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Evaluation of floral biology, physicochemical characteristics, and shelf life of four selected Ber cultivars grown in Bangladesh

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ABSTRACT

Purpose: Ber (*Ziziphus mauritiana*) is a highly nutritious fruit widely cultivated in tropical and subtropical regions, valued for its rich nutritional and medicinal properties. Despite its economic importance, limited research exists on the comparative floral biology, physicochemical characteristics, and post-harvest shelf life of different ber cultivars Bangladesh. **Research Method:** Four ber cultivars (Apple Kul, Khurma Kul, BARI Kul 5, and Gutti Kul 2) were assessed for their floral biology, physicochemical characteristics, and shelf life in 2023. Floral data, including flowering duration, male-to-female flower ratio, and fruit set per axil, were collected using randomized full block design with three replications. Physicochemical properties were measured using standardized laboratory methods such as ash, carbohydrates, protein, vitamins, and minerals. **Findings:** First flowering was recorded on September in Khurma Kul and Gutti Kul, with flowering durations ranging from 51 to 60 days. The male-to-female ratio was highest in Apple Kul (10.67), while BARI Kul 5 had more fruit sets per axil. Apple Kul and BARI Kul 5 exhibited the highest levels of ash (0.5-0.65%), carbohydrates (9.39-14.34%), total soluble solids (12.76-17.51 °Brix), and total sugars. Gutti Kul 2 had the highest vitamin C content (75.65 mg/100 g). The shelf-life evaluation revealed that Khurma Kul and Gutti Kul 2 retained their marketability the longest, while Apple Kul and BARI Kul 5 showed reduced longevity despite their superior nutrient profiles. **Research Limitations:** This study analyzed only four cultivars. **Originality/Value:** The study highlights that Apple Kul and BARI Kul 5 are promising for nutrition, while Khurma Kul and Gutti Kul 2 excel in shelf life. These findings suggest cultivar-specific strategies for ber cultivation and commercialization.

INTRODUCTION

Jujube (*Ziziphus mauritiana*) commonly known as ber or boroi in Bangladesh, tsao in China, and jujube or ber in India belongs to the *Rhamnaceae* family (Wilkins, 2007). This fruit has been cultivated for centuries across China, North America, Europe, North Africa, Australia, and the tropical and subtropical regions of Asia (Shahrajabian et al., 2020). One of the biggest producers of ber, China, produced 7,464,000 tons in 2019, which is around 90% of the global total (Dou et al., 2023). Among the 135 to 170 species, *Ziziphus mauritiana* Lam. and *Ziziphus jujuba* Mill. are widely cultivated in China, Taiwan, India, and Bangladesh (Li et al., 2005). These species display significant genetic diversity in fruit morphology, color, flavor, and other characteristics (Ma et al., 2011). Ber's long-standing popularity is attributed to its nutritional value and extensive medicinal applications, particularly in China, where it is used to treat liver disorders, chronic bronchitis, depression, and other conditions (Reche et al., 2018; Li et al., 2005). In Bangladesh, ber, locally referred to as ber, boroi, or kul, is a commercially significant fruit with a robust market presence. Though widely cultivated across the country, high-quality fruits are primarily produced in Rajshahi, Comilla, Khulna, Barishal, and Mymensingh. In the 2016-17 periods, ber cultivation spanned 7.06 thousand acres, with a production yield of 89.88 thousand metric tons (BBS, 2018). Ber plants in Bangladesh typically produce fruit twice a year, with flowering seasons in June–July and September-October (Hasan et al., 2022). Despite its prominence, there is limited research on the floral biology, nutritional value, and physicochemical characteristics of ber fruits grown locally.

The flowering and fruiting of ber vary across regions. For instance, in India, flowering occurs between April and June, with fruiting from January to March (Kulkarni, 2016), while in China, flowering happens from April to June and fruiting spans August to October. Ber flowers are small and pale yellow, with prominent pollinators including honeybees and wasps. A single flower's lifespan is brief (2-3 days), and many blossoms drop before pollination (Yao et al., 2015). However, information on the floral biology and fruiting habits of ber in Bangladesh is sparse. The consumption of ber fruits occurs in various forms, including fresh, dried, and processed varieties. These fruits are esteemed for their significant content of ascorbic acid, minerals, and carbohydrates, as highlighted in previous study (Larondelle, 2004). The fruits exhibit a wealth of vitamins, minerals, fibers, and phytochemicals, including ascorbic acid, thiamine, and riboflavin, as documented in various studies (Chen et al., 2019). The nutritional attributes of ber, along with its rich content of polyphenols and organic acids, position it as a nutritionally dense fruit. This unique profile suggests significant potential for its application in the food industry, particularly as a flavoring agent or in dried forms suitable for teas and infusions (Krška & Mishra, 2009).

Fresh ber, while rich in nutritional benefits, presents a challenge in terms of preservation. Its high moisture content significantly contributes to a reduced shelf life, leading to accelerated spoilage (Siddiq & Uebersax, 2012). The interplay of environmental factors, including temperature, humidity, and light, plays a crucial role in the development of flowers and fruits in ber. These elements significantly affect key processes such as sporogenesis, pollination, and fertilization. This, in turn, has significant implications for the quality of fruit and its shelf life.

