

Research

Development and evaluation of punching mechanism for de-seeding of ber fruit

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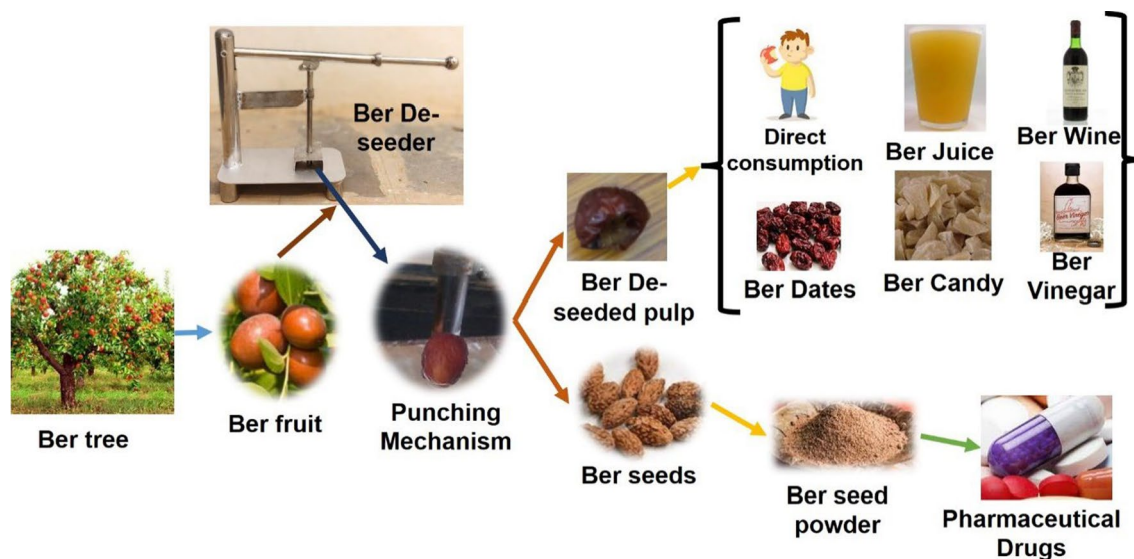
Abstract

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/ h and 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.

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Graphical Abstract



Highlights

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.

Keywords Ber Fruit · Ber Fruit Pulp · Ber Fruit Seeds · Punching Mechanism · De-Seeder · Mechanical Properties · Physical Properties · Efficiency

Abbreviations

S_a	Surface Area
P_w	Pulp Wastage
S_p	Sphericity
AMD	Arithmetic 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 [1–4]. 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 μ g), 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 $12.38 \pm 0.92\%$, titratable acidity at $0.39 \pm 0.03\%$, total sugar at $7.0 \pm 0.43\%$, and moisture content at $86.8 \pm 1.2\%$ [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 [8–12]. 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 [6, 13]. 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

