**Development and Evaluation of Punching Mechanism for De-seeding of Ber Fruit**

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**ABSTRACT**

Ber (*Ziziphus mauritiana* L.), commonly known as Indian jujube, is an underutilized seasonal fruit rich in nutrients and consumed directly. A punching type mechanism was developed to separate the seed and pulp of ber fruit, based on the analysis of its physical (length, width, thickness measured by vernier caliper) and mechanical properties (cutting and extruding forces measured by texture analyzer). The Pearson correlation coefficient showed that the physical parameters (width, thickness, geometric mean diameter, arithmetic mean diameter) were strongly correlated with the sphericity and surface area of the ber fruits and seeds, whereas length was not significantly correlated. The developed punching type de-seeding mechanism consists of a fruit resting seat, punching rod, guider, crank and lever mechanism, supporting stand, handle, and base. The performance of the developed de-seeder was analyzed, showing fruit pulp wastage from 1.89 % to 8.62 % and efficiency from 91.38 % to 98.11%. The Pearson correlation coefficient indicated that the performance parameters (pulp wastage and efficiency) of de-seeder are negatively correlated. The capacity of the developed de-seeder varies from 15 – 17 kg/ hand 220 – 280 fruits/ h. The developed de-seeder reduces the labour requirement by 67 %. In economic evaluation, the de-seeder has reduced the cost of operation (₹ h-1) by 73% and increase the net benefit (₹ year-1) by 6960 over manual operation. Its high efficiency and less pulp wastage make the machine preferable for progressive farmers.

**Keywords:**Ber Fruit, Ber Fruit Pulp, Ber Fruit Seeds, Punching Mechanism, De-Seeder, Mechanical Properties, Physical Properties, Efficiency

**Highlights of the study**

1. Design and Development of Punching type mechanism for de-seeding of ber fruits
2. Measurement of physical and mechanical properties of ber fruit and seeds.
3. Statistical analysis of performance of ber fruit de-seeder
4. Ergonomic and Economic analysis of ber fruit de-seeder in comparison to manual operation.

**List of Abbreviations/ Nomenclature**

|  |  |
| --- | --- |
| **Sa** | Surface Area |
| **Pw** | Pulp Wastage |
| **Sp** | Sphericity |
| **AMD** | Arthematic Mean Diameter |
| **GMD** | Geometric Mean Diameter |
| **H** | Height |
| **W** | Width |
| **L** | Length |
| **MT** | Million Tones |
| **g** | Grams |
| **₹** | Rupees |
| **h** | hour |
| **mg** | Milli Grams |
| **Mha** | Million Hectares |
| **CAD** | Computer aided design |

1. **Introduction**

Ber (*Ziziphus mauritiana* L.), commonly known as the Indian jujube, Chinese apple, Indian plum, Masau, and Chinese date, belongs to the Rhamnaceae family and is often referred to as the "King of Arid Fruits." While it is considered to have originated in India, ber is widely cultivated in various regions, including China, Africa, Afghanistan, Malaysia, Australia, and Fiji[1] [2][3][4].The commercial cultivation of ber in India is primarily confined to the states of Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, and Andhra Pradesh. Currently, the total area dedicated to ber fruit cultivation is approximately 50,000 hectares, yielding an annual production of around 6.3 million tones[4].

Ber fruit is rich in protein (0.8 ± 0.04 g), ascorbic acid (25.83 ± 1.73 mg), vitamin A (15.22 ± 0.51 µg), and minerals such as calcium (21.64 ± 1.06 mg) and phosphorus (24.72 ± 0.33 mg) per 100 g. The fruit also contains total soluble solids (TSS) at 12.38 ± 0.92%, titratable acidity at 0.39 ± 0.03%, total sugar at 7.0 ± 0.43%, and moisture content at 86.8 ± 1.2% [5]. Additionally, ber fruit is rich in vitamins C, A, and B complex [6][7].

Ber fruit pulp is highly consumable and offers numerous health benefits, including disease-fighting vitamin C, improved blood circulation, reduced stress and anxiety, enhanced bone strength, better cognitive function, increased hair growth, weight control, and improved immunity. People typically consume the pulp and leftover seeds from ber fruits. Ber fruit seeds are rich in medicinal values and are used in pharmaceuticals to manufacture drugs for treating cancer, sleeping disorders, insomnia, gastrointestinal diseases, abdominal pains during pregnancy, and chronic constipation relief[8][9][10][11][12]. Consequently, the fruit’s pulp is often discarded while the seeds are utilized in pharmaceuticals. Additionally, there is significant potential for processing ber fruit pulp into various products such as dried ber, murabba, ber candy, squash, nectar, beverages, and jam. The ripe fruit can be canned in sugar syrup, and dried damaged ber fruits can be used to produce nutritional animal feed[13] [6]. To reduce the wastage of seeds and pulp, a punching mechanism was developed for de-seeding ber fruits based on their physical and mechanical properties. The uses of ber fruits in different products are shown in Fig.1.