This research aims to fill the existing gap in knowledge regarding the floral biology, physicochemical characteristics, and shelf life of ber fruits in Bangladesh. This study centers on four widely recognized cultivars- Apple Kul, Khurma Kul, BARI Kul 5, and Gutti Kul 2 - seeking to uncover those with exceptional agronomic, nutritional, and post-harvest characteristics. Understanding these factors is essential, as the flavor, nutrient composition,

and longevity of the fruit significantly impact consumer choices and its appeal in the marketplace.

MATERIALS AND METHODS

Examination of floral structures and determination of fruit development

From each of the four trees, three panicles were chosen at random, and all data were documented visually using a digital camera (Nikon D7500 DSLR). The process of data collection commenced with the onset of blooming in the plant and persisted with each observed alteration in the flowering stages, including initial flowering, duration of flowering, quantity of fruits per axil, and the ratio of male to female flowers, among other factors. The flowering time was documented at 4-hour intervals, commencing at 6:00 am and concluding at 6:00 pm. The categorization of phases was conducted in accordance with the methodologies established by Asatryan and Tel-Zur (2014).

Examination of physicochemical alterations and assessment of shelf-life

Collection and preparation of samples

Fresh ber fruits were collected by hand from the Chapainawabganj Ber Orchard (Table 1) at the Horticultural Research Station at the stage of green maturity, approaching ripeness (130 days' post full bloom). The fruits were systematically transferred to the postharvest laboratory located at the Regional Horticulture Research Station in Chapainawabganj, Bangladesh. The ambient circumstances were preserved, and the evaluation was conducted according to size, color, and the presence or absence of flaws and external damage. The experiment was conducted with four replications, each consisting of 20 fruits, utilizing a factorial, randomized, full-block design comprising three components.

Weight loss

The initial (Wi) and final (Wf) weights of the fruit were measured using a digital scale with a precision of 0.01 g, after a significant duration at a room temperature of 25°C. The weight loss (WL) observed in fruits using the formula (1):

$$\% \text{ Weight loss (WL)} = \frac{Wi - Wf}{Wi} \times 100 \qquad (1)$$

Where, WL = Weight loss (%); Wi = Initial weight (g); Wf = Final weight (g).

Moisture content

The measurement of moisture content was conducted following the procedure outlined by Karmas (1981). Following the measurement of the designated amount of raw material in a porcelain crucible, the sample was subjected to heating at 100°C for duration of approximately 6 hours within an electric oven. The procedure was conducted iteratively until a stable weight was achieved, and expressed as g/100g of the edible portion of Ber through the application of the formula (2):

$$\% \text{ Moisture} = \frac{\text{Weight of the moisture}}{\text{Weight of the ber sample(edible portion)}} \times 100 \qquad (2)$$

Table 1. Designation and developmental stage of ber cultivars.

Name of the fruits	Maturation Status of Fruits
Apple kul	Matured, nearly ripe
Khurma kul	Matured, nearly ripe
BARI kul 5	Matured, green
Gutti kul 2	Matured, nearly ripe

Measurement of pH

A standard procedure involving the use of a pH meter was employed to assess the pH level of ber. A pH 7.0 buffer tablet (BDH Chemicals LTD. Pools, England) was utilized in conjunction with distilled water to prepare the standard buffer solution, which was then diluted to the specified volume of 100 ml (Islam et al., 2016).

Measurement of titratable acidity (TA)

The total titratable acidity was calculated using the Folin technique as described by Bernard & Jacobs (1965). A standard solution of NaOH (0.1 N) and a 1% solution of phenolphthalein were utilized as reagents.

Assessment of total ash

The ash content was assessed utilizing the method established by Jayaraman (1981). In a thoroughly cleaned porcelain crucible, a sample of 6 to 10 grams of edible ber fruit was subjected to heating at approximately 100°C, subsequently cooled, and then accurately weighed. The percentage of ash content (g per 100 g of Ber sample) was determined using the following formula (3):

$$\% \text{ Ash} = \frac{\text{Weight of the ash obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (3)$$

Assessment of total soluble carbohydrates

The phenol sulphuric acid technique, as described by Dubois et al. (1956), was employed to determine the total soluble carbohydrates. Following the extraction of the sample, the spectrophotometer recorded the wavelength of the sample at 490nm. The following formula was employed to determine the proportion of total soluble carbohydrates, specifically the percentage of total soluble carbohydrates (g per 100 g of ber sample) using the following formula (4):

$$\text{Total soluble carbohydrates (g/100g)} = \frac{\text{Weight of total soluble carbohydrate obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (4)$$

Assessment of total soluble protein content

The soluble protein content of the ber sample was determined according to the method established by Lowry et al. (1951). The methods described above were employed to prepare the sample. A series of nine glass test tubes were utilized to prepare varying volumes of the standard protein solution, specifically 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, and 0.8 milliliters. Each tube's volume was subsequently adjusted to one milliliter by the addition of sterilized distilled water (SDW). A test tube containing 1 ml of the sample was prepared, along with a duplicate for verification purposes. After duration of 10 minutes, each test tube received an addition of five milliliters of the 1+2 mixture along with 0.5 milliliters of the FCR solution. Following duration of 30 minutes, the absorbance of the solution at 650 nm was assessed utilizing a

spectrophotometer. The sample, expressed as a percentage of soluble protein (g per 100 g of ber sample). Total Soluble Protein content was calculated using the following formula (5):

$$\text{Total soluble protein (g/100g)} = \frac{\text{Amount of soluble protein obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (5)$$

Total soluble solids (TSS)

A digital refractometer (model N-20; Atago, Bellevue, WA, USA) was employed to measure total soluble solids (TSS) at a temperature of 20°C. The findings were documented in °Brix.