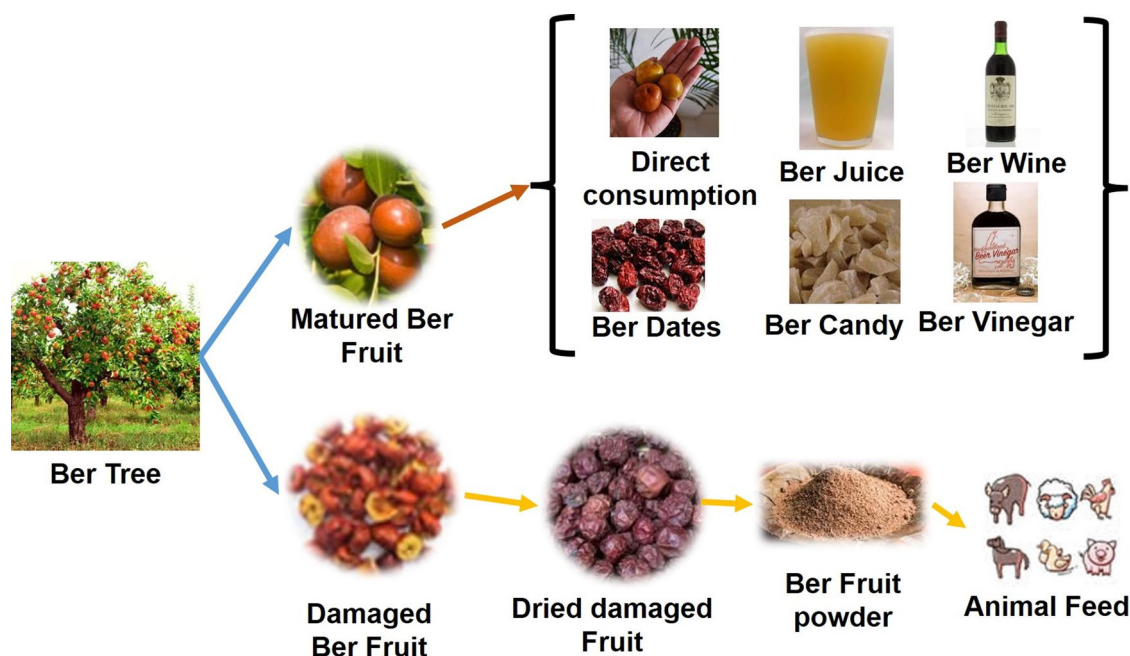


Fig. 1 Application of Ber Fruits in Various Products

Fig. 2 Stages of Ber Fruit

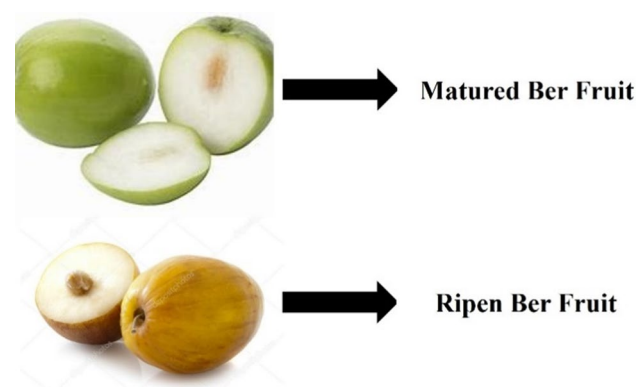


Table 1 Physico-chemical characteristics of mature and ripen Kaithali Ber fruits. Source [21, 22]

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

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.

2 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.

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 b. Standard equations from) were utilized for these calculations [25].

$$D_g = (LWT)^{\frac{1}{3}} \quad (1)$$

$$D_a = \frac{(L + W + T)}{3} \quad (2)$$

$$S_p = \frac{(D_g)}{L} \quad (3)$$

$$A = \pi D_g^2 \quad (4)$$

where, D_g : Geometric mean diameter, D_a : Arithmetic mean diameter, S_p : 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 5 mm Ø cylindrical probe at a pre-test speed of 0.5 mm/s, test speed of 0.5 mm/s, post-test speed of 10 mm/s, contact time of 8 s, penetration depth of 5 mm, and return distance of 5 mm. 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].

2.2.1.1 Assumptions/considerations for handle The measured force required to punch the fruit, as shown in Fig. 4b, is 34 kg (F_1). Based on assumptions from [26, 29], and [30], the average hand push strength that a person can exert is 8.8 kg (F_2), and the average hand pull strength is 9.3 kg (F_3). The position of the punching point from the pivoted point is 165 mm (L_1). Using the formula for the length of the handle:

$$\text{Length of Handle} = \frac{F_1 \times L_1}{F_2} = \frac{34 \times 165}{8.8} = 637 \text{ mm}$$

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:

$$650 \times 60 = 165 \times N$$

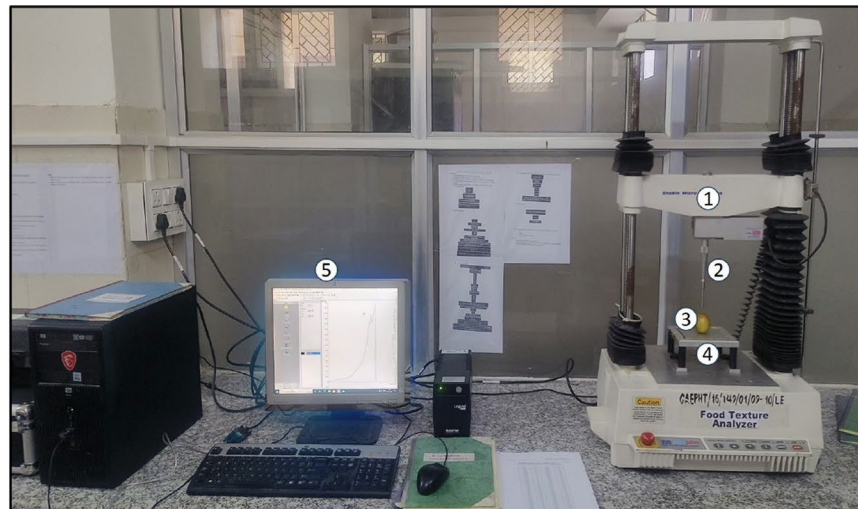
Fig. 3 **a** Geometric dimensions. **b** Measurement by vernier caliper