Despite its numerous benefits, the ber fruit remains largely underutilized and non-commercialized due to inadequate post-harvest processing technology. This results in significant losses, as much of the harvested fruit accumulates as waste during the peak season when availability is high. Previous researchers found that the idea of separating seeds and pulp from the whole fruit not only facilitates the processing of edible pulp but also creates value for the inedible portions (seeds and peels), presenting a beneficial opportunity for the development of new products like bakery items (cookies, muffins)[14][15]. A major global challenge today is food waste, with approximately one-third of all food produced worldwide being discarded[16] [17]. Specifically, around 40% of fruits and vegetables are wasted due to their highly perishable nature and moisture content [18] [19]. The design and development of post-harvest machinery heavily depend on understanding their physicochemical properties[20]. Therefore, this study focuses on determining the physical attributes of ber fruits and their seeds to develop a machine capable of separating seeds from the whole fruit. This innovation aims to enhance post-harvest value addition for ber fruits while also creating value from the seeds.  By addressing these challenges through improved technology and processing methods, it is possible to significantly reduce waste and increase the economic viability of ber cultivation, ultimately contributing to food security and sustainability efforts.

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| **Fig.1: Application of Ber Fruits in Various Products** |

1. **Materials and methods**

The ber fruits of the Kaithali variety were procured from the local market in Madakasira (13.9408° N, 77.2754° E), Andhra Pradesh, India. These fruits are typically available in two growth stages: mature and ripe, as illustrated in Fig. 2. The physico-chemical properties of the fruits are provided in Table 1. For the present study, only mature ber fruits that were free from damage were selected. The fruit surfaces were cleaned to remove any adhered dirt and sorted to eliminate defects such as surface blemishes.

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| **Fig.2: Stages of Ber Fruit** |

**Table 1. Physico-chemical characteristics of mature and ripen Kaithali Ber fruits**

|  |  |  |
| --- | --- | --- |
| **Constituent** | **Mature** | **Ripen** |
| **Average weight (g)** | 19.0 | 19.0 |
| **Moisture (%)** | 81.70 | 80.40 |
| **Rehydration ratio** | 2.16 | 2.04 |
| **Total sugars (%)** | 9.17 | 10.24 |
| **Reducing sugars (%)** | 5.41 | 6.03 |
| **Non-reducing sugars (%)** | 3.76 | 4.21 |
| **Acidity (%)** | 0.32 | 0.39 |
| **pH** | 5.00 | 4.00 |
| **Ash (%)** | 0.45 | 0.49 |
| **Fat (%)** | 0.170 | 0.159 |
| **Protein (%)** | 0.34 | 0.31 |
| **Bulk density (g/cc)** | 0.922 | 1.052 |
| **True density (g/cc)** | 0.877 | 0.947 |

**Source:** [21][22]

**2.1 Physical Properties of Ber Fruit**

The physical properties of the ber fruits, including length (L), width (W), and thickness (T), were measured using a Vernier caliper with an accuracy of 0.01 mm. Other parameters, such as the Arithmetic Mean Diameter (AMD) and Geometric Mean Diameter (GMD) in millimeters, as well as the surface area (Sp) and projected area (Sa) in square millimeters, were calculated from the measured dimensions (L, W, T) to aid in the design of various components of the ber fruit de-seeder[23][24]. The principal dimensions of both the ber fruits and their seeds were recorded with the Vernier caliper, as illustrated in Fig. 3a and Fig. 3b. Standard equations from) were utilized for these calculations[25].

|  |  |
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|  |  |
| **Fig. 3a) Geometric dimensions 3b) Measurement by vernier caliper** | |

(1)

(2)

(3)

(4)

Where, *Dg:* Geometric mean diameter, *Da*: Arithmetic mean diameter, *Sp:* Sphericity, *A*: Surface Area.

**2.2 Design of Key Parts of Hand Operated Punching type Ber Fruit De-Seeder**

The design of the ber fruit de-seeder is conceptualized as a hand-operated punching type mechanism. The key components of the developed de-seeder include a perforated punching rod, a fruit resting stand, and a handle for operation.

**2.2.1 Handle**

The handle in the machine operates on the principle of a crank and lever mechanism, transmitting the force from the operator’s hand to the punching rod. The cutting force of the ber fruit was measured using a texture analyzer with a 5mm Ø cylindrical probe at a pre-test speed of 0.5mm/s, test speed of 0.5mm/s, post-test speed of 10mm/s, contact time of 8 seconds, penetration depth of 5mm, and return distance of 5mm. The test setup diagram for cutting force measurement is shown in Fig.4a. The force was measured for three ber fruit samples in a longitudinal position, with the results displayed in graph Fig.4b. The highest measured cutting force was 34 kg. The average hand push strength of an individual is 8.8 kg, while the average hand pull strength is 9.3 kg [28].

