Stewart Postharvest Review
An international journal for reviews in postharvest biology and technology

# Postharvest physiology and storage of ber

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## Abstract
**Purpose of review:** This article reviews studies conducted on maturity indices, climacteric behaviour, artificial ripening, and pre- and postharvest treatments, which affect the shelf-life, packaging, storage and postharvest pathology of ber fruits.
**Findings:** Ber fruits show climacteric respiration behaviour. Various maturity indices including colour, total soluble solids, harvesting date, days from full bloom to maturity, etc, have been characterised. The postharvest quality and shelf-life of ber fruits are influenced by both pre- and postharvest factors; plant growth regulators, stage of maturity, composition of fruits, storage conditions, type of storage and packaging have been identified as important factors. Low storage temperatures (3–5°C) can extend the shelf-life beyond 2–3 weeks.
**Limitations:** Ber is largely found in India and not much advanced research has been carried out on this fruit. To date standardised storage conditions are not available for commercial recommendations. Controlled and modified atmosphere use has not been investigated.
**Directions for further research:** More attention should be focused on characterising the physiology of ber fruit, including ripening, gene expression, protein synthesis and regulation of enzymes catalysing sugar formation and translocation. Reliable maturity and international standards, with respect of quality, should be developed. Low temperature storage methods such as controlled and modified atmosphere should be studied and standardised, and ethylene management with 1-methylcyclopropene should be investigated.

**Keywords:** ber; maturity; storage; ripening; preharvest factors; postharvest factors

**Abbreviation**

| | |
|---|---|
| **PLW** | Physiological weight loss |
| **TSS** | Total soluble solids |
| **ZECC** | Zero energy cool chamber |

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**Stewart Postharvest Review 2009, 5:5**
Published online 01 October 2009
doi: 10.2212/spr.2009.5.5

## Introduction
Ber is a tropical and subtropical fruit native to the northern hemisphere [1]. It belongs to the genus *Ziziphus* of the family Rhamnaceae and order Rhamnales. The family has 50 genera and more than 600 species [2] of which the species *Z. jujube* Mill (Chinese jujube or Chinese date), *Z. mauritiana* Lamk (Indian jujube or ber) and *Z. spina-christi* (L.) wild (Christ's thorn) are the most important in terms of distribution and economic significance. *Z. mauritiana* is commonly cultivated throughout the northwest of India and in the drier parts of South India [3–5]. Ber is also found in disturbed areas near settlements and along roads in African countries [6] where fruits are harvested from naturally-seeded plantations and sold in local markets. *Z. jujube* Mill is cultivated in China, Korea and in parts of Southeast Africa [7]. Ber is considered an underutilised fruit crop in semi-arid regions of the world and can be successfully cultivated in the marginal ecosystem of the subtropics and tropics [8].


Online ISSN:1945-9656
www.stewartpostharvest.com

**Figure 1. Mature ber fruits**

Ber fruit is generally eaten fresh and is a rich source of ascorbic acid, essential minerals and carbohydrates [9–17]. It is richer than apple and mango in vitamin C, protein and minerals and contains higher phosphorus and iron than orange [18]. In general, the fruits contain 85.9% moisture, 12.8% carbohydrates, 0.8% protein, 0.1% fats, 0.8% iron, 0.03% each of calcium and phosphorus, and 70 I.U. vitamin A/100 g with an energy value of 55 calories/100 g [19]. Physico-chemical characteristics of major ber cultivars are provided in Table 1.

Extensive studies have been carried out using ber fruits to prepare various processed products, such as candy [13, 20–26], dehydrated products [26–32], juice and wine [25, 33, 34], jam and jelly [21, 35], and shreds and powder [36].