a) Geometric dimensions

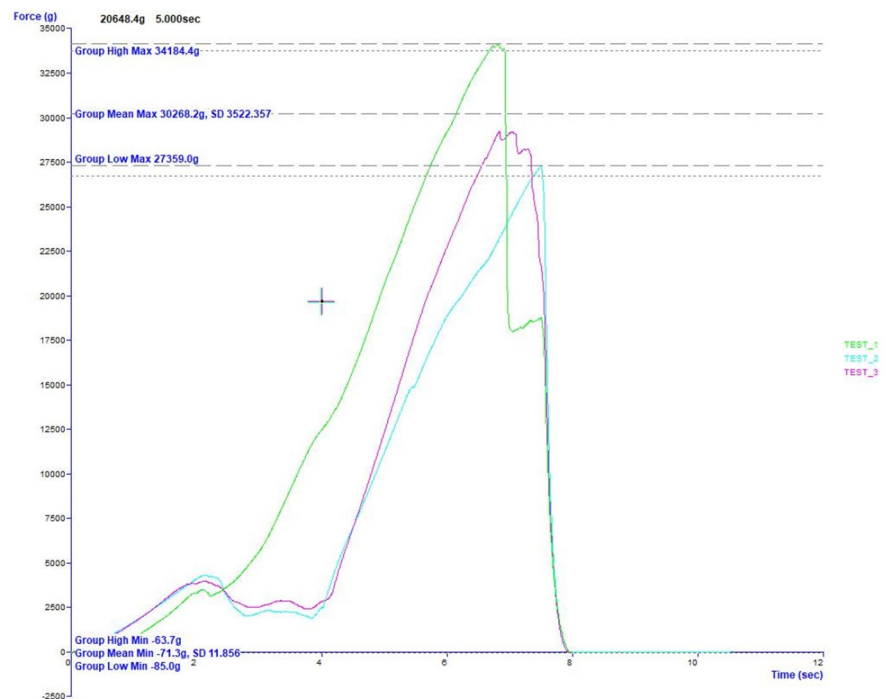
b) Measurement by vernier caliper

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



a: Measurement of cutting force by texture analyzer

(1. Moving arm; 2. Probe; 3. Ber fruit; 4. Platform; 5. PC showing graph)



b: Graph of measured cutting force of ber fruits

Solving for (N):

$$N = \frac{650 \times 60}{165} = 236 \text{ mm}$$

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:

$$\text{Total Length of the Punching Rod} = 100 \text{ mm} + 30 \text{ mm} + 5 \text{ mm} + 65 \text{ mm} = 200 \text{ mm}$$

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.

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].

$$W_p = W_f - W_s \quad (5)$$

$$P_w = \frac{W_s - W_p}{W_p} \times 100 \quad (6)$$

$$\eta = 100 - P_w \quad (7)$$

where, W_p : weight of pulp in ber fruit, W_f : Total weight of ber fruit, W_s : Weight of seed in ber, P_w : Pulp wastage in %, η : 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:

Depreciation (D)

$$D = \frac{P - S}{LXH} \quad (8)$$

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).

Table 2 Measured physical parameters of ber fruits and seeds

Ber Fruits physical parameters							
S. No	L	W	T	GMD (mm)	AMD (mm)	S _p (mm)	S _a (mm ²)
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
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

L Length, W Width, T Thickness, GMD Geometric Mean Diameter, AMD Arithmetic Mean Diameter, S_p Sphericity and S_a Surface area

Interest(I)

$$I = \frac{P + S}{2} \times \frac{i}{H} \quad (9)$$

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).