Total sugar

The total sugar content of an edible portion of ber was assessed utilizing the Anthrone method (Jayaraman, 1981), a notable scientific procedure. For the preparation of the sample, approximately 4-6 g of the edible portion of ber was utilized, and the extraction of the sugar solution was conducted according to the specified methods. The absorbance of the blue-green solution was measured at 680 nm using a Gallen Kamp color spec colorimeter. Finally, the subsequent formula (6) was employed to determine the proportion of free sugar in the ber.

$$\text{Total sugar (g/100g)} = \frac{\text{Weight of sugar}}{\text{Weight of the ber sample}} \times 100 \qquad (6)$$

Reducing sugar content

The reducing sugar content in the ber sample was determined utilizing the DNS (dinitro salicylic acid) method, as outlined by Miller (1959).

Assessment of non-reducing sugar content

The proportion of non-reducing sugar, calculated as a percentage of the total sugar excluding reducing sugar as expressed as (g/100 g) of ber sample.

Assessment of vitamin C

The evaluation of vitamin-C content was conducted utilizing the Folin-Ciocalteu reagent (FCR) method as described by Jagota & Dani (1982), representing a scientifically rigorous approach. The reagents employed in this study include 2.0 M Flolin-Ciocalteu, 10% trichloroacetic acid (TAA), 80% methanol, and standard vitamin C (Kumar et al., 2017).

Assessment of β-Carotene

The quantification of β-carotene in the ber sample was conducted utilizing third-derivative ultraviolet spectrophotometry, adhering to the methodologies outlined by Souri et al. (2005). The optical density of the sample's clear filtrate was assessed at 440 nm using a UV spectrophotometer. The blank consisted of n-butanol that had been thoroughly soaked with water. The quantity of β-carotene in the ber sample was determined using the formula (7) and is expressed as mg/100g.

$$\text{β-Carotene (mg/100g)} = \frac{\text{mg of β carotene obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (7)$$

Determination of calcium content

The determination of calcium content in the ber sample was conducted using the Colorimetric method as outlined by Stern and Lewis (1957). The methodologies employed facilitated the generation of the requisite sample and the removal of the violet hue, while a

spectrophotometer was utilized to assess the absorbance at 570 nm. The calcium content of the Ber sample was determined through the application of the standard curve, expressed in mg/100g of the Ber sample using the following formula (8):

$$\text{Calcium (mg/100g)} = \frac{\text{(mg) of calcium obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (8)$$

Determination of phosphorus and iron content

The colorimetric technique was employed to ascertain the phosphorus and iron content in the ber sample (Fiske & Row, 1925). The sample was carefully pipetted along with all reagents utilized in the proposed methods. The absorbance was subsequently measured at 420 nm and 510 nm using a spectrophotometer to determine the phosphorus and iron content, respectively. The quantification of phosphorus (P) and iron (Fe) in the ber sample was achieved through the application of the standard curve, with results articulated as mg/100g of the ber sample using the following formula (9):

$$\text{Phosphorus/Iron (mg/100g)} = \frac{\text{mg of phosphorus/iron obtained}}{\text{Weight of the ber sample}} \times 100 \qquad (9)$$

Shelf-life (days)

The assessment of fruits' shelf-life at ambient temperatures involved the evaluation of non-marketability factors, which included decay or damage, shriveling, skin browning, ripening state, and unusual flavor.

Statistical analysis

The samples were examined in triplicate, and the means of three results with SD (standard deviation) were provided. The Statistical Package for the Social Sciences (SPSS, version 25.0; University of Washington, Seattle, WA, USA) was used for the statistical evaluation of all the parameters, and a one-way analysis of variance (ANOVA) for mean differences was used to assess the significance of the results.

RESULTS AND DISCUSSION

Floral biology and fruiting of ber cultivar

The study of the floral biology and fruiting characteristics of four ber cultivars demonstrated significant differences, especially concerning flowering traits and fruit set efficiency (Table 2, Fig. 1). Among the cultivars, the flowering initiation difference was very short. The first flowering was happened in Khurma kul (8th September) followed by Apple kul (9th September) and comparably delayed flowering in Gutti kul-2 (13th September). In similar studies, Early flower initiation was recorded in Gola (16-21August) whereas, comparatively delayed in Umran (24-31 August). In the last week of September, the flowering was ended (85-90%) flower open (Hardeep et al., 2022).

Each cultivar has a comparatively constant amount of flowers, which can be utilized as an additional characteristic to identify the cultivar (Yao et al., 2015). In our study, Apple Kul exhibited the greatest flower density per axil, recorded at 35, alongside a male-to-female flower ratio of 3:1, establishing it as the most prolific flowering cultivar. In the USA, Yao et al. (2015) reported, only two to three flowers were present on each node of the extremely little fruit of "Abbeville," while the medium-sized fruit of "Zhongning" similarly had few flowers. Both ‘Abbeville’ and ‘Zhongning’ had good fruit set each year.

