Review

Underutilized Fruit Crops of Indian Arid and Semi-Arid Regions: Importance, Conservation and Utilization Strategies

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Abstract: Nowadays, there is a large demand for nutrient-dense fruits to promote nutritional and metabolic human health. The production of commercial fruit crops is becoming progressively input-dependent to cope with the losses caused by biotic and abiotic stresses. A wide variety of underutilized crops, which are neither commercially cultivated nor traded on a large scale, are mainly grown, commercialized and consumed locally. These underutilized fruits have many advantages in terms of ease to grow, hardiness and resilience to climate changes compared to the major commercially grown crops. In addition, they are exceptionally rich in important phytochemicals and have medicinal value. Hence, their consumption may help to meet the nutritional needs of rural populations, such as those living in fragile arid and semi-arid regions around the world. In addition, local people are well aware of the nutritional and medicinal properties of these crops. Therefore, emphasis must be given to the rigorous study of the conservation and the nutritional characterization of these crops so that the future food basket may be widened for enhancing its functional and nutritional values. In this review, we described the ethnobotany, medicinal and nutritional values, biodiversity conservation and utilization strategies of 19 climate-resilient important, underutilized fruit crops of arid and semi-arid regions (Indian jujube, Indian gooseberry, lasora, bael, kair, karonda, tamarind, wood apple, custard apple, jamun, jharber, mahua, pilu, khejri, mulberry, chironji, manila tamarind, timroo, khirni).

Keywords: climate resilient; arid zone fruits; adaptation; nutritional quality

1. Introduction

The world population (7.87 billion) is currently growing at a rate of 1.03% per year and is expected to reach around 9.6 billion in 2050. India has 1.38 billion people accounting for 17.5% of the world population, with a meager 2.4% of the world surface area [1]. Nowadays, the greatest challenge is to provide this burgeoning population with stable, safe and nutritious quality food. In the current Global Hunger Index (GHI), India stands at position 101 of 116 countries; this presents a gloomy situation in combating malnutrition, eventually affecting the socio-economic progress [2]. The World Health Organization (WHO) has also indicated that hungeriness is the most serious problem worldwide, particularly for African countries and India. Therefore, 195 nations have decided to adopt sustainable
development goals (SDG) for addressing the serious malnutrition problems with a holistic approach by the year 2030 [3]. Consumer awareness about the health benefits of fruits offers great thrust for their regular consumption as part of a balanced diet. Worldwide demand of nutrient-dense fruit has increased immensely in recent years not only for enhancing people’s nutritional status but also for their positive effects on immune and metabolic health. This is particularly interesting considering the COVID-19 pandemic scenario.

In India, major fruit crops, such as mango, banana, citrus, guava and apple, account for more than 72% of the total area under fruit crops, while indigenous (native) fruit crops contribute only 6.56% of the area (0.437 mha) with quite high productivity (11.47 tons/ha) [4]. Climate change is inducing a rise in air temperatures, UV radiation levels and in the frequency of extreme events, such as drought or flood, which, especially in arid or semi-arid areas, can result in an intensification of the negative impact of salinity, mineral deficiency/toxicity and of diseases and insect-pest attacks on crops [5–8]. Consequently, climate change represents a great threat to obtaining the sustainable production of major commercial fruits [5]. Under such environmental conditions, the fulfillment of the consumers’ choice and nutritional food security at an affordable and sustainable level is a major concern for the researchers as well as the growers.

Under the given circumstances, specific growing areas may be utilized for exploiting the potential of underutilized crops producing edible fruits that meet the food and nutritional demand of local population. It is necessary to explore some biotic and abiotic resistant/tolerant native underutilized fruit crops that could be resilient to certain climatic variations and adapt to a wide range of agro-climatic conditions. The indigenous fruit crops are not only proven to be superior in terms of wider adaptability to environmental conditions but are also known for their nutritional value [9]. However, a limited amount of research has been carried out for the development of production protocols and utilization of these underutilized fruit species. Moreover, the limited number of identified varieties, the low availability of quality planting materials and the inadequate availability of suitable cultural and post-harvest management practices are still major limitations challenging the systematic cultivation of these underutilized crops.

The vegetation of arid areas includes a large number of edible fruit-bearing and food-producing species. In the Indian arid zone, around 30 plant species are known for their different edible uses, and around 19 of them bear edible fruits and possess horticultural importance [10]. Many of the underutilized fruit crops can be used as fresh fruit but also for culinary and medicinal purposes providing important nutrients, and some of them also have ornamental values. Local people are aware of their medicinal and nutritional properties. Indeed, most indigenous underutilized fruit crops, such as ber, kair, aonla, lasora and phalsa, are richer in minerals, antioxidants and phytonutrients compared to many commercial fruit crops. Moreover, these underutilized fruits are not very popular and are sold at very low prices in the local markets because of the lack of (a) people’s awareness of their nutritive values, (b) consumption habits, (c) limited research and (d) developmental policies by the government agencies for their potential exploitation.