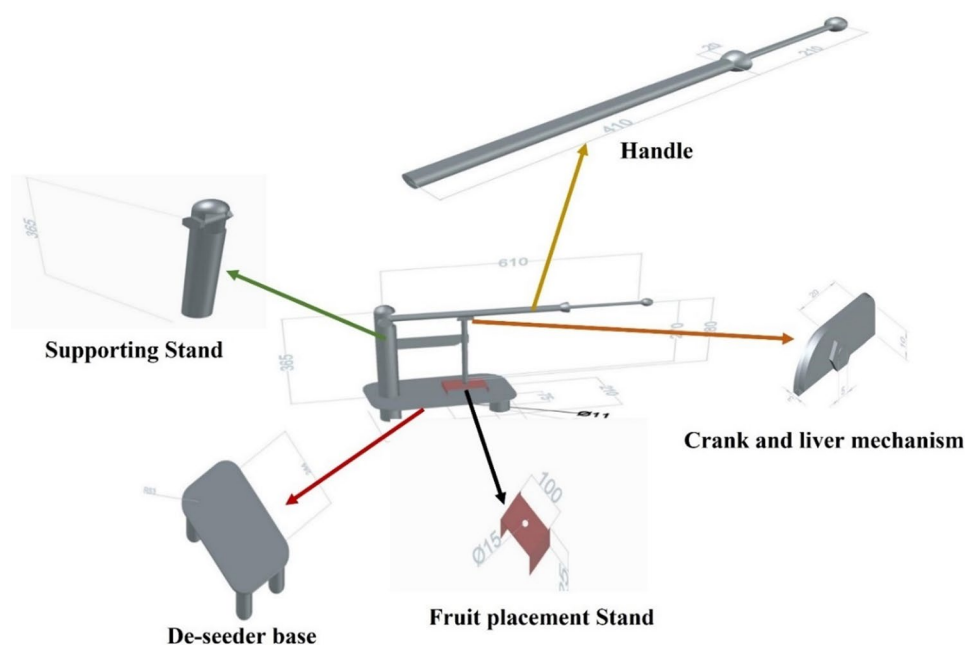
Net Benefit (NB):

$$NB = CH - OC \quad (10)$$

where,

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

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



Payback period (PBP)

$$PBP = \frac{NB}{IC} \quad (11)$$

where,

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

3 Results and discussion

3.1 Physical parameters of ber fruits and ber fruit seeds

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

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 is higher than that of ber fruits, indicating the shape of the ber fruit seeds is more uniform than that of the fruits. Figure 6a, b, c and d illustrate a decreasing trend from ber fruits to ber fruit seeds.

3.1.1 Statistical analysis of physical parameters

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

From Table 3, the width of the ber fruit strongly correlates with GMD (0.981), S_a (0.981), AMD (0.972), S_p (0.894), and thickness (0.834). Therefore, an increase in width leads to an increase in GMD, S_a , AMD, S_p , and thickness of ber fruits. However, there is no significant effect on the length of the ber fruit at ($p \geq 0.05$) 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), S_a (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