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| **Fig. 4a: Measurement of cutting force by texture analyzer**  **(1. Moving arm; 2. Probe; 3. Ber fruit; 4. Platform; 5. PC showing graph)** |
|  |
| **Fig. 4b: Graph of measured cutting force of ber fruits** |

**2.2.1.1. Assumptions/considerations for handle**

The measured force required to punch the fruit, as shown in Fig.4b, is 34 kg (F1). Based on assumptions from [26], [29], and [30], the average hand push strength that a person can exert is 8.8 kg (F2), and the average hand pull strength is 9.3 kg (F3). The position of the punching point from the pivoted point is 165 mm (L1). Using the formula for the length of the handle:

Length of Handle = ​​= ​= 637 mm

The total length of the handle in the developed de-seeder is 650 mm considering minor losses. As it is pivoted at one end, the handle can move in a circular pattern. The stroke length is 60 mm. The handle’s vertical movement towards the punching point, calculated using an analogous triangle, is:

650×60=165×N

Solving for (N):

N= ​ = 236 mm

Thus, the movement of the circular pattern arc length of the handle is 236 mm.

**2.2.2 Punching Rod**

The perforated punching rod is designed to penetrate the fruits vertically for seed removal. It is attached to the handle using a screw and nut arrangement, allowing the handle and punching rod to operate like a crank and lever mechanism. The stroke length of the punching rod is 100 mm. The guider has a length of 30 mm, with an extension below the guider of 5 mm. The distance between the punching rod hinge point and the guider is 65 mm. Therefore, the total length of the punching rod is:

**Total Length of the Punching Rod=100 mm+30 mm+5 mm+65 mm=200 mm**

**2.2.3 Fruit Resting Stand with Platform**

The fruit resting stand has a punched hole at the center, surrounded by a depression to hold the fruit parallel to the punching rod for punching. When force is applied by the operator on the handle, the punching rod, attached to the handle by a screw and nut linkage, penetrates the fruit and separates the seeds. The maximum width of the ber fruit is 18 mm, with an allowance of 10 mm from all sides. The maximum width of the ber seed is 4 mm, with an allowance of 1 mm from all sides. The diameter of the hole is based on the maximum seed size, and the diameter of the platform is based on the maximum fruit size, as given in Table 2. The fruit pulp remains on the fruit resting stand, while the seed is collected at the base of the de-seeder. The machine is made of food-grade stainless steel no. 316 with an 18 mm gauge thickness. Stainless steel is resistant to corrosion and low maintenance, making it an ideal material for many applications [26][31][32]. The designed CAD model of the ber fruit de-seeder with key parts is shown in Fig.5.

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| **Fig.5: CAD design of ber fruit de-seeder with key parts** |

**2.3 Performance Parameters of De-Seeder**

The performance of the de-seeder was evaluated by measuring the efficiency of the de-seeder and the percentage of pulp wastage (% Pw). These parameters can be measured using the following equations [26][27].

|  |  |
| --- | --- |
|  | (5) |
|  | (6) |
|  | (7) |

Where, *Wp:* weight of pulp in ber fruit, *Wf* : Total weight of ber fruit, *Ws*: Weight of seed in ber, *Pw:* Pulp wastage in %, ŋ ; Efficiency of De-Seeder.

**2.4 Methodology for economic assessment of developed de-seeder**

The machine’s operating costs were estimated using the test code for calculating agricultural machinery operating costs [33], which takes into account both fixed and variable expenses as shown in Table 7. The following equations estimate the net benefit and payback period:

1. Depreciation (D):

(8)

Where,

P = Capital cost (₹) ; D = Depreciation (₹ h-1 ) ; S = Salvage value, 10 % of capital cost (₹); H = Number of working hours per year and L = Life of machine (years).

2. Interest(I):

(9)

Where,

I = interest per year (₹ year-1); P= Capital cost of machine (₹); S= Salvage value of machine (₹); H=Number of working hours per year, and i = interest rate per year (usually assumed as 10 % of capital cost).

3. Net Benefit (NB):

(10)

Where,

NB = Net Benefit (₹ h-1); OC = Operational cost (₹ h-1); CH = Custom hiring charges (₹ h-1 )

4. Payback Period (PBP):

(11)

Where,

PBP= Payback period (years) ; IC = Initial cost of machine(₹) ; NB = Net Benefit (₹ year-1)

1. **Results and Discussion**

**3.1 Physical Parameters of Ber fruits and Ber fruit Seeds**

The measured physical properties of L, W, T, GMD, AMD, Sp and Sa of 14 ber fruits and their seeds are shown in Table.2 and illustrated in Fig.6a, 6b, 6c and 6d.

