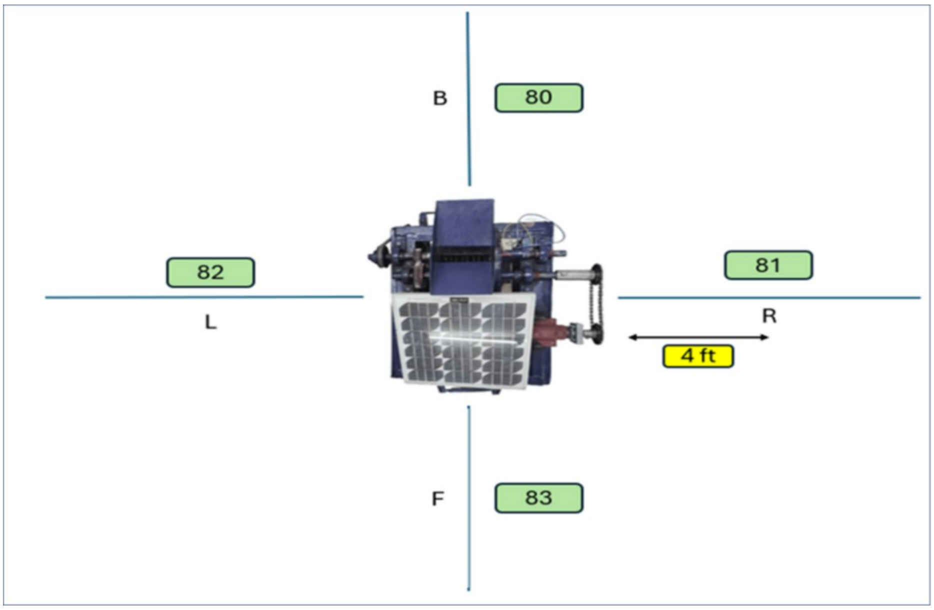

FIGURE 9: Noise measurement in automated chilli seed extractor

Cost assessment

The cost assessment and comparative evaluation between manual and automated chilli seed extractor was carried out in terms of operating cost (Rs. h^{-1}), breakeven point (kg), benefit-cost ratio, payback period (hours), and unit cost of extraction (Rs. kg^{-1}), Table 4. The automation turned the batch type manual chilli seed extractor into continuous type sensor integrated power operated chilli seed extractor with Rs. 97.34 per hour operating cost, 2277.8 kg breakeven point, 1.35 benefit cost ratio, 723 hours payback period, and Rs. 6 per kg unit cost of extraction of seed from chilli pods.

Parameter	Chilli seed extractor		Significance
	Manual	Automated	
Operating cost, Rs. h^{-1}	89.32	97.34	It highlights the fixed and variable cost of operating chilli seed extractor.
Breakeven point, kg	1066.0	2277.8	It is a no-profit, no-loss point i.e. beyond this limit the machine starts giving positive results.
Benefit-cost ratio	1.31	1.35	It is the benefit accrued to the cost invested.
Payback period, hour	339	723	It is the duration in which the invested money will be recovered.
Unit cost of extraction, Rs. kg^{-1}	5.5	6	It highlights the unit cost of extracting seeds from chilli pods.

TABLE 4: Estimation of cost parameters of automated chilli seed extractor

Discussion

The findings clearly demonstrate the effectiveness of automation in improving machine performance and reducing operator fatigue in chilli seed extraction. Higher extraction and separation efficiencies in the automated system align with those reported by Mohiuddin et al., confirming the advantage of consistent mechanical action and optimized screen oscillation. The 17.13% increase in extraction efficiency is significant, considering the minimal increase in mechanical seed damage. Physiologically, operators endured higher HRs, blood pressure, and energy expenditures in manual operation. This validates the assumption that automation reduces human drudgery-especially critical for older operators (e.g., Subject C), who experienced physical strain and breathlessness. Torque readings revealed mechanical stress in the manual cutting section, potentially causing fatigue and increasing the probability of jamming. The sensor-based automated system eliminated these issues, maintaining smoother operation. Noise reduction in the automated model is particularly important for prolonged usage in field conditions, as continuous high noise exposure can contribute to long-term hearing impairment. The potential for PWFS (White Finger Syndrome) further emphasizes the need for vibration-reducing interventions in manual systems. Economically, while automation raises upfront costs, it results in a more productive and ergonomically friendly machine with long-term benefits. The longer payback period is justified by a higher benefit-cost ratio and safer working environment.

Conclusions

The study focused on the performance evaluation of the manual chilli seed extractor involving ergonomic, machine, and environmental parameters with an objective of automating the system to improve the working environment for the operators and improve efficiency. It was observed that HR, blood pressure, oxygen consumption, energy expenditure, noise, and occurrence of PWFS were higher with the manual chilli seed extractor. The PWFS was recorded to appear after 54 years of operation with the manual chilli seed extractor. Accordingly, an infra-red sensor, DC motor, solar panel, battery, relay, and Arduino were integrated to automate the chilli seed extractor. The evaluation of the automated chilli seed extractor revealed an improvement in extraction efficiency (17.13%), separation efficiency (2.40%), and reduction in noise for the operator. Moreover, the difference in unit cost of extraction of seed from chilli pod was observed as Rs. 0.5 per kg. This study highlighted the need to automate agricultural machinery for transforming them into efficient technologies for higher productivity and adoption.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Rizwan Ul Zama Banday, Mohd. Muzamil

Acquisition, analysis, or interpretation of data: Rizwan Ul Zama Banday, Muneeb Manzoor, Amir Ali, Danish Gul, Masrat Mohi Ud Din, Saqib Rashid, Athar Bashir, Mohd. Muzamil

Drafting of the manuscript: Rizwan Ul Zama Banday, Muneeb Manzoor, Amir Ali, Danish Gul, Mohd. Muzamil

Supervision: Rizwan Ul Zama Banday, Danish Gul, Mohd. Muzamil

Critical review of the manuscript for important intellectual content: Masrat Mohi Ud Din, Saqib Rashid, Athar Bashir, Mohd. Muzamil

Disclosures

Human subjects: Consent was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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