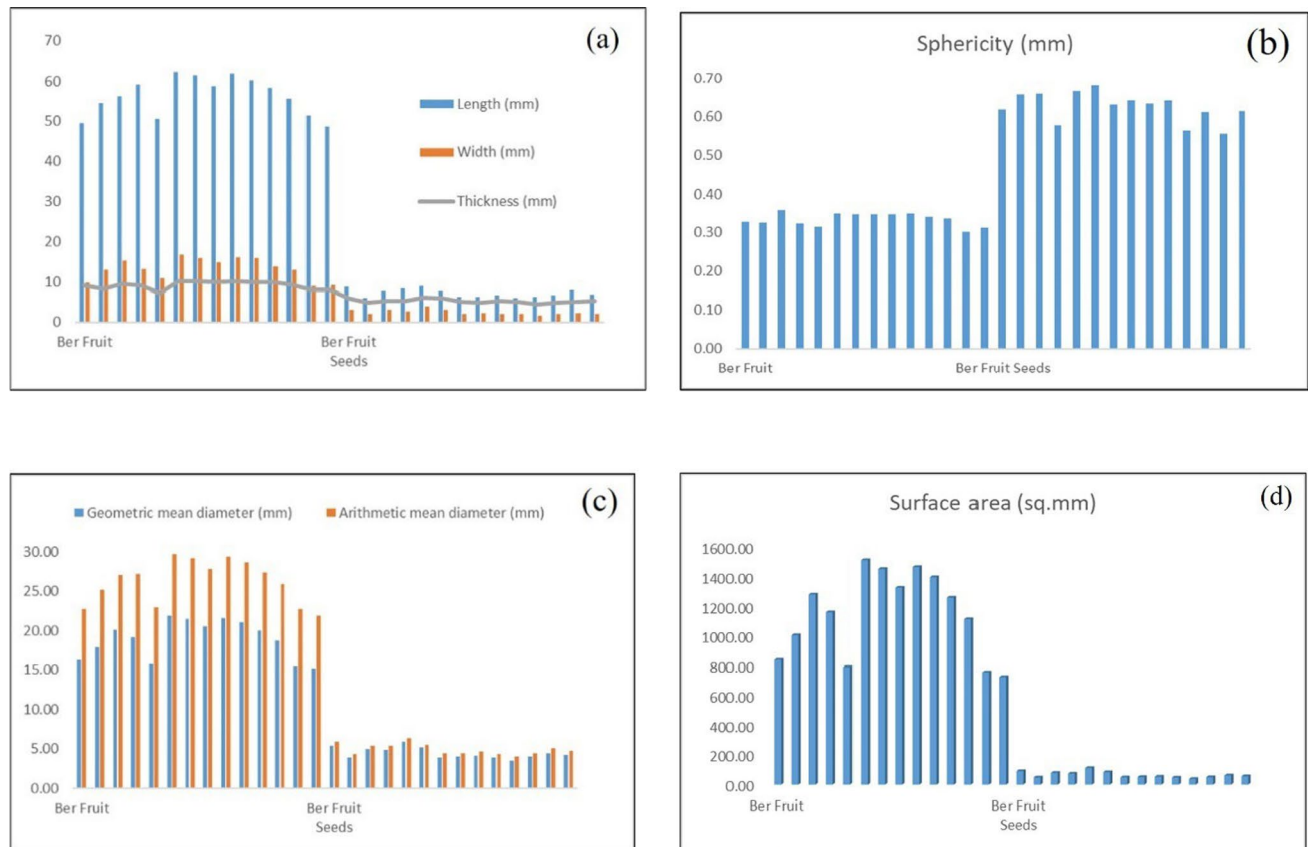


Fig. 6 shows the graphical variation of measured parameters **(a)** (Length, Width and Thickness); **b** Sphericity; **c** Geometric and Arithmetic Mean Diameter; **d** Surface area of Ber fruits and seeds

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	S_p	S_a
L	Pearson correlation	1	0.190	0.306	0.246	0.258	0.210	0.232
W	Pearson correlation	0.190	1	.834**	0.982**	0.972**	0.894**	0.981**
T	Pearson correlation	0.306	0.834**	1	0.915**	0.889**	0.858**	0.915**
GMD	Pearson correlation	0.246	0.982**	0.915**	1	0.993**	0.886**	0.999**
AMD	Pearson correlation	0.258	0.972**	0.889**	0.993**	1	0.827**	0.993**
S_p	Pearson correlation	0.210	0.894**	0.858**	0.886**	0.827**	1	0.880**
S_a	Pearson correlation	0.232	0.981**	0.915**	0.999**	0.993**	0.880**	1
L	Pearson correlation	1	0.812**	0.753**	0.903**	0.945**	-0.033	0.893**
W	Pearson correlation	0.812**	1	0.878**	0.978**	0.947**	0.530	0.981**
T	Pearson correlation	0.753**	0.878**	1	0.916**	0.903**	0.526	0.910**
GMD	Pearson correlation	0.903**	0.978**	0.916**	1	0.992**	0.393	0.998**
AMD	Pearson correlation	0.945**	0.947**	0.903**	0.992**	1	0.285	0.988**
S_p	Pearson correlation	-0.033	0.530	0.526	0.393	0.285	1	0.399
S_a	Pearson correlation	0.893**	0.981**	0.910**	0.998**	0.988**	0.399	1

L Length, W Width, T Thickness, GMD Geometric Mean Diameter, AMD Arithmetic Mean Diameter, S_p Sphericity and S_a Surface area

**Correlation is significant at the 0.01 level (2-tailed)

Table 4 Specifications of the developed ber fruit de-Seeder

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

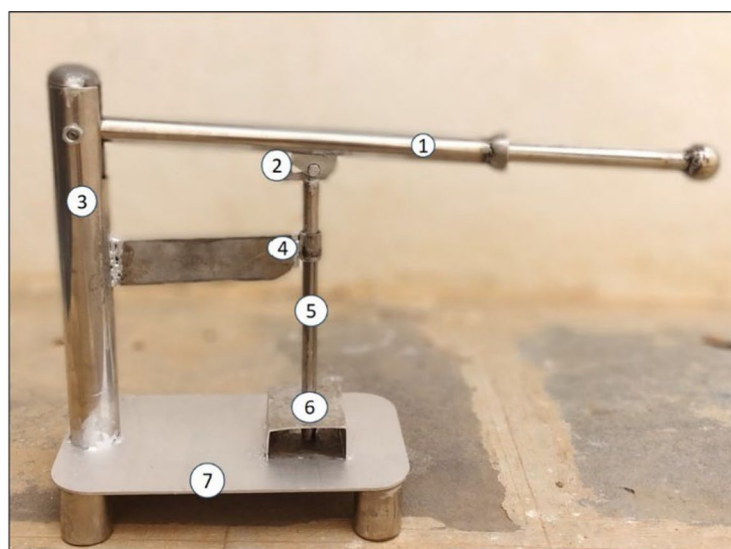
other parameters are significantly correlated with S_p and S_a . The same pattern is observed in ber fruit seeds, with even stronger correlations. Therefore, the shape and S_a of the ber fruit and seed were considered for designing the fruit resting stand platform and aperture size.