**Table.2: Measured physical parameters of ber fruits and seeds**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Ber Fruits physical parameters** | | | | | | | |
| **S. No** | **L** | **W** | **T** | **GMD (mm)** | **AMD (mm)** | **Sp (mm)** | **Sa (mm2)** |
| 1 | 49.51 | 9.83 | 8.96 | 16.34 | 22.77 | 0.33 | 838.11 |
| 2 | 54.63 | 12.86 | 8.12 | 17.87 | 25.20 | 0.33 | 1002.49 |
| 3 | 46.23 | 15.32 | 9.51 | 20.16 | 27.02 | 0.36 | 1276.05 |
| 4 | 49.16 | 13.06 | 9.15 | 19.19 | 27.12 | 0.32 | 1156.62 |
| 5 | 33.69 | 10.89 | 7.23 | 15.86 | 22.92 | 0.31 | 789.43 |
| 6 | 52.34 | 16.68 | 10.12 | 21.91 | 29.71 | 0.35 | 1507.85 |
| 7 | 51.53 | 15.96 | 10.09 | 21.48 | 29.19 | 0.35 | 1448.56 |
| 8 | 38.69 | 14.89 | 9.89 | 20.52 | 27.82 | 0.35 | 1322.41 |
| 9 | 41.96 | 16.08 | 10.08 | 21.58 | 29.37 | 0.35 | 1461.62 |
| 10 | 50.23 | 15.81 | 9.81 | 21.06 | 28.62 | 0.35 | 1392.75 |
| 11 | 48.36 | 13.85 | 9.89 | 19.99 | 27.37 | 0.34 | 1255.37 |
| 12 | 55.61 | 12.95 | 9.23 | 18.80 | 25.93 | 0.34 | 1110.06 |
| 13 | 51.32 | 8.98 | 8.09 | 15.51 | 22.80 | 0.30 | 754.98 |
| 14 | 38.56 | 9.06 | 7.95 | 15.18 | 21.86 | 0.31 | 723.51 |
| **Mean** | **47.27** | **13.30** | **9.15** | **18.96** | **26.26** | **0.34** | **1145.70** |
| **SD** | **6.60** | **2.69** | **0.95** | **2.41** | **2.73** | **0.02** | **279.88** |
|  | **Ber Fruit Seeds physical parameters** | | | | | | |
| **S. No** | **L** | **W** | **T** | **GMD (mm)** | **AMD (mm)** | **Sp (mm)** | **Sa (mm2)** |
| 1 | 8.69 | 3.01 | 5.96 | 5.38 | 5.89 | 0.62 | 90.95 |
| 2 | 5.98 | 2.08 | 4.89 | 3.93 | 4.32 | 0.66 | 48.56 |
| 3 | 7.62 | 3.09 | 5.36 | 5.02 | 5.36 | 0.66 | 79.00 |
| 4 | 8.37 | 2.56 | 5.29 | 4.84 | 5.41 | 0.58 | 73.54 |
| 5 | 8.73 | 3.89 | 6.09 | 5.97 | 6.31 | 0.67 | 111.73 |
| 6 | 7.59 | 3.06 | 5.96 | 5.17 | 5.54 | 0.68 | 84.02 |
| 7 | 6.27 | 1.96 | 5.06 | 3.96 | 4.43 | 0.63 | 49.28 |
| 8 | 6.31 | 2.16 | 4.86 | 4.05 | 4.44 | 0.64 | 51.41 |
| 9 | 6.53 | 2.06 | 5.26 | 4.14 | 4.62 | 0.63 | 53.72 |
| 10 | 6.06 | 1.92 | 5.06 | 3.89 | 4.35 | 0.64 | 47.52 |
| 11 | 6.19 | 1.56 | 4.43 | 3.50 | 4.06 | 0.57 | 38.41 |
| 12 | 6.53 | 2.01 | 4.87 | 4.00 | 4.47 | 0.61 | 50.20 |
| 13 | 7.96 | 2.18 | 4.98 | 4.42 | 5.04 | 0.56 | 61.38 |
| 14 | 6.89 | 2.06 | 5.36 | 4.24 | 4.77 | 0.615 | 56.37 |
| **Mean** | **7.12** | **2.40** | **5.25** | **4.47** | **4.93** | **0.63** | **64.01** |
| **SD** | **1.01** | **0.64** | **0.48** | **0.70** | **0.67** | **0.04** | **20.80** |

**Note:** L – Length, W- Width, T- Thickness, GMD - Geometric Mean Diameter, AMD- Arthematic Mean Diameter, Sp- Sphericity and Sa- Surface area.

From Table 4, the maximum values of ber fruits length, width, thickness, geometric mean diameter, arithmetic mean diameter, sphericity and surface area are 55.34 mm, 16.68 mm, 10.12 mm, 21.91 mm, 29.71 mm, 0.35 and 1508 mm², respectively. For the seeds, the maximum values are 8.73 mm, 3.89 mm, 6.09 mm, 5.97 mm, 6.31 mm, 0.67 and 111.73 mm², respectively. As shown in Fig.6b, the sphericity of seeds are higher than that of ber fruits, indicating the shape of the ber fruit seeds is more uniform than that of the fruits. Fig. 6a, 6b, 6c and 6d illustrate a decreasing trend from ber fruits to ber fruit seeds.