Table 2. Floral biology and fruiting of ber cultivars.

Cultivar	First Flowering	Flowering duration (Days)	No. of flowers per axil	Male Flower	Female Flower	Male and Female Ratio	No. of fruit per axil
Apple Kul	9th September	58	35	32	3	10.67	2
Khurma Kul	8th September	56	18	15	3	5.00	2
BARI kul 5	10th September	59	21	17	4	4.25	3
Gutti Kul-2	13th September	60	14	10	4	2.50	2
Mean		58.25	22	18.5	3.5	3.78	2.25
Range		58-60	14-35	10-32	3-5	2.50-10.67	2-3

However, its fruit set per axil, measured at 2, was similar to that of Khurma Kul and Gutti Kul-2. Gutti Kul-2, despite presenting the lowest flower density at 14 per axil, demonstrated an extended flowering duration of 60 days, albeit with the least reproductive efficiency observed. BARI Kul 5 emerged as the most productive variety, attaining the highest fruit set per axil (3) while exhibiting balanced flowering characteristics. The flowering duration across the cultivars exhibited consistency, spanning 58 to 60 days. This duration is notably shorter than the ranges documented by Babu and Kumar (1998), which extend from 68 to 94 days, as well as those reported by Dhaliwal and Bal, ranging from 57 to 75 days (Pareek et al., 2007). Larondelle (2004) noted a significant variation, identifying the shortest flowering period at 47 days in Tikadi, while the longest duration was recorded at 71 days in Umran. According to the result of Hardeep et al. (2022), the minimum flowering duration was recorded in Gola (49 days) while, the maximum flowering duration was recorded in Umran (62 days), followed by Kaithli (57 days). In contrast, flowering to fruit set was recorded in Goma Kirti (16 days), while the maximum time taken from flowering to fruit set was recorded in Umran (21 days), followed by Thar Bhubhraj (20 days) (Hardeep et al., 2022).

In South China, Indian ber varieties that are planted in spring exhibit blooming during the fall or winter (Pareek et al., 2007). The results highlight the distinctive floral and fruiting characteristics of the examined cultivars in relation to their specific local environments, with BARI Kul-5 demonstrating the highest productivity in fruit set and Apple Kul exhibiting the greatest flowering abundance.

Physicochemical properties of fresh ber

The physical properties of the selected ber cultivars demonstrated significant variability, aligning partially with previous studies (Table 3). For instance, this study found the highest moisture content in Apple Kul (85.18 ± 0.07%) and Khurma Kul (85.53 ± 0.23%), which is consistent with Yan et al. (2022) reported in this study, the highest moisture content varied between 89.31% and 86.52% in the matured fruit stage. Our study also in line with (Wojdyło et al., 2016; Pareek, 2013) found the moisture content contain (81–83%) in ber fruits. Additionally, Guti Kul-2 exhibited the lowest moisture content (79.00 ± 0.70%) and the highest dry matter content (19.17 ± 0.70%), closely corresponding to findings by Islam et al. (2016), where Gutti Kul had the highest dry matter (20.5%) and ash percentage.

Table 3. Physical properties of selected ber cultivars.

Cultivars	Fruit weight Mean ± SD	Stone weight (%) Mean ± SD	Edible portion (%) Mean ± SD	Moisture (%) Mean ± SD	Dry matter (%) Mean ± SD
Apple Kul	23.63^{cd}± 0.91	10.31^{b} ± 1.20	89.69^{b} ± 1.40	85.18^{a} ± 0.07	14.61^{bc} ± 0.10
Khurma Kul	31.45^{a}± 1.07	14.32 ^{a}± 1.00	86.68 ^{b}± 1.78	85.53 ^{a}± 0.23	15.68^{b} ± 3.43
BARI 5	27.00^{b}± 1.36	9.24 ^{c}± 0.15c	90.76 ^{a}± 0.62	84.83 ^{a}± 0.47	15.00^{b} ± 1.00
GUTI KUL 2	24.33^{c}± 1.53	7.43 ^{bc}± 1.76	92.57 ^{a}± 1.02	79.00 ^{b}± 0.70	19.17^{a} ± 0.70
LSD (5%)	2.33	2.22	2.40	0.83	3.42
The significance level	**	**	**	ns	**

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.