The storage life of ber fruits is extremely short and the rapid perishability of the fruits is a problem. At ambient temperature a shelf-life of 2–4 days is common. Due to the surplus of fruits in the local markets during peak season, a substantial quantity goes to waste, resulting in heavy postharvest losses. A cost and returns analysis performed by Gupta *et al.* [37] showed that ber production is highly remunerative but requires proper handling with respect to preharvest, harvesting and postharvest treatments, packaging, transportation, storage, postharvest pathology, processing, etc [38]. Profits could be enhanced if efforts to increase production are supplemented with efforts to minimise postharvest losses and enhance shelf-life. The purpose of this review is to examine the literature related to ber research, much of which have been carried out in India, to determine what is known about postharvest events in ber and to outline the knowledge required in order to extend the storage life of this fruit while maintaining nutritional and sensory quality.

## Determination of harvesting time

Maturity determination at harvest is one of the most important factors that determine storage life and fruit quality. Immature fruits are more subject to shrivelling and mechanical damage, and are of inferior quality when ripe. Overripe fruits are likely to become soft and mealy with insipid flavour soon after harvest. Fruits harvested either too early to too late are more susceptible to physiological disorders and have a shorter storage life than fruits picked at the proper maturity [39, 40]. Ber fruits that are allowed to ripen on the tree normally have a shorter shelf-life, and the best results were obtained when fruits were picked before the onset of ripening [41–43]. The development of fruit skin colour is one of the most reliable maturity indices. Fruits are harvested at the mature golden yellow stage for Umran [44] and Kaithli [45] cultivars, and at the mature green stage for Mallaey and Bambadawi [46] cultivars.

The time required for ber fruits to develop from fruit set to maturity is dependent on cultivar and location. In general ber fruits required about 150–154 days from fruit set to maturity [47–49]. The development period of fruit from fruit set to maturity was 108 days in cultivar Gola [44], 147 days in cultivar Umran [44], 150 days in cultivar Jogiya [50] and 135 days in cultivar Banarasi Karaka [51]. However, the time required for full maturity was 170–180 days for Kaithli and ZG-2 cultivars [52], 180 days for cultivar Sanaur-2 [53]and 180–190 days for cultivar Umran [54, 55]. Ber cultivars grown in Hisar, India could be harvested 120 days after fruit set [56]. Neog *et al.* [57] observed that the interval between fruit set and maturity was 130 days, implying location as a factor. Gupta and Kadam [25] suggested that harvesting of fruits at appropriate maturity is vital for improving the shelf-life and quality of the fruits. The difference between fruit set and maturity in days might be dependent on edaphic factors, climatic factors and cultivar characteristics.

Several physiological and biochemical changes in maturing ber have been assessed as possible maturity indices. Such changes include an increase in total soluble solids (TSS), loss of chlorophyll, decrease in titratable acidity, accumulation of carotenoids and increase in ascorbic acid content [58]. At maturity ber fruits contain sucrose, glucose and fructose in the ratio of 3:1:1 [59]. On maturity, the TSS, acidity and ascorbic acid content varies between 12–21%, 0.13–1.42% and 39–166 mg/100g, respectively, in different cultivars and regions [13]. According to Bhatia and Gupta [60] TSS, acidity and TSS:acid ratio at maturity should be 16.7–17.0, 0.20–0.24% and 76–84 for cultivar Gola; and 16.2–17.4, 0.16–