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| **Fig.6: shows the graphical variation of measured parameters (a) (Length, Width and Thickness); (b) Sphericity; (c) Geometric and Arthematic Mean Diameter; (d) Surface area of Ber fruits and seeds** | |

**3.1.1 Statistical analysis of physical parameters**

The correlation co-efficient of the measured physical properties (L, W, T, GMD, AMD, Sp and Sa) of Ber fruits and seeds are shown in Table.3.

**Table.3: Pearson Correlation of physical parameters of ber fruits and seeds**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pearson Correlation of physical parameters of ber fruits** | | | | | | | | | | |
|  | | **L** | **W** | **T** | **GMD** | | **AMD** | | **Sp** | **Sa** |
| **L** | **Pearson Correlation** | 1 | .190 | .306 | .246 | | .258 | | .210 | .232 |
| **W** | **Pearson Correlation** | .190 | 1 | .834\*\* | .982\*\* | | .972\*\* | | .894\*\* | .981\*\* |
| **T** | **Pearson Correlation** | .306 | .834\*\* | 1 | .915\*\* | | .889\*\* | | .858\*\* | .915\*\* |
| **GMD** | **Pearson Correlation** | .246 | .982\*\* | .915\*\* | 1 | | .993\*\* | | .886\*\* | .999\*\* |
| **AMD** | **Pearson Correlation** | .258 | .972\*\* | .889\*\* | .993\*\* | | 1 | | .827\*\* | .993\*\* |
| **Sp** | **Pearson Correlation** | .210 | .894\*\* | .858\*\* | .886\*\* | | .827\*\* | | 1 | .880\*\* |
| **Sa** | **Pearson Correlation** | .232 | .981\*\* | .915\*\* | .999\*\* | | .993\*\* | | .880\*\* | 1 |
| **Pearson Correlation of physical parameters of ber fruit seeds** | | | | | | | | | | |
|  | | **L** | **W** | **T** | **GMD** | **AMD** | | **Sp** | | **Sa** |
| **L** | **Pearson Correlation** | 1 | .812\*\* | .753\*\* | .903\*\* | .945\*\* | | -.033 | | .893\*\* |
| **W** | **Pearson Correlation** | .812\*\* | 1 | .878\*\* | .978\*\* | .947\*\* | | .530 | | .981\*\* |
| **T** | **Pearson Correlation** | .753\*\* | .878\*\* | 1 | .916\*\* | .903\*\* | | .526 | | .910\*\* |
| **GMD** | **Pearson Correlation** | .903\*\* | .978\*\* | .916\*\* | 1 | .992\*\* | | .393 | | .998\*\* |
| **AMD** | **Pearson Correlation** | .945\*\* | .947\*\* | .903\*\* | .992\*\* | 1 | | .285 | | .988\*\* |
| **Sp** | **Pearson Correlation** | -.033 | .530 | .526 | .393 | .285 | | 1 | | .399 |
| **Sa** | **Pearson Correlation** | .893\*\* | .981\*\* | .910\*\* | .998\*\* | .988\*\* | | .399 | | 1 |
| **\*\*. Correlation is significant at the 0.01 level (2-tailed).** | | | | | | | | | | |

**Note:** L – Length, W- Width, T- Thickness, GMD - Geometric Mean Diameter, AMD- Arthematic Mean Diameter, Sp- Sphericity and Sa- Surface area.

From Table 3, the width of the ber fruit strongly correlates with GMD (0.981), Sa (0.981), AMD (0.972), Sp (0.894), and thickness (0.834). Therefore, an increase in width leads to an increase in GMD, Sa, AMD, Sp, and thickness of ber fruits. However, there is no significant effect on the length of the ber fruit at (p ≥ 0.05) due to its physical structure. The same pattern is observed with the thickness, GMD, and AMD of the ber fruit. Sphericity strongly correlates with width (0.894), GMD (0.886), Sa (0.880), thickness (0.858), and AMD (0.827), but again, there is no significant effect on the length of the ber fruit at ( p < 0.001 ) due to its physical structure. Based on this correlation, it was concluded that, besides length, all other parameters are significantly correlated with Sp and Sa. The same pattern is observed in ber fruit seeds, with even stronger correlations. Therefore, the shape and Sa of the ber fruit and seed were considered for designing the fruit resting stand platform and aperture size.

**3.2 Specifications and working of developed de-seeder**

The dimensions and specifications of the developed ber de-seeder are based on the measured physical properties of the ber fruits and their seeds, as shown in Table 4. The developed de-seeder and its working is illustrated in Fig.7a and 7b.