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 is illustrated in Fig. 7a and its working is shown in Fig. 7b.

3.3 Performance parameters of the developed ber fruit de-seeder

The measured performance parameters, including the total weight of pulp in ber fruit (W_p), total weight of ber fruit with seed (W_f), weight of seed in ber fruit (W_s), pulp wastage percentage (P_w), and efficiency of the de-seeder (η) for 9 samples, are shown in Table 5 and illustrated in Fig. 8.



a: 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

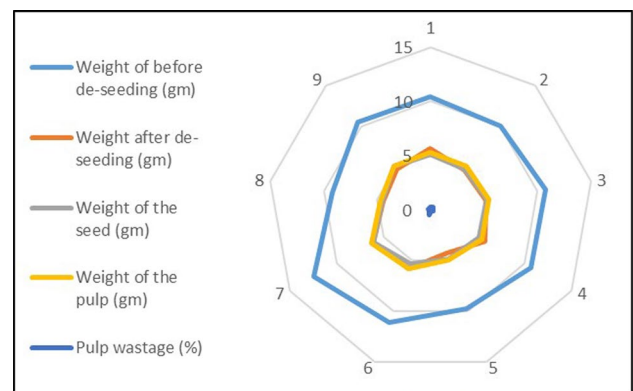


b: Working of developed hand operated ber fruit de-seeder

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

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

		WBD	WAD	WS	WP	PW	Efficiency
WBD	Pearson correlation	1	0.861**	0.991**	0.992**	0.119	-0.119
WAD	Pearson correlation	0.861**	1	0.815**	0.890**	0.390	-0.390
WS	Pearson correlation	0.991**	0.815**	1	0.966**	-0.015	0.015
WP	Pearson correlation	0.992**	0.890**	0.966**	1	0.242	-0.242
PW	Pearson correlation	0.119	0.390	-0.015	0.242	1	-1.000**
Efficiency	Pearson correlation	-0.119	-0.390	0.015	-0.242	-1.000**	1

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 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%.

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.

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 h, but the operator can only operate the machine for 5 h 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 h 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.

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 h 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.

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 × 4 = 240)	240			
Fixed cost	0.8			
a. Depreciation @ 10% salvage value, ₹ h ⁻¹				
b. Interest @ 10% per year, ₹ h ⁻¹	0.3			
A. Total fixed cost, ₹ h ⁻¹	1.1			
Variable cost				
a. Labour required	1	3		67
b. Working hour, h day ⁻¹	5	4	20	
c. Labour cost, ₹ day ⁻¹	600	1800		67
d. 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	6960			
Pay Back Period, years	0.15			

4 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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Author contributions BKK: Data curation, Formal analysis, Investigation, Methodology, Software, Writing– original draft. MB: Conceptualization, Supervision, Project administration, Writing – review & editing SSM: Supervision and Project administration KKV and UD: Software, Methodology, Validation, Visualization SKA, JK and SKV: Funding acquisition, Formal analysis and Writing – review & editing.

Data availability All data analyzed during this study are included in this article.

Declarations

Ethics approval and consent to participate I Bharath Kumar Komatineni (corresponding author) give the Consent of Participate of all co-authors in the present study in all aspects of research work in data curation, evaluation and investigation etc. All participants provided informed consent before participating in the study.

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Competing interests The authors declare no competing interests.