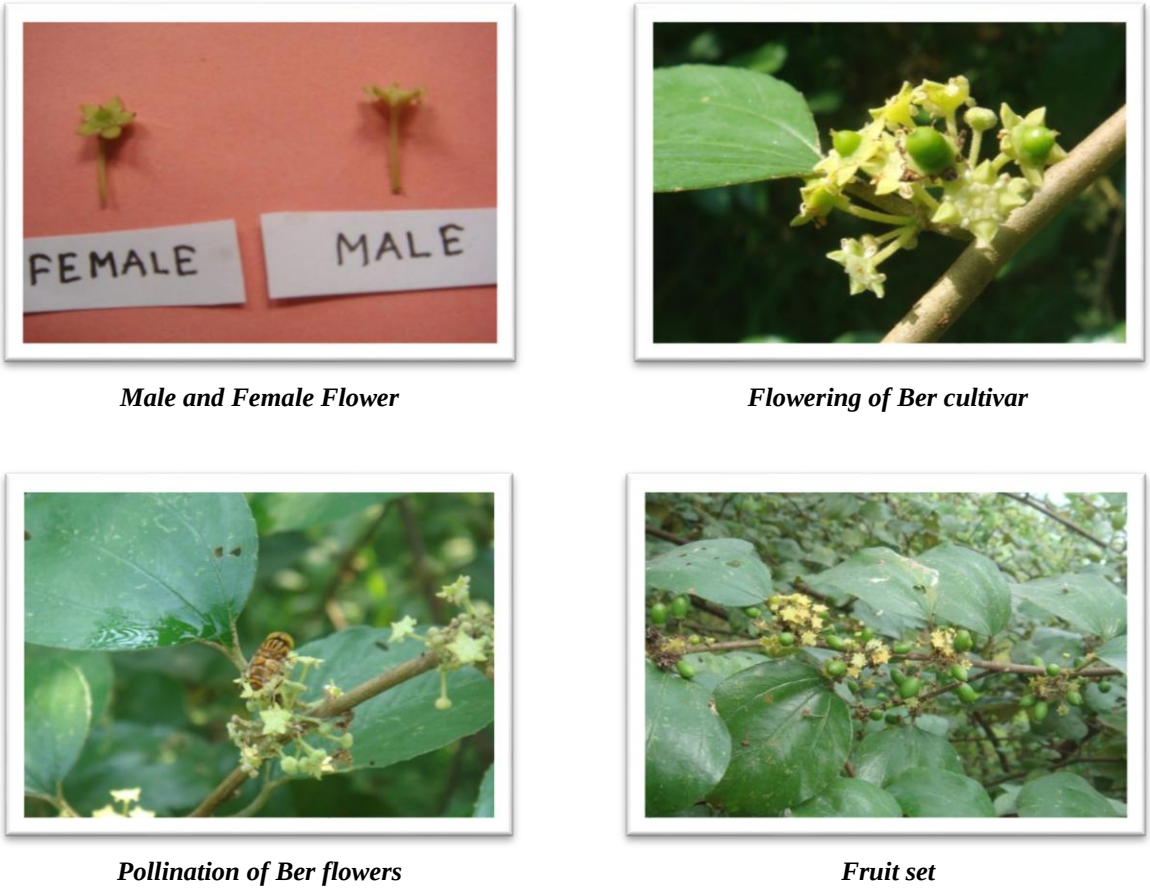
In terms of edible portions and stone weight, Guti Kul-2 stood out with the highest edible portion (92.57 ± 1.02%) and lowest stone weight percentage (7.43 ± 1.76%), suggesting superior flesh-to-stone ratios. This contrasts with Khurma Kul, which showed the highest stone weight percentage (14.32 ± 1.00%) but a relatively lower edible portion (86.68 ± 1.78%). On the other hand, Ivanišová et al. (2017) reported, genotype ZJ1 had the lowest fruit weight (2–2.52) g, and the percentage of stone to fruit weight was 12.3%. The producers are particularly interested in ber genotypes with large stones than those with smaller stones. While (Islam et al., 2016) found BARI Kul-2 to have a significantly lower dry matter content (0.72%), this study highlighted BARI Kul 5 for its balanced physical traits, including a high edible portion (90.76 ± 0.62%) and low stone weight (9.24 ± 0.15%).

The Physicochemical properties of selected Ber cultivars demonstrate notable differences (Table 4 and Table 5). Apple Kul is distinguished by its elevated carbohydrate content of 14.34% and total soluble solids at 17.51%, establishing it as the sweetest cultivar. Our findings regarding soluble solid content were in line with Gao et al. (2014) study. In contrast, Guti Kul 2 is recognized for its superior protein level of 1.31% and ash content of 0.65%, albeit with a lower pH of 4.17 and total soluble solids measuring 12.76%. Khurma Kul demonstrates the lowest acidity at 0.29% and a moderately elevated total soluble solid (TSS) of 17.47%. In contrast, BARI 5 shows the highest acidity at 0.30%, alongside the lowest carbohydrate content at 9.39% and a TSS of 15.26%, indicating a distinctly tart flavor profile. The statistically significant differences observed for most traits ($p < 0.05$) underscore the distinct nutritional and flavor profiles among the cultivars, with Apple Kul and Guti Kul 2 demonstrating superior sweetness and protein content, respectively.

Table 4. Physicochemical properties of selected ber cultivars (Mean ± SD).

Cultivars	pH	Acidity (%)	Ash %	Carbohydrate (g) /100g	Soluble Protein (g) /100g	TSS%
Apple Kul	4.58^{b} ± 0.17	0.16 ^{b} ± 0.02	0.50^{b} ± 0.10	14.34^{a} ± 0.97	1.10 ^{ab} ± 0.08	17.51^{a} ± 1.63
Khurma Kul	5.96^{a} ± 0.06	0.29^{b} ± 0.02	0.60^{b} ± 0.10	10.54^{c} ± 1.20	0.78^{b} ± 0.02	17.47 ^{ab} ± 1.00
BARI 5	4.50 ^{b} ± 0.05	0.30 ^{a} ± 0.02	0.63^{ab}± 0.08	9.39^{c} ± 0.73	0.79^{c} ± 0.01	15.26^{c} ± 0.41
GUTI KUL 2	4.17^{c} ± 0.03	0.14 ^{c} ± 0.02	0.65^{a} ± 0.07	12.66^{b} ± 0.38	1.31^{a} ± 0.49	12.76 ^{cd} ± 0.29
LSD (5%)	0.18	0.04	0.17	1.65	0.47	1.86
The significance level	ns	ns	ns	**	**	**

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.