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| **Fig.7a: Developed Hand Operated punching type Ber Fruit De-Seeder**  **1: Handle 2: Crank and lever mechanism by screw nut linkage 3: Support stand 4: Guider 5: Punching rod 6: Fruit resting stand 7: Base** |

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| **Fig.7b: Working of developed hand operated ber fruit de-seeder** |

**Table.4: Specifications of the developed ber fruit de-Seeder**

|  |  |  |  |
| --- | --- | --- | --- |
| **S. No** | **Components** | **Specification in mm** | **Purpose** |
| 1. | Base | Rounded Rectangle, 350 x 210 | To provide support to the all parts of ber fruit de-seeder |
|  | L x B |
|  | No. of circular cylinders (D x H) | Four, (30 x 60) |
| 2. | Supporting Stand (L x B x T) | (365 x 50 x 2) | The handle is fixed to this supporting stand. The angle from which the handle is fitted to supporting stand is 45o |
| 3. | Handle  (L x B x T) | (650 x 20 x 2) | The handle is used to hold the operator with his hand grip. |
| 4. | Punching rod | Circular (200 x 13 x 2) | The punching pipe will penetrate into the ber fruit and extrude the seed in the ber fruit.  The 10 mm is the average ber fruit seed diameter of 42 samples. |
| Shape,  L x B x T (initial) |
| tapered angle | 15º |
| Shape,  L x B x T (final) | Tapered circular (280 x 10 x 2) |
| 5. | Fruit resting Stand  (L x B x T) | Square  (50 x 50 x 50) | Semicircular shaped platform is punched on the fruit stand on which the ber fruit is placed. |
| 6. | Fruit resting stand platform and  Aperture size | Circular  60 mm and 12 mm | An aperture of 12mm is perforated through which Punching rod passes while punching to separate the seed from ber fruit |
| 7. | Overall dimensions  (L x B x T) | 350 x 500 x 350 mm | The machine was compact and light weight for operators’ comfortability to place on the stand/table and use it. |
| 8. | Total weight | 3kg |

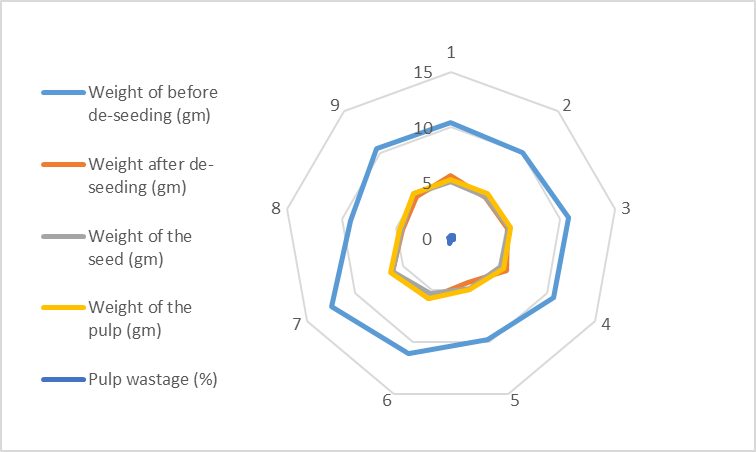
**3.3 Performance Parameters of the Developed Ber Fruit De-Seeder**

The measured performance parameters, including the total weight of pulp in ber fruit (Wp), total weight of ber fruit with seed (Wf), weight of seed in ber fruit (Ws), pulp wastage percentage (Pw), and efficiency of the de-seeder (ŋ) for 9 samples, are shown in Table 5 and illustrated in Fig. 8.

From Table 5, the percentage of fruit pulp wastage varied from 1.89% to 8.62% (lowest to highest). The efficiency of the de-seeder ranged from 91.38% to 98.11% (lowest to highest), which is attributed to the non-uniform sizes of the fruits and seeds [34]. In comparison, the efficiency of manual operation varied from 66% to 69%.

**Table.5: Measured performance parameters of ber fruit de-seeder**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S. No** | **Weight before de-seeding (gm)** | **Weight after de-seeding (gm)** | **Weight of the seed (gm)** | **Weight of the pulp (gm)** | **Pulp wastage (%)** | **Efficiency of De-seeder (%)** |
| 1 | 10.4 | 5.6 | 5.1 | 5.3 | 3.77 | 96.23 |
| 2 | 10.1 | 4.8 | 4.9 | 5.2 | 5.77 | 94.23 |
| 3 | 10.8 | 5.2 | 5.3 | 5.5 | 3.64 | 96.36 |
| 4 | 10.7 | 5.8 | 5.2 | 5.5 | 5.45 | 94.55 |
| 5 | 9.7 | 4.3 | 4.8 | 4.9 | 2.04 | 97.96 |
| 6 | 11.1 | 5.8 | 5.3 | 5.8 | 8.62 | 91.38 |
| 7 | 12.4 | 6.1 | 6.1 | 6.3 | 3.17 | 96.83 |
| 8 | 9.2 | 4.4 | 4.5 | 4.7 | 4.26 | 95.74 |
| 9 | 10.5 | 4.9 | 5.2 | 5.3 | 1.89 | 98.11 |

****

**Fig. 8: Graphical view of measured performance parameters**

**3.3.1 Statistical Analysis of performance parameters of ber fruit de-seeder**

The correlation coefficients of the measured performance parameters, including the weight of the fruit before deseeding (WBD), weight of the fruit after deseeding (WAD), weight of the seed (WS), weight of the pulp (WP), pulp wastage (PW), and efficiency of the de-seeder, are shown in Table 6.