**Table 1. Physico-chemical characters of ber fruits.**

| Characteristics | Major ber cultivars | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Katha** | **Bagwari** | **Umran** | **Chhuhara** | **Illaichi** | **Karaka** | **Mundia Murhra** | **Narma** |
| Appearance | Golden yellow | Yellow to reddish brown | Golden yellow | Greenish yellow | Yellow to reddish brown | Yellow to reddish brown | Greenish yellow | Light green |
| Average fruit weight (g) | 18.50 | 16.00 | 21.00 | 12.50 | 3.60 | 23.00 | 22.00 | 17.50 |
| Pulp:stone ratio | 25.00 | 13.30 | 19.60 | 11.30 | 24.80 | – | 16.70 | 12.90 |
| Moisture (%) | 74.33 | 77.92 | 77.81 | 76.42 | 73.97 | 86.60 | 88.13 | 79.30 |
| Total soluble solids (ºB) | 21.40 | 18.00 | 22.70 | 17.20 | 24.70 | 11.80 | 13.00 | 16.80 |
| Acidity (%) | 0.10 | 0.11 | 0.29 | 0.35 | 0.22 | 0.31 | 0.22 | 0.25 |
| Reducing sugars (%) | 4.54 | 5.94 | 4.38 | 3.72 | 3.91 | 5.88 | 4.00 | 3.70 |
| Total sugars (%) | 19.65 | 16.17 | 14.84 | 16.23 | 16.98 | 9.97 | 11.10 | 14.90 |
| Ascorbic acid (mg/100 g) | 97.76 | 126.46 | 150.99 | 146.69 | 129.41 | 103.50 | 174.60 | 146.50 |

**Source:** [8].

0.17% and 93–100 for cultivar Umran, respectively. No significant change was observed in pulp:stone ratio during maturity in different ber cultivars [50, 52, 56]. Meel *et al*. [56] found that length, weight, volume of fruit, pulp weight, pulp: stone ratio, TSS:acid ratio and chlorophyll content could be used to judge maturity. Rate of respiration and ethylene production increased as the fruit entered the ripening phase. TSS, sugars, carotenoids and ascorbic acid content increased while acidity, total chlorophyll and total phenolics decreased with fruit maturity [46, 57]. TSS and polyphenol oxidase activity could be used as the most promising indices for harvesting [61]. TSS, carotenoids, sugars and ascorbic acid contents increased towards maturity, but total chlorophyll, total phenolics, acidity and moisture content decreased with maturity [62].

Specific gravity is also considered a reliable indicator for harvest timing, and this is attributed to a decrease in specific gravity with increasing intercellular spaces. Fruit specific gravity decreased continuously from fruit set to harvest [59]. Specific gravity markedly decreased up to 45 days after fruit set and then stabilised until harvest [51]. Specific gravity values at harvest maturity in Kaithli, Gola and Umran cultivars have been observed to be 0.88, 0.93 and 0.81, respectively, with corresponding fruit wall pressure values of 2.07, 2.52 and 2.80 [60]. Meel *et al*. [56] recommended that fruits of cultivar Sandhura Narnaul should have a specific gravity less than 1 for harvest maturity.

Harvest date of fruits in widely varying climates can be predicted with the help of heat units. For each cultivar, the requirement for fruit growth and development can be calculated in terms of degree days. The degree day heat requirement above a base of 7.2°C for maturity in cultivars Gola, Kaithli and Umran were 1,980–2,236, 2,236–2,466 and 2,566–2,920 degree days, respectively [37]. In general, the harvest period in North India is mid February to March for cultivar Gola, mid March to the last week of March for cultivar Kaithli and March to April for cultivar Umran [52, 60]. Availability periods of ber fruits in India vary from December to March. These differences are due to climatic conditions. Therefore, degree days required for maturity should be computed for different regions.

## Respiration and ripening

Ripening is the composite of the processes that occur from the later stages of growth and development through the early stages of senescence, and which result in characteristic aesthetic or food quality, as evidenced by changes in composition, colour, texture or other sensory attributes [40]. It is generally assumed that the rate of respiration of a fruit is a measure of its metabolic activity. After the fruit is detached from the tree, the rate of respiration becomes an indicator of its rate of loss of respirable substrates. The rate of respiration of mature green ber fruits of both *Z. mauritiana* and *Z. spina-christi* was low but increased as the fruits matured, reaching a peak value at the ripening phase and then declining rapidly [58]. Ethylene evolution as well as respiration rate increased from the mature green to fully ripe stage, then declined again in overripe fruits [63]. Abbas and Fandi [64] found that the respiration rate was high at 3 weeks after anthesis, but then declined steadily until 12 weeks after anthesis, when it reached 14.2 mg $CO_2$/kg/h. The rate subsequently increased, first slowly and then rapidly to a maximum value of 100.3 mg $CO_2$/kg/h as the fruit entered the ripening phase. Thereafter the rate of $CO_2$ production declined rapidly as the fruit became over-ripe. This pattern of respiratory change is characteristic climacteric fruits. Singh *et al*. [44] observed that on an average the rate of respiration was 52.4 mg $CO_2$/kg/h at the green stage and reached up to 127.64 mg $CO_2$/kg/h at the red ripe stage. The rate of respiration among various cultivars was found to be 119.72 mg, 131.54 mg, 137.32 mg, 132.32 mg and 133.33 mg $CO_2$/kg/h in Umran, Rashmi, Kaithli, ZG-3 and Ponda cultivars, respectively, at red-ripe stage. The lowest rate of respiration was observed in cultivar Umran while the highest rate was observed in cultivar Ponda.