Considering the importance of these tree crop species in traditional medicine, their nutritional richness and wide adaptability, the Government of India, under their centrally sponsored scheme, i.e., Mission on Integrated Development of Horticulture (MIDH, then ‘National Horticulture Mission’, NHM) during 2005–2006 gave a special impetus to establish orchards of underutilized fruit species. This paper reviews the importance of 19 underutilized fruit crops endemic to Indian arid and semi-arid conditions, and their adaptation mechanism to stress conditions, genetic diversity, ethnobotany, medicinal and nutritional values and possible ways for their conservation and potential exploitation for improving nutritional and socio-economic security of the regions.

2. Characteristics and Potential Uses of Indigenous Underutilized Fruit Crops

Abiotic stresses caused by environmental factors are the most common yield-limiting factors globally, and they cause up to 70% of the yield losses in major fruit crops [11,12].
In more detail, the individual potential yield losses induced by the different climatic adversities were reported to be the following: high temperature: 40–50%; salinity: 20%; drought: 17%; low temperature: 15% [13]. Arid and semi-arid regions are considered the hotspot for abiotic stresses, such as extreme temperatures, intense solar radiation, salinity, drought and nutrient deficiency, where the commercial fruit crops either fail to grow or struggle to express their potential performance. Under such climatic conditions, the integration of arid-zone underutilized fruit crops can be a better strategy to sustain the crop productivity under stress due to their typical morphological, physiological, anatomical and biochemical xerophytic characteristics that allow them to perform optimally under harsh climates. Therefore, adaptive traits such as those that increase the overall resilience and resistance to suboptimal environmental conditions do not necessarily result in a yield penalty. It is generally assumed that adaptive traits ensure yield stability in specific conditions, being fitness typically measured in terms of fertility, fruits and seeds. For instance, these traits include phenology shifts (flowering/ripening in a specific period of the year) and/or morphological characteristics (root/shoot ratio, leaf macro and/or micro-morphological traits, etc.) that allow specific genotypes to escape environmental stresses (not necessarily involving an active and metabolically costly response to stress). This can result in the capacity of these genotypes to have fruits reaching ripening compared to those that did not have any adaptive trait.

In order to cope with abiotic stresses, the arid-zone underutilized fruit crops, such as ber (Zizyphus spp.), aonla (Emblica officinalis), bael (Aegle marmelos), jamun (Syzigium spp.) and wood apple (Feronia limonia), have modified and/or developed their organs to assure vital morpho-physiological functions (i.e., strong deep root system, a high root-to-shoot ratio for reaching into deeper moist soil layers and uptake more water and nutrients) [14]. Similarly, crops such as asher, bael, lasora (Cordia mixa) and pilu (Salvadora persica) have round, thick and barked stems for easier water storage and reduced cuticle transpiration. Some crops such as kair (Capparis decidua), lasora, aonla and pilu have synchronized flowering and fast fruit development during the season characterized by larger moisture availability [15,16]. Crops such as ber, phalsa and bael exhibit leaf shedding/dormancy for reducing water loss in summer and for protecting the plants from frost in winter [17–19]. Similarly, other underutilized crops possess numerous morphological characters, such as spines instead of leaves (ber), scanty foliage (kair), spiny cladodes (prickly pear), mucilaginous sap for reduced transpiration loss (kair, lasora, pilu, bael, etc.), small-sized and thick leaves, fur/hairiness and waxy coating on the leaf surface and sunken and deep stomata, for water-saving through the reduction in transpiration rate and heat shocks (ber, phalsa, lasora, fig), and selective or reduced absorption of cation (Na\(^{+}\)) and anions (Cl\(^{-}\), SO\(_4^{2-}\)) [19]. These characteristics are also associated with the accumulation of osmolytes, compatible organic and inorganic solutes (proline, phenolics, flavonoids, soluble sugars, glycine, betaine, etc.), and biosynthesis of enzymatic and non-enzymatic antioxidants, heat shock proteins and drought-responsive genes to maintain cell turgor, allowing better survival under the adverse conditions of arid and semi-arid environments [20,21]. In addition, the genetic basis of the adaptive traits deserves to be studied because this information could be used in future breeding programs that may also involve novel tools, such as genome editing.

These underutilized fruit crops may represent the next generation of futuristic crops, which could enhance the farmer’s income through sustainable production systems even under a climate-change scenario. The characteristics and the potential uses of the 19 underutilized fruit crops of arid and semi-arid regions are separately described below, and a summary of their main traits is provided in Table 1.