Male and Female Flower

Flowering of Ber cultivar

Pollination of Ber flowers

Fruit set

Fig. 1. Flowering, pollination, and fruit set characteristics of selected ber cultivars.

Table 5. Sugar profiles and vitamin C content in selected ber cultivars (Mean ± SD).

Cultivars	Total sugar g//100g	Red. Sugar g/100g	Non reducing Sugar(g) /100g	Vitamin C mg/100g
Apple Kul	6.23a ± 0.28	1.28^{a} ± 0.20	4.95^{a}±0.47	45.10^{bc}±5.18
Khurma Kul	4.97c ± 0.07	1.53^{a} ±0.15	3.44^{c}±0.21	48.22^{b} ±2.00
BARI 5	4.32c ± 0.28	1.21^{b} ±0.12	3.10^{c}±0.16	75.65^{a}±3.01
GUTI KUL 2	5.30b ± 0.20	1.30^{bc}±0.10	4.00^{b}±0.17	43.58^{c}±2.87
LSD (5%)	0.42	0.28	0.53	6.53
The significance level	ns	ns	ns	**

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.

Table 5 (*Continued*). Micronutrient composition of selected ber cultivars (Mean ± SD).

Cultivars	β-Carotene mg/100g	Calcium (Ca) mg/100g	Iron(Fe) mg/100g	Phosphorus(P) mg/100g
Apple Kul	0.02^{a}±0.02	41.06^{b}±0.52	0.14^{b} ± 0.03	12.42^{bc}±0.81
Khurma Kul	0.03^{a}±0.03	25.32^{d} ±1.04	0.12^{bc}± 0.02	19.19^{a} ±0.79
BARI 5	0.02^{a}±0.01	34.00 ^{c}±2.65	1.45^{a} ± 0.52	2.66^{c}±0.59
GUTI KUL 2	0.03^{a}±0.01	48.07^{a}±1.01	0.15^{ca}± 0.03	17.96^{b}±0.88
LSD (5%)	0.03	2.88	0.49	1.46
The significance level	ns	**	ns	**

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.

The acidity levels documented in this investigation (spanning from 0.14% to 0.30%) align with the acid content of previous reports (Pareek, 2013), identified 0.3–2.5% acids in Chinese Ber pulp. In a comparable manner, the TSS values observed in this study (spanning from 12.76 °Brix to 17.51 °Brix) correspond with the results presented by Mohd et al. (2020), who noted notably elevated TSS in *Z. mauritiana* fruits (11.70 °Brix). With their unique flavors and nutritional profiles, the ber cultivars Apple Kul, Guti Kul 2, Khurma Kul, and BARI 5 are suggested for fresh consumption, protein-rich nutritious goods, pickles, jams, and moderate acidity.

The biochemical analysis of the selected Ber cultivars reveals notable differences in essential nutrients. The total sugar content in Apple Kul is the highest at 6.23%, with Khurma Kul following at 4.97% and BARI 5 at 4.32%. Guti Kul 2 is positioned in the middle with a sugar content of 5.30%. The highest content of non-reducing sugars is observed in Apple Kul at 4.95%, while Khurma Kul and BARI 5 exhibit lower levels at 3.44% and 3.10%, respectively. Our results consistent with Pareek et al. (2009) findings were total Sugars (g) (5.4-10.5), Reducing Sugars (g) (1.4-6.2), and Non-Reducing Sugars (g) (3.2-8.0). The variations among the cultivars for sugars content were probably due to genetic make-up, agronomic practices and position of fruits on the tree in respect to sunlight.

BARI 5 exhibits remarkable vitamin C content, measuring at 75.65 mg, which is considerably higher than that of the other cultivars. In previous study, Koley et al. (2016) discovered the differences in ascorbic acid content in ber cultivars. The vitamin C differed among the cultivars possibly due to genetic factors, cultural practices and ripening stage. Across all cultivars, β-Carotene levels are relatively low, with Khurma Kul and Guti Kul 2 exhibiting marginally higher values in comparison to Apple Kul and BARI 5. The highest levels of calcium (Ca) are observed in Guti Kul 2, measuring 48.07 mg, while the lowest levels are found in Khurma Kul at 25.32 mg. The content of Iron (Fe) exhibits variation among different cultivars, with BARI 5 presenting the highest concentration at 1.45 mg, whereas Apple Kul and Guti Kul 2 display comparable, moderate levels. The phosphorus (P) content is observed to be highest in Khurma Kul at 19.19 mg; whereas BARI 5 exhibits the lowest value at 2.66 mg. Notable differences ($p < 0.05$) were observed for the majority of traits, especially concerning vitamin C, calcium, and iron. The biochemical findings presented herein are consistent with, and in certain instances contrast with, earlier investigations. The vitamin C content in the cultivars varies, with Guti Kul 2 presenting 43.58 mg and BARI 5 showing 75.65 mg. These values are significantly lower than those documented by Pareek (2013), which indicated that Chinese ber cultivars had ascorbic acid content ranging from 192 to 359 mg/100g. The findings indicate that the cultivars examined in this study could exhibit comparatively lower levels of ascorbic acid when juxtaposed with those found in Chinese ber. Furthermore, although BARI Kul-2 was noted to possess the highest phosphorus content (24.30 mg) according to Islam et al. (2016), the current study identifies Khurma Kul as having the highest phosphorus level (19.19 mg), albeit still below that of BARI Kul-2. The calcium content of Guti Kul 2 in this study (48.07 mg) aligns with the findings of Islam et al. (2016), which indicated that Gutti Kul possesses the highest calcium levels (55.25 mg).