Fruit ripening can be considered an aspect of development that is triggered by the achievement of the necessary hormonal balance together with the programming of cells to respond to such a change. Fruits have been classified as climacteric or nonclimacteric on the basis of their respiratory behaviour during ripening [65]. For climacteric fruits, there is considerable evidence that the natural plant hormone ethylene plays a key role in the ripening process [66, 67]. Ber fruits had a high respiration rate and a climacteric respiration pattern and reached their prime eating quality at the climacteric peak [16, 44, 46, 63, 68, 69]. Ber fruits produced high amounts of ethylene and showed responses to exogenous ethylene treatments as measured by changes in skin colour, juice colour and composition [70]. The rate of respiration increased gradually and reached its peak when the fruits attained a chocolate tinge colour in Kaithli, Rashmi, Umran, Ponda and ZG-3 cultivars, indicating the late peak climacteric nature of fruits [45]. Sharma *et al*. [71] observed an increase in respiration rate with advancement of ripening of ber cultivars Umran, Gola and Kaithli. Observation of ber fruits detached from the tree and stored at 20°C revealed that ethylene production is low in mature green fruits, but the rate of production increases rapidly as the fruit advances towards maturity and reaches a peak value, then declined rapidly [58]. The peak of ethylene production precedes that of $CO_2$ production by 2days [72]. Ethylene production was not detected until the 12th week after anthesis. Thereafter, ethylene production increased rapidly, reaching a maximum of 13.0 µL kg/h as the fruit entered the maturity phase 18 weeks after anthesis and then declined rapidly. The rise in ethylene production by ripe ber fruits is considered very high according to the classification of Kader and Kasmire [70].

It is possible that the high rate of respiration and ethylene production during ber fruit ripening are responsible for the short storage life under room temperature conditions [58]. Experiments were conducted to enhance the shelf-life of ber fruits by reducing the respiration rate and evolution of ethylene production. The rate of ethylene evolution by the fruits of cultivar Umran was reduced by the application of ascorbic acid (150 ppm) and cycocel (500 and 1,000 ppm) throughout the storage period, however application of ascorbic acid (300 ppm) and $KMnO_4$ (0.05% and 0.1%) increased the ethylene evolution [73]. Water dipping treatments (cold water and hot water at 40°C) did not affect ripening, but on the 8th day of storage ripening was reduced significantly only in the hot-water treated fruit packed in sealed polythene bags [74]. The delayed ripening under hot water treatment and polythene bag packaging can be attributed to slower senescence, respiration and ethylene liberation rate by oxidising ethylene to ethylene glycol [75] and including polygalacturonase activity [76].

Various problems are encountered during cultivation of ber, some of which are related to harvesting of fruits. These include variation in ripening time among fruits, failure of green fruits to ripen after harvest and poor retention of ripe fruits on the tree. Ethephon is responsible for the quick ripening and improvement of fruit quality in ber [58, 64, 77–79]. However, ber's response to ethephon has been variable according to concentration, cultivar, time of application, temperature during the ripening period, etc. Kader *et al*. [80] found that exposing Chinese ber fruits to 100 ppm ethylene at 20°C for 4 h or dipping in 2,000 ppm ethylene solution for 2 min induced rapid and uniform ripening. Ethephon at 500 mg/L advanced ripening by 6–7 days compared with controls. Furthermore, TSS and ascorbic acid content were significantly increased by ethephon treatment, whereas titratable acidity was significantly reduced [62].