2.1. Indian Jujube (Ziziphus mauritiana L.)

The Indian jujube (ber) belongs to the family Rhamnaceae, and it is known as the king of arid-zone fruits or as poor man’s apple. The ber tree is fast growing and has a spreading canopy and a short bole; branches are slender, downy, brown bold spines in pairs [22]. The ber tree is extremely drought-hardy due to the deep taproot system and xerophytic
characteristics, such as (a) dormancy (leaf shedding) during the peak period of hot summer preventing transpiration, (b) waxy and hairy leaves, (c) thick bark [14]. It grows well even in marginal or poor soils where most other commercial fruit trees either fail to grow or have very poor performance. The jujube seeds contain saponins, jujubogenin and obelin lactone [23,24]. Jujube wood is utilized as fuel or charcoal making and its leaves are used as fodder for sheep and goats [25].

The fruit has a spongy, sweet, tasty pulp and is an excellent source of vitamins C, A, B, carotenoids, protein, Ca, P, K, Rb, Br, La and sugars (fructose, glucose and galactose) [26]. The smoke of its burning leaves is also utilized to cure cutaneous, cough and cold. Ber fruit is mostly consumed as fresh within 4–5 days after harvest due to the short shelf life. Thus, it is necessary to develop a value-added product at a farmer-field or industry level, and there is the need to work on the diversification and popularization of jujube products. It is the only fruit crop that can give good returns even under rainfed conditions due to its wide adaptability under a large variety of soils, water availability conditions and climates (with the exception of heavy frosts) in arid and semi-arid regions. In addition to nutritional and economic health, some jujube cultivars, such as Dragon, Mushroom, So and Teapot, are known for their landscape values, such as unique fruit shape, fruit color and tree shape, and are planted in gardens and backyards due to their dwarf habit and compact canopy [27,28].

2.2. Indian Gooseberry (Emblica officinalis G.)

The Indian gooseberry is an indigenous and important minor fruit. It belongs to the family Euphorbiaceae, and it is grown in diverse soil and climatic conditions of India [29]. The medicinal and therapeutic properties of aonla are considered as ‘amritphal’ or a wonder fruit for health [30]. The aonla fruit is 3 and 160-times richer in protein and vitamin C compared to apples, respectively [31]. It is the richest source of Vitamin C (500–1800 mg/100 g) among the fruits after Barbedos cherry, and the content in leucoanthocyanins polyphenols, pectin, iron, calcium and phosphorus makes its fruit largely used in Ayurvedic medicines for making Triphala and Chyavanprash [30,32].

As a result of the intensive research carried out since the beginning of the 21st century and the development of 30 varieties, this fruit species is grown commercially in some areas, and it was proven to be a fruit crop potentially suitable also for arid ecosystems. It is hardy, productive and highly remunerative even when managed without much care under drought and saline areas of arid and semi-arid regions. The aonla fruit is highly perishable, acidic and astringent; consumers do not prefer them for fresh consumption [33], whereas aonla fruit is generally used to prepare a number of delicious, processed food products, such as preserve, candy, jelly, toffee, pickle, leather, squash, juice, RTS beverage, cider, shreds, dried powder and ayurvedic tonics, such as Chayvanprash, Triphala, Amrit Kalash and Amol Ki Rasayan [34,35].

2.3. Lasora (Cordia myxa L.)

Cordia, locally known as Gonda, Lasora, Lehsua, Indian cherry, Assyrian Plum or Bird’s Nest Tree, belongs to the Boraginaceae family and is grown across India except for the high hills and the temperate climates [36]. Cordia is a fast-growing tree with a beautiful inverted dome/umbrella crown, utilized as an avenue tree and ornamental furniture; ovate, alternate and stalked leaves used as fodder during hot summer when green grasses are not available and also used as rearing lac insect [37,38]. Trees bear white color hermaphrodite flowers in March and drupaceous green unripe fruit ready for harvesting from April to June. It is mostly used as green fresh vegetables and pickles, especially in the lean period when the availability of conventional vegetables is limited [39]. The fruit is considered as a naturally rich source of antioxidants, i.e., carotenoids, ascobic acid, phenols, and minerals, crude fiber, protein, ascobic acid, ash and vitamins, which represent essential nutrients for human health and for curing certain human ailments (improve digestion, birdlime, anti-tumor, anti-helmentic, diuretic, demulcent and expectorant; improve hair growth) [40–42].
2.4. Bael [Aegle marmelos L. (Correa)]

Bael is the only species of the genus *Aegle*, which belongs to the family *Rutaceae* [43]; it is one of the oldest indigenous fruits known by various names in different parts of India, such as billi, Bengal quince, stone apple, golden apple and Japanese bitter orange [44]. Bael has a wide distribution in various ranges of edaphic-climatic conditions due to its ability to withstand heat, drought and low-temperature poor-