In this study, Khurma Kul exhibited a calcium content of 25.32 mg, which is lower than the 25.12 mg found in Comilla Kul, as reported by Islam et al. (2016). The comparisons highlight the differences in nutrient content among various cultivars and regions, with the present study focusing on a reduced range of specific nutrients such as vitamin C, while maintaining consistency in the findings related to calcium and phosphorus.

Biochemical changes and post-harvest shelf-life determination

The biochemical changes observed in Ber cultivars during storage at 25°C reveal significant modifications in weight, total sugar content, and acidity levels (Table 6). All cultivars exhibited weight loss, with BARI 5 demonstrating the most significant percentage decrease at 34.59%, while Apple Kul recorded the least at 18.62%. The notable decrease in weight is probably indicative of moisture loss occurring over a period of time. Bhowmick et al. (2015) reported that uncoated ber fruits lost 24.46% of their weight at 12 days after storage. The analysis revealed an increase in total sugar across all cultivars, with the most significant percentage rise noted in Apple Kul at 61.75%, succeeded by Khurma Kul at 56.27%. The observed rise in sugar content is characteristic of the ripening and dehydration processes that fruits experience, leading to a content of sugars. All cultivars exhibited a decrease in acidity, with BARI 5 demonstrating the most significant reduction at 68%, suggesting a notable decline in tartness throughout the storage period. The findings indicate that Khurma Kul and Guti Kul 2 underwent notable reductions in acidity, measuring 64% and 50%, respectively. The observed biochemical alterations indicate that storage at ambient temperature expedites the ripening process, enhancing sweetness through increased sugar content and diminishing tartness by lowering acidity, concurrently leading to weight reduction attributed to water evaporation.

The Biochemical alterations and evaluation of post-harvest shelf-life in the chosen Ber cultivars indicate variations in their stability after harvest (Table 7). The analysis revealed an increase in Total Soluble Solids (TSS) across all cultivars, with Apple Kul exhibiting the most significant rise at 32.16%, while Guti Kul 2 demonstrated the greatest decline in TSS, recorded at 58.37%. This indicates that Apple Kul preserves a greater quantity of its soluble sugars as time progresses, thereby increasing its sweetness throughout the storage period. The analysis revealed a reduction in Vitamin C content across all cultivars, with BARI 5 exhibiting the most significant decline at 74.80%. This suggests a greater vulnerability to ascorbic acid degradation in BARI 5 relative to the other cultivars. The determination of shelf life was conducted by assessing the quality retention of the fruit. Both Apple Kul and Khurma Kul exhibited a shelf life of 10 days, whereas BARI 5 demonstrated a marginally extended shelf life of 11 days. Guti Kul 2 exhibited the briefest shelf life, lasting only 8 days, likely attributable to its elevated rate of biochemical degradation. The findings indicate that BARI 5 exhibits the most extended shelf life and preserves a higher content of vitamin C, whereas Guti Kul 2 demonstrates the least shelf life, potentially restricting its marketability for prolonged storage. The results of this investigation align with earlier studies that emphasize the limited shelf life of Ber fruits.

Hesami et al. (2021) highlighted the issue of limited storage duration in ber, presenting a considerable obstacle to the advancement of its industry. This observation is consistent with the findings of the present study, which revealed that Guti Kul 2 exhibited the shortest shelf life of 8 days, while Apple Kul and Khurma Kul demonstrated shelf lives of 10 days. In a similar vein, Aboutalebi et al. (2014) observed that the processes of postharvest handling and transportation contribute to a reduction in the shelf life of the fruit, a conclusion reinforced by the notable deterioration evident in all cultivars following storage. The findings further support the conclusions drawn by Larondelle (2004), indicating that Z. mauritiana fruits are unable to be stored for over 10 days in ambient conditions without experiencing significant deterioration. Hesami et al. (2021) reported that, the untreated ber fruits being stored at 25°C were completely unmarketable in 14 days after storage. This study underscores the concept that ber fruits exhibit restricted postharvest durability and necessitate meticulous management to prolong their shelf life.

Table 6. Changes in weight, total sugar, and acidity of ber cultivars during storage at 25 °C.

Cultivars	Weight (Mean ± SD)			Total Sugar (Mean ± SD)			Acidity (Mean ± SD)		
	Initial day	Final Day	% Loss	Initial Day	Final Day	% Increase	Initial Day	Final day	% Decrease
Apple Kul	23.63^{b}±0.91	19.33^{a}±2.00	18.62	6.38^{a}±0.17	12.32^{a}±2.08	61.75	0.16^{a}± 0.02	0.09^{a} ±0.01	43.75
Khurma Kul	31.45^{a}±1.07	21.80^{a}±1.38	30.68	5.26^{a}±0.32	12.22^{a}±0.91	56.27	0.25^{a}± 0.05	0.09^{a} ±0.02	64
BARI 5	27.00^{a}±1.36	17.66^{b}±1.58	34.59	4.46^{a}±0.28	9.78^{b}±0.67	52.01	0.25^{a} ±0.05	0.08^{a} ±0.02	68
GUTI KUL 2	24.33^{b}±1.53	19.12^{a}±1.16	24.41	5.04^{a}±0.51	11.71^{a}±1.23	34.63	0.12^{a} ±0.02	0.06^{a} ±0.02	50

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.