## Preharvest treatments to extend shelf-life

Use of certain chemicals as preharvest applications has been reported to affect the weight loss of fruits during storage. Physiological loss in weight (PLW) is mainly due to evaporation of water, respiration and degradative processes during postharvest handling of fruits. The PLW of fruits gradually increases with increase in storage period in ber [81–84].

Efforts have been made to increase the shelf-life and quality of fruits using calcium compounds. Calcium is involved in a number of physiological processes of plants including cell walls, membranes, chromosome structure and enzyme activities. Ber contain calcium as pectate, carbonate, oxalate and phosphate [85]. Spraying ber fruits 10 days before harvest with $CaCl_2$ (1.7 g/L) with 1% Teepol as a surfactant, reduced PLW, delayed colour development and maintained good quality ber fruits during the storage period [86]. Reduction in respiration rate was associated with increased calcium content due to exogenous application of calcium nitrate [87]. Spraying of 1% $CaNO_3$ at the colour turning stage improved the shelf-life of fruits at room temperature [88–90]. Singh *et al*. [91, 92] observed that a preharvest spray of 0.03% boron and 0.05% zinc along with 50 ppm NAA on Pewandi ber improved fruit quality. Siddiqui *et al*. [88] reported that zinc sulphate at 0.4% and boric acid at 0.1% were more effective than other concentrations on fruits of Umran cultivar.

Bal and Chauhan [77] reported advanced ripening by a week in Sandhura Narnaul, Umran and Gola cultivars with ethephon application. Preharvest spraying of Umran cultivar fruits with ethephon increased the TSS and vitamin C and decreased acidity [93, 94]. At 400 ppm, ethephon resulted in the highest TSS content and also improved the fruit colour to golden yellow for cultivar Umran fruits [95]. Applying a preharvest spray of ethephon at 300 ppm to ber trees induced uniform ripening of fruits and the fruits harvested at optimum maturity could be stored for up to 40 days at 0–3.3°C and 85–90% relative humidity [96]. Preharvest sprays of 500 ppm Captan, Difolatan and thiabendazole have been reported to improve the shelf-life of Kaithli fruits. The effect of Captan was more in reducing loss in weight and that of thiabendazole was more in reducing decay loss during storage [97]. However, the shelf-life of Gola fruits was not improved by thiabendazole [87].

## Postharvest treatment to extend shelf-life

Postharvest dipping of fruits in cold water reduced respiration, ethylene production and enzymatic activities, whereas hot water treatment hinders the development of pathogens, thereby prolonging the shelf-life and quality of fruits. After harvest, dip treatments of Gola fruits in cold water for 2 h or keeping them exposed to air for 4 h improved their shelf-life [98].

Hot water (40°C) dipping of fruits has been reported to reduce water loss and PLW of fruits during storage. The hot water dipping treatment may prevent surface moulds from developing, resulting in decreased decay loss [99]. Postharvest water dipping at 50º C for 5 min significantly increased shelf-life and maintained the quality of Umran fruits, particularly late in the storage period. It also retarded enzymatic activity, respiration and activity of postharvest pathogens [74]. Dipping of fruits in a 1–2% fungicide solution prolonged their shelf-life in cultivar ZG-3 [100] and reduced PLW in Gola fruits [98]. Ripening in harvested Umran fruits was delayed by treatments with $CaCl_2$ (4.5 or 9 g Ca/L) solution [101]. Dipping Gola fruits in 500 ppm thiabendazole, Captan and Dithane M-45 improved the shelf-life by reducing rate of respiration [98]. Dipping of Umran fruits in 0.05 and 0.1% $KMnO_4$ also reduced decay loss during storage [89]. Postharvest dipping of cultivar Gola in 1,000 ppm of $KMnO_4$ at colour turning stage gave the best result , prolonging the shelf-life of fruits to 14 days at room temperature [102]. Fruits of Umran cultivar were dipped for 15 min in a solution of $KMnO_4$ (0.05, 0.1%) using Teepol as surfactant, resulting in reduced PLW, over ripening and decay loss compared with controls at the 6th day of storage [73].