**Table.6: Pearson Correlation of performance parameters of ber fruit de-seeder**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **WBD** | **WAD** | **WS** | **WP** | **PW** | **Efficiency** |
| WBD | Pearson Correlation | 1 | .861\*\* | .991\*\* | .992\*\* | .119 | -.119 |
| WAD | Pearson Correlation | .861\*\* | 1 | .815\*\* | .890\*\* | .390 | -.390 |
| WS | Pearson Correlation | .991\*\* | .815\*\* | 1 | .966\*\* | -.015 | .015 |
| WP | Pearson Correlation | .992\*\* | .890\*\* | .966\*\* | 1 | .242 | -.242 |
| PW | Pearson Correlation | .119 | .390 | -.015 | .242 | 1 | -1.000\*\* |
| Efficiency | Pearson Correlation | -.119 | -.390 | .015 | -.242 | -1.000\*\* | 1 |

**Note:** WBD – Weight of fruit before deseeding, WAD - Weight of fruit after de-seeding, WS – Weight of the seed, WP – Weight of the pulp, PW – Pulp Wastage, Efficiency of De-seeder, \*\* Correlation is significant at the 0.01 level (2-tailed)

From Table 6, the WBD and WAD are strongly correlated with WP (0.992, 0.890) and WS (0.991, 0.815), but they have no significant effect on PW (0.119, 0.390) and are negatively correlated with efficiency (-0.199, -0.390). Therefore, an increase in WBD and WAD leads to a strong increase in WP and WS, an insignificant increase in PW, and an insignificant decrease in efficiency. The same pattern is observed with WAD. The WS is negatively correlated with PW and positively correlated with de-seeder efficiency, whereas WP shows the opposite trend. Thus, PW is inversely proportional to de-seeder efficiency.

**3.4 Cost estimation of the developed de-seeder**

The average operating time for the de-seeder is 8 hours, but the operator can only operate the machine for 5 hours before experiencing pain. Ber is a seasonal fruit, so a working period of two months per year is assumed. The hiring charges for the machine are assumed to be ₹150 per hour, and labor wages are assumed to be ₹600 per day. The cost economics of the developed de-seeder is given in Table 7. The capacity of the ber fruit de-seeder varies from 15 to 17 kg per hour and 220 to 280 fruits per hour. In manual operation, the capacity for de-seeding ber fruits varies from 5 to 7 kg per hour and 130 to 140 fruits per hour, with an average working time of 4 hours per day. Consequently, the maximum capacity per day for manual operation is 28 kg, while the ber fruit de-seeder’s maximum capacity per day is 85 kg. Therefore, the de-seeding procedure with the de-seeder is equivalent to three manual labor operations.

**Table 7: Cost economics of developed de-seeder**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Particulars** | **Ber Fruit**  **de-seeder** | **Manual Operation** | **Percentage increase/decrease over manual operation** | |
| **Percentage increased** | **Percentage decreased** |
| Cost of equipment, ₹ | 1000 |  |  |  |
| Life, year | 5 |  |  |  |
| Annual use, h year-1 (60 x 4 = 240) | 240 |  |  |  |
| Fixed cost   1. Depreciation @ 10% salvage value, ₹ h-1 | 0.8 |  |  |  |
| 1. Interest @ 10 % per year, ₹ h-1 | 0.3 |  |  |  |
| 1. Total fixed cost, ₹ h-1 | 1.1 |  |  |  |
| Variable cost |  |  |  |  |
| 1. Labour required | 1 | 3 |  | 67 |
| 1. Working hour, h day-1 | 5 | 4 | 20 |  |
| 1. Labour cost, ₹ day-1 | 600 | 1800 |  | 67 |
| 1. Labour cost, ₹ h-1 | 120 | 450 |  | 73 |
| B. Total variable cost, ₹ h-1 | 120 | 450 |  | 73 |
| Total cost of operation, ₹ h-1 (A+B) | 121 | 450 |  | 73 |
| Custom hiring charges ₹ h-1 | 150 | - |  |  |
| Net Benefit, ₹ h-1 | 29 |  |  |  |
| Net Benefit, ₹ y-1 | 6,960 |  |  |  |
| Pay Back Period, years | 0.15 |  |  |  |

**3.5 Limitations of the Ber Fruit De-Seeder**

The developed hand-operated punching type ber fruit de-seeder has some limitations and challenges. First, due to the manual operation, the operator cannot continuously operate the de-seeder by hand for 8 hours as it causes fatigue in the shoulder, elbow, and neck joints, making the operation ergonomically cumbersome. Second, the timeliness of operation is affected because the manual punching and seating of the fruit result in a low capacity (kg h-1) for bulk processing. Third, there is wastage of ber fruit pulp on the top and bottom parts of the fruit with the seed due to the non-uniform seed sizes. These challenges highlight the need for advanced mechanization in ber fruit de-seeding to overcome the cumbersome nature of the process, reduce fruit pulp wastage, and increase the de-seeding capacity.