Table 7. Changes in TSS, vitamin C content, and shelf life of selected ber cultivars during storage at 25 °C.

Cultivars	TSS (Mean ± SD)			Vitamin-C (Mean ± SD)			Shelf Life
	Initial day	Final Day	%Loss	Initial Day	Final day	%Loss	Mean ± SD
Apple Kul	15.64^{a} ± 1.40	20.67^{a} ± 1.53	32.16	42.76^{c} ±1.67	22.20^{b} ±0.69	48.08	10.00^{a} ±1.00
Khurma Kul	15.75^{a} ± 1.39	21.67^{a} ± 2.52	37.58	52.01^{b} ±3.11	29.30^{a} ±7.56	43.64	9.00^{a} ±1.00
BARI Kul 5	14.60^{a}± 1.04	18.33^{b} ±2.08	25.54	76.69^{a} ±1.78	19.32^{b} ±1.15	74.80	11.00^{a} ±1.00
GUTI KUL 2	11.46^{b}± 1.26	18.15^{b} ±0.99	58.37	41.57^{c} ±3.55	16.47^{c} ±1.08	60.38	8.00^{b} ±1.00

Means ± SDs followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤0.05) according to the LSD test. ** and ns indicate significance at 5% and non-significance levels, respectively.

Correlations Analysis

The analysis demonstrates notable associations among biochemical parameters and the postharvest traits of ber cultivars. For plant breeders, a correlation analysis is an essential technique that allows them to examine relationships between different qualities and simultaneously improve features that are favorably associated with each other (Anwar et al., 2009). The analysis reveals a negative correlation between moisture content and dry matter (r = -0.75), indicating that increased moisture levels correspond to decreased dry matter. In a similar vein, the total sugar content exhibits a strong positive correlation with non-reducing sugar (r = 0.97), suggesting a concurrent increase in these sugars, whereas the correlation with reducing sugar is less pronounced.

Previous research findings revealed that reducing sugars had highly significant but negative correlation (-0.76) with non-reducing sugars and Vitamin C had significant and negative (-0.57) correlation with reducing sugars (Anjum et al., 2018). Kumar et al. (2024) reported, TSS and TA (citric acid equivalent) were significantly positively correlated with ascorbic acid concentration. A significant inverse relationship is identified between vitamin C and carbohydrates (r = -0.82), indicating that an increase in carbohydrate content corresponds with a reduction in vitamin C levels. In Vitamin C showed positive association with viscosity (0.58) and TA (0.47) while negatively with ash (-0.77). Phenotypic relationships are significantly influenced by environmental factors (Kumar et al., 2017).

Furthermore, pH exhibits a notable positive correlation with acidity (r = 0.62), while calcium demonstrates a robust negative correlation with both pH and acidity (r = -0.88 and r = -0.88, respectively). Variation of arils biochemical traits such as TA, TSS and anthocyanin content was reported in Turkish pomegranate genotypes (Caliskan & Bayazit, 2013). This indicates that an increase in calcium content may lead to a decrease in the acidity of the fruit. The shelf life of ber exhibits a positive correlation with both initial and store weight (r = 0.86 and r = 0.72, respectively), suggesting that fruits of greater weight are associated with an extended shelf life. Moreover, the analysis indicates a negative correlation between the edible

portion and shelf life (r = -0.73), suggesting that an increased edible portion may result in accelerated deterioration. According to earlier studies, several physicochemical factors have been found to have a significant positive relationship or association with certain tropical fruits (Ejiako et al., 2023). The observed correlations highlight the intricate relationships among biochemical factors and postharvest characteristics, which significantly affect the quality and storage capabilities of the fruit.

CONCLUSION

Ber rank among the most widely consumed and nutritious fruits in Bangladesh, possessing considerable commercial value, particularly due to their availability during periods when other fruits are limited. They serve as a crucial component of the diet, fulfilling the nutritional requirements of the population. This study aimed to explore the nutritional composition, flowering characteristics, and post-harvest longevity of four ber cultivars cultivated in Chapainawabganj, Bangladesh. Significant variations were observed among cultivars regarding floral traits, physicochemical attributes, post-harvest alterations, and shelf-life efficacy. The study elucidated the exceptional floral behavior exhibited by cultivars such as Apple Kul, Khurma Kul, and BARI Kul 5, alongside their elevated levels of vitamin C and total sugar content. The study revealed alterations in TSS, carbohydrates, and vitamin C levels during storage at room temperature. The cultivars BARI Kul-5 and Apple Kul demonstrated the most extended shelf lives observed in the study. The results indicate that ber fruits serve as a significant source of essential vitamins and minerals, with fresh consumption recommended to maximize nutritional advantages. Subsequent investigations ought to emphasize the creation of processed ber products that preserve superior quality for extended periods of storage.

Conflict of interest

There are no disclosed conflicts of interest for the authors.

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