Plant growth regulators are applied after harvest with multipurpose objectives such as to: hasten or delay uniform ripening of fruits; reduce postharvest decay losses of fruits; improve the physico-chemical characteristics of fruits; and improve the shelf-life, keeping quality and marketability of fruits for a longer period [103]. Treatments with 500 ppm cycocel for 15 min [73]; 1,000–2,000 ppm cycocel for 10 min [104], and cycocel at 200 ppm [58] have been reported to result in lower weight loss and improvement in quality. Cycocel was found to be the most suitable chemical, compared with ascorbic acid and $KMnO_4$ [73]. Siddiqui *et al.* [105] with 100 ppm and Sandhbhor and Desai [106] with 10 ppm benzyl adenine observed reduced PLW but increased ethylene evolution in Umran fruits during storage. Postharvest dipping in 150 and 300 ppm ascorbic acid solution reduced over ripening and increased TSS, but had no effect on acidity and ascorbic acid during storage [89]. Postharvest dipping of ber fruits cultivars Gola and Umran in 200 ppm of maleic hydrazide increased the marketability percentage and improved the storage life and keeping quality of ripe ber fruits for up to 12 days [107, 108]. Ber fruits treated with 2% mustard oil with 50 ppm $GA_3$ and stored in perforated polythene bags had reduced PLW, rotting and maintenance of physical appearance, colour and quality of fruits for up to 12 days of storage [109]. Growth regulators $GA_3$ and cycocel at concentrations of 10 mg/L and 200 mg/L, respectively, delayed ripening by 2 days [58].

## Effect of packaging on shelf-life of ber

Fruits of Kaithli and Umran cultivars, packed in hard-board corrugated cartons of 3–9 kg (40×45×20 cm) with 6 holes of 1 cm diameter on two sides with a cushion of shredded paper retained good quality for 9–12 days [110]. Decay and weight loss were reduced by using 5g bleaching powder/kg fruit as a fumigant [111]. Diphenyl impregnated paper lining in boxes improved the shelf-life of Umran and Gola fruits by 12 days [98, 101] . Paper lining proved a better cushioning material than *Cynedon dactylon* [112]. Perforated polythene bags [74, 104, 113–117] could be used for sale of ber fruits in the local markets. Wrapping fruits in brown paper or butter paper followed by bagging in perforated polythene promoted storage life and reduced PLW cultivar Narikeli fruits. The different wrapping materials increased physical limitations to free exchange of $CO_2$ and $O_2$ and a reduction in $O_2$ levels.

For long distance transport (800 km), cardboard containers and mulberry baskets with straw as cushioning material proved to be the best packaging material [113]. For short distance transport (200 km) of Umran fruits, cardboard boxes proved the best with the least per cent loss in weight, with the highest losses arising from the use of gunny bags. Mode of transportation also influenced the PLW of fruits. Transport by rail resulted in lower PLW than by truck [118]. Modified wire bound boxes, made of cheaper wood, proved better for transporting ber over a distance of 350 km than traditional boxes [119]. Various types of containers for packaging of ber fruits, depending upon the bulk of the fruits, were suggested and prevail in the market. For small packages of 1–2 kg, perforated polyethylene bags, nylon net bags and cardboard cartons can be used. Fruits are also packed in large packages of 10–20 kg in gunny bags, cloth packages or wooden or plywood boxes with holes or slits [120].