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References

1. Abioye EA, Abidin MSZ, Mahmud MSA, Buyamin S, Ishak MHI, Rahman MKIA, et al. A review on monitoring and advanced control strategies for precision irrigation. *Comput Electron Agric.* 2020;173: 105441. <https://doi.org/10.1016/j.compag.2020.105441>.
2. Li J-W, Fan L-P, Ding S-D, Ding X-L. Nutritional composition of five cultivars of Chinese jujube. *Food Chem.* 2007;103:454–60. <https://doi.org/10.1016/j.foodchem.2006.08.016>.
3. Li S, Mao Z, Wang P, Zhang Y, Sun P, Xu Q, et al. Brewing jujube brandy with <sc>D</sc> aqu and yeast by solid-state fermentation. *J Food Process Eng.* 2016;39:157–65. <https://doi.org/10.1111/jfpe.12208>.
4. Shrivastva D, Pal AK, Singh SP, Barman K. Minimization of physiological losses and enhancement of shelf life of ber (*Ziziphus Mauritiana* Lamk) fruits Cv Banarasi. *Plant Arch.* 2020;2:4417–22.
5. Mansuri SM, Gautam PV, Jain D, Nickhil C. Computer vision model for estimating the mass and volume of freshly harvested Thai apple ber (*Ziziphus mauritiana* L.) and its variation with storage days. *Sci Hortic (Amsterdam).* 2022. <https://doi.org/10.1016/j.scienta.2022.111436>.
6. Xu T, Zhou X, Degen A, Yin J, Zhang S, Chen N. The inclusion of jujube by-products in animal feed: a review. *Sustainability.* 2022;14:7882. <https://doi.org/10.3390/su14137882>.