**Conclusion**

A punching type de-seeding mechanism for ber fruit was designed and developed based on the physical and mechanical properties of ber fruits and seeds. The maximum values for ber fruits’ length, width, thickness, GMD, AMD, Sp, and Sa are 55.34 mm, 12.68 mm, 10.12 mm, 21.91 mm, 29.71 mm, 0.35, and 1508 mm², respectively, while for the seeds, they are 8.73 mm, 3.89 mm, 6.09 mm, 5.97 mm, 6.31 mm, 0.67, and 111.73 mm², respectively. Statistical analysis shows that the physical parameters (width, thickness, GMD, AMD) are strongly correlated with the sphericity and surface area of the fruits and seeds. The performance parameters (pulp wastage and efficiency) of the de-seeder varied from 1.89% to 8.62% and 91.38% to 98.11%, respectively. The variation in the values due to the non-uniform fruit and seed sizes. Statistical analysis also indicates that performance parameters are negatively correlated, meaning an increase in pulp wastage leads to a decrease in the efficiency of the de-seeder. The developed de-seeder reduces labor requirement by 67%, and economic evaluation shows it reduces the cost of operation by 73% (₹ h-1) and increases the net benefit by ₹6,960 per year over manual operation.

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**Authors Contribution**

**BKK:** Data curation, Formal analysis, Investigation, Methodology, Software, Writing– original draft.

**MB:** Conceptualization, Supervision, Project administration, Writing – review & editing

**KKV and UD:** Software, Methodology, Validation, Visualization

**SKA:** Formal analysis and Writing – review & editing.

**JK and SKV:** Funding acquisition andWriting – review & editing.

**Declarations**

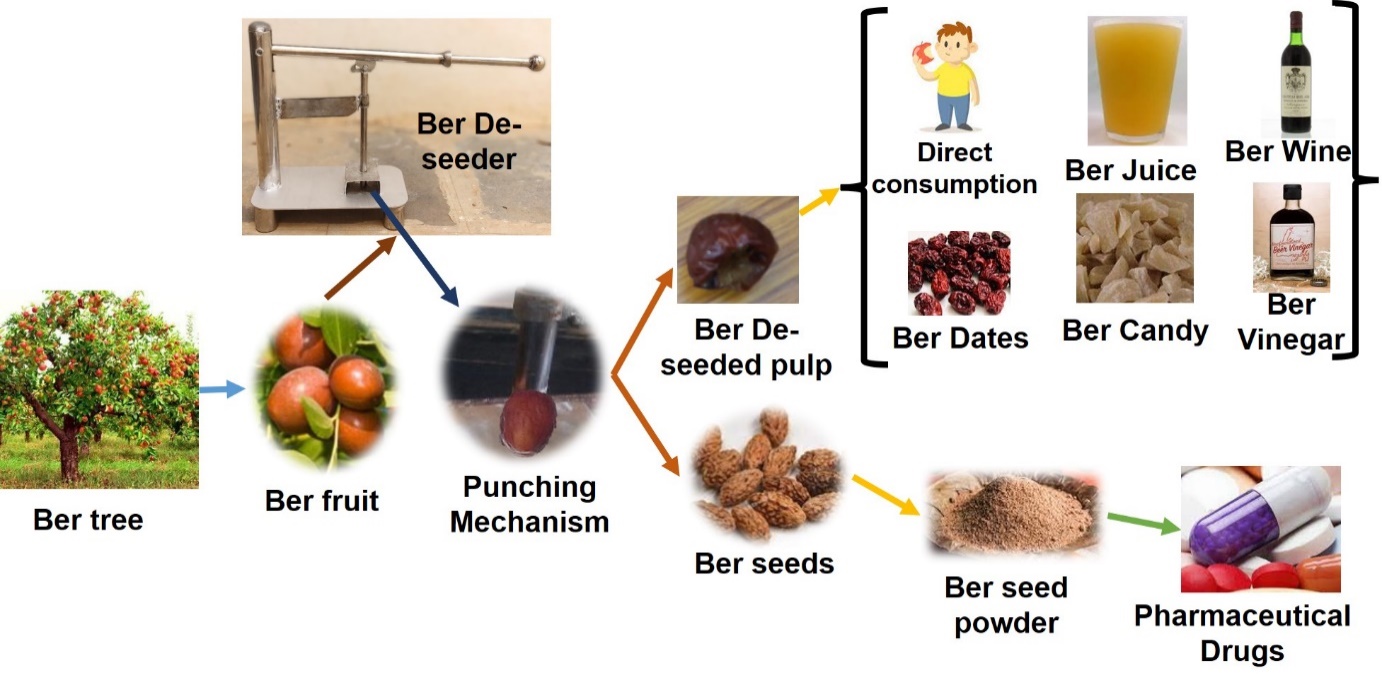
**Data Availability Statement**

All data analyzed during this study are included in this article

**Conflict of Interest**

The author and Co-authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Graphical Abstract**



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