## Effect of storage

### Room temperature storage

Ber fruits are usually stored at ambient/room temperature (25–35°C) from harvest until their consumption. Jawanda *et al.* [82] observed that Umran and Sanaur-2 fruits could be stored for up to 10–12 days at room temperature. Panwar [114] reported that ber fruits remained in marketable condition for about 1 week. Ripe fruits of ber when stored at room temperature without any treatment remained for up to 7 days [83]. Gupta *et al.* [121] observed that the shelf-life at room temperature was the longest in Sanaur-5, followed by Ponda, Reshmi and Umran cultivars. Pareek and Gupta [120] observed the shelf-life of Gola and Kaithli cultivars at ambient temperature for up to 7 and 10 days, respectively. *Z. spinachristi* fruits could be stored for 6 days at room temperature [84, 41]. Golden yellow colour ripe fruits of Umran could be stored for about 1 week at 30°C [122]. The fruits of cultivar

Gola were suitable for eating for up to 8 days of storage [123]. Siddiqui and Gupta [73] observed 38% PLW, 35.3% over ripening and 13.4% decay loss in cultivar Umran at room temperature after 6 days of storage. In contrast to this Gupta and Kadam [25] reported that ber fruits stored at ambient temperature had a short life of 3 days only. Under ambient conditions, ber fruits showed a high degree of pathological infection and loss in colour, and could be stored for only 9 days [124]. Pareek *et al*. [125] observed that the storage environment did not affect the levels of total sugars in the fruits. It was observed that Virosil Agro (2.5 and 5%) and Bavistin (1%) maintained the original levels of reducing sugars during the storage period.

**Storage in zero energy cool chamber**

High temperature and moderate humidity at the time of fruit maturity (February to March) leads to the attack of different micro-flora that caused decay, increased PLW and reduced shelf-life and quality. These factors lead to heavy losses which can be minimised by storing fruits in a zero energy cool chamber (ZECC). ZECC have been designed to enhance the shelf-life of fruits and vegetables by lowering the temperature and increasing the relative humidity inside the chambers via passive evaporative cooling [126]. Ber fruits of Kaithli, Umran and Gola cultivars could be stored in these chambers for 14, 15 and 18 days, respectively [127]. Siddiqui and Gupta [128] stored fruits in these chambers up to 6–10 days. The fruits of cultivar Gola were found to be in acceptable condition up to 12 days of storage in ZECC. There was a decrease in fruit firmness, specific gravity and organoleptic score with a corresponding increase in acidity of fruits under ZECC [123]. Mean PLW (10.36%) was recorded for Umran cultivar stored in ZECC after 12 days of storage which were organoleptically acceptable, while PLW was more than double (24.13%) under ambient temperature [129, 130]. The significant reduction in PLW under cool chamber was due to prevailing higher humidity and lower temperature, which lowered the transpiration rate as well as ethylene production at the lower temperatures.

**Cold storage**

Several studies have examined the effect of low temperature on postharvest changes in the chemical constituents of ber fruits and on their storage behaviour [9, 41, 42, 68, 114, 115, 120, 131–133]. Jawanda *et al*. [9] observed that Umran and Sanaur-2 fruits could be stored for up to 30 and 40 days, respectively, in commercial cold storage (0–3.3°C). Jain *et al*. [131] reported that fruits stored in perforated polythene bags and baskets at 13°C in biochemical oxygen demand (BOD) incubators remained at acceptable organoleptic quality for up to 3 weeks. Panwar [114] stored Umran and Kaithli ber up to 42 days at 10°C. The shelf-life of Gola and Kaithli cultivars of ber at 1.7°C was found to be 42 and 28 days, respectively [120]. In cold storage (10°C, 79% relative humidity), fruits of cultivars Gola, Kaithii and Umran remained acceptable for up to 42, 28 and 35 days, respectively [127]. The golden yellow coloured ripe fruits of Umran could be stored for about 3 weeks at low temperatures ranging from 0–4°C [122]. According to Monthira [115], fruits could be stored in perforated polythene bags for 8, 16 and 24 days at 15°C, 10°C and 5°C, respectively. Fruits stored at 5$^{o}$C lost only 48% of their weight during the entire 12-week storage duration, while fruits stored at 22 and 15$^{o}$C lost 70 and 75% of their weight, respectively. At 3 weeks of storage more than 40% of fruits had shrivelled under the 22$^{o}$C and 15$^{o}$C storage temperatures compared with only 3% under the 5$^{o}$C storage temperature [134]. The difference in storage life seems due to variation in year of production, regions, orchard management practices, irrigation geometry, maturity stages, locations of the fruits and the time of harvesting fruits from tree, and the storage environment, etc.