7. Choi S-H, Ahn J-B, Kozukue N, Levin CE, Friedman M. Distribution of free amino acids, flavonoids, total phenolics, and antioxidative activities of jujube (*Ziziphus jujuba*) fruits and seeds harvested from plants grown in Korea. *J Agric Food Chem*. 2011;59:6594–604. <https://doi.org/10.1021/jf200371r>.
8. Gowd V, Karim N, Xie L, Shishir MRI, Xu Y, Chen W. In vitro study of bioaccessibility, antioxidant, and α -glucosidase inhibitory effect of pelargonidin-3-O-glucoside after interacting with beta-lactoglobulin and chitosan/pectin. *Int J Biol Macromol*. 2020;154:380–9. <https://doi.org/10.1016/j.ijbiomac.2020.03.126>.
9. Xu Y, Xie L, Xie J, Liu Y, Chen W. Pelargonidin-3-O-rutinoside as a novel α -glucosidase inhibitor for improving postprandial hyperglycemia. *Chem Commun*. 2019;55:39–42. <https://doi.org/10.1039/C8CC07985D>.
10. Feng C, Wang B, Zhao A, Wei L, Shao Y, Wang Y, et al. Quality characteristics and antioxidant activities of goat milk yogurt with added jujube pulp. *Food Chem*. 2019;277:238–45. <https://doi.org/10.1016/j.foodchem.2018.10.104>.
11. Shishir MRI, Karim N, Gowd V, Xie J, Zheng X, Chen W. Pectin-chitosan conjugated nanoliposome as a promising delivery system for neohesperidin: characterization, release behavior, cellular uptake, and antioxidant property. *Food Hydrocoll*. 2019;95:432–44. <https://doi.org/10.1016/j.foodhyd.2019.04.059>.
12. Ji X, Peng Q, Yuan Y, Shen J, Xie X, Wang M. Isolation, structures and bioactivities of the polysaccharides from jujube fruit (*Ziziphus jujuba* Mill.): a review. *Food Chem*. 2017;227:349–57. <https://doi.org/10.1016/j.foodchem.2017.01.074>.
13. Rashwan AK, Karim N, Shishir MRI, Bao T, Lu Y, Chen W. Jujube fruit: a potential nutritious fruit for the development of functional food products. *J Funct Foods*. 2020;75: 104205. <https://doi.org/10.1016/j.jff.2020.104205>.
14. Khaleel G, Sharanagat VS, Singh L, Kumar Y, Kumar K, Kishore A, et al. Characterization of kinnow (citrus reticulata) peel and its effect on the quality of muffin. *J Food Process Preserv*. 2022. <https://doi.org/10.1111/jfpp.16716>.
15. Kumar S, Keshav SP, Sharma S, Kumar V, Bisht B, et al. Functional and nutritional perspectives of low-fat cookies fortified with jamun pulp, jamun seed, mango kernel powder. *Appl Food Res*. 2023. <https://doi.org/10.1016/j.afres.2023.100340>.
16. Marimuthu S, Saikumar A, Badwaik LS. Food losses and wastage within food supply chain: a critical review of its generation, impact, and conversion techniques. *Waste Dispos Sustain Energy*. 2024. <https://doi.org/10.1007/s42768-024-00200-7>.
17. Junaid PM, Saikumar A, Nazim MS, Zaidi S, Badwaik LS, Ahmad F. Film-based packaging for food safety and preservation: issues and perspectives. *Microb Biotechnol*. 2024. https://doi.org/10.1007/978-3-031-51417-3_17.
18. Saikumar A, Singh A, Dobhal A, Arora S, Junaid PM, Badwaik LS, et al. A review on the impact of physical, chemical, and novel treatments on the quality and microbial safety of fruits and vegetables. *Syst Microbiol Biomanufacturing*. 2024;4:575–97. <https://doi.org/10.1007/s43393-023-00217-9>.
19. Saikumar A, Singh A, Kaur K, Kumar N, Sharma S, Dobhal A, et al. Numerical optimization of hypochlorous acid (HOCl) treatment parameters and its effect on postharvest quality characteristics of tomatoes. *J Agric Food Res*. 2023;14: 100762. <https://doi.org/10.1016/j.jafr.2023.100762>.
20. Saikumar A, Nickhil C, Badwaik LS. Physicochemical characterization of elephant apple (*Dillenia indica* L.) fruit and its mass and volume modeling using computer vision. *Sci Hortic (Amsterdam)*. 2023. <https://doi.org/10.1016/j.scienta.2023.111947>.
21. Kumar M, Singh S, Pathak D V. Impact of natural ripening on physico-chemical characteristics of ber fruits Impact of natural ripening on physico-chemical characteristics of ber fruits 2016.
22. Kumar D, Prakash O, Sarfaraj KS, Kumar V, Yadav S. Varietal evaluation of ber (*Zizyphus mauritiana* Lamk.) for yield and fruits quality attributes under Bundelkhand Region of Uttar Pradesh India. *Int J Environ Clim Chang*. 2023;13:1698–704. <https://doi.org/10.9734/ijeccl/2023/v13i92400>.
23. Goyal RK, Kingsly ARP, Kumar P, Walia H. Physical and mechanical properties of aonla fruits. *J Food Eng*. 2007;82:595–9. <https://doi.org/10.1016/j.jfoodeng.2007.03.019>.
24. Sachan N, Gangwar S, Sharma R, Kumar Y. An investigation into photochemical profile and nutraceutical value of amla (*Emblica Officialis*) fruits. *Int J Mod Pharm Res*. 2013;2:1–12.
25. Chandra Naithani D, Rawat JMS, Singh B, Khanduri VP, Riyal MK. Determination of Physico-chemical Properties of Aonla (*Emblica officinalis* Gaerth) Fruits among Different Populations in Garhwal Himalaya. *Int J Fruit Sci*. 2020;20:S1579–89. <https://doi.org/10.1080/15538362.2020.1822264>.
26. Ganachari A, Thangavel K, Manohar Jesudas D, Viswanathan R. Design and development of a machine for aonla seed removal. *Ama, Agric Mech Asia Afr Lat Am*. 2008;39(2):80.
27. Brimapureswaran R, Anandakumar S. Physical Properties and Pulp Efficiency of Aonla Fruit (*Emblica officinalis* gaerthn) 2015;1:1–6.
28. Mehta CR, Pandey MM, Tiwari PS, Gite LP, Khadatkhar A. Tractor controls actuating force limits for Indian operators. *Ind Health*. 2011;49:523–33. <https://doi.org/10.2486/indhealth.MS1190>.
29. Komatineni BK, Satpathy SK, Venkat Reddy KK, Sukdeva B, Dwivedi U, Lahre J. Development and evaluation of bluetooth based remote controlled battery powered drum seeder. *E-Prime - Adv Electr Eng Electron Energy*. 2023;6: 100333. <https://doi.org/10.1016/j.prime.2023.100333>.
30. Komatineni BK, Satpathy SK, Kavan Kumar V, Arjun Naik M, Dwivedi U, Lahre J. An unmanned rice seeder with WiFi based mobile-control system for drugery reduction. *Smart Agric Technol*. 2024;8: 100471. <https://doi.org/10.1016/j.atech.2024.100471>.
31. Swarnakar AK, Bathre RK. Design and development of Aonla stone (Seed) removing cum slicing equipment. *J Pharm Phytochem*. 2018;7:27–30.
32. Shrivastava SP, Pandey S, Jain P. Development of manually operated Aonla destoner cum slicer. *Bhartiya Krishi Anusandhan Patrika*. 2018. <https://doi.org/10.18805/BKAP87>.
33. IS:1979. Guide for Estimating Cost of Farm Machinery Operation. *Indian Stand Inst* 1979:1–17.
34. Makam S, Komatineni BK, Meena SS, Meena U. Unmanned aerial vehicles (UAVs): an adoptable technology for precise and smart farming. *Discov Internet Things*. 2024;4:12. <https://doi.org/10.1007/s43926-024-00066-5>.