**Postharvest pathology**

Ripened fruits are susceptible to attack by a variety of pathogenic fungi and bacteria that are able to colonise them during the period of development on and off the tree. Ber fruits are susceptible to a number of postharvest diseases. During the period of packaging, storage and transport fruits may be exposed to various decay-causing microflora. Some of the predominant organisms observed on freshly harvested fruits were *Aspergillus niger*, *A. sydowii*, *Rhizopus oryzae*, *Penicilium chrysogenum*, *Alternaria tenisima*, *Phoma spp*., *Cuvrularia spp.*, of which *A. niger* and *R. oryzae* caused the greatest spoilage *in vitro* [135]. Singh and Gupta [112] found that *Ulocladium chartarum*, *Phoma hissarensis* and *Botryodiplodia theobromae* caused decay losses more frequently in the packages. When fruits are weakened by senescence and chilling injury, they are attacked by several pathogens that cause fruit rot [58]. About 16 fungi belonging to 12 genera have been reported to cause fruit rot in ber during harvest, transit and storage. A number of other minor pathogens also cause fruit rot in ber, including *Geotrichum spp*., *Phoma herbarium* [136]; *Phytophytora micotianae* and *Sclerotium rolfsii* [137].

The soft rot of *Z. jujube* starts as light brown lesions at the site of a cut or incision, and later changes to dark brown or black with the increase in severity of the symptoms. The outer skin of the spot remains intact but the flesh inside turns dark brown; visibly macerated and water soaked. As the time of incubation advances rotting penetrates inside the tissue up to the seed in the centre and quickly encircles it, emitting a foul smell [138].

Lal *et al*. [139] evaluated five fungicides *in vitro* and *in vivo* and found that Bavistin and Difolation performed best and could be recommended as fruit dips at 500 ppm and 1,000 ppm, respectively. Treatment with 1% Bavistin and 5% Virosil reduced both pathological and physiological losses in ambient (30°C) as well as in cold storage (7°C) [124]. Fungal pathogens like *Rhizopus sexualis*, *R. microperum* and *R. oligosporus* followed by *Mucerpyriformis*, *A. niger*, *A. fiavus*, *Alternaria alternata*, *Trichothecium roseum*, *Tridadium splendens*, *Phoma scrghuia***,** *Fusarium culminorum* and *Penvciallum spp.* were observed on stored Gola fruits. However,

fruits stored at low temperature (7°C) after treatment with cold water (30 min), hot water (50°C for 5, 10 min), and 0.5% calcium chloride suppressed these fungal infections. Fruits stored at room temperature (28±2°C) after treatment with cold water (15 min), hot water (5 min), and 2,500 ppm Virosil and 0.5% calcium nitrate had significantly reduced infection rates by 93.3% [140].

## Conclusions and directions for future research

Further studies should be done to characterise the physiology of ber fruits. Research should include characterising gene expression, protein synthesis and regulations of enzymes catalysing sugar formation and translocation. Reliable maturity indices and international standards with respect to quality should be developed. New techniques, eg. immunological and molecular biology methods, should be used to study ripening and work on ethylene management with 1 MCP should be initiated. Low temperature storage methods and commercial recommendations should be standardised and the use of controlled and modified atmosphere should be investigated. Alternative treatments used during pre- and postharvest stages should be developed to replace any chemical treatments currently in use that are questionable human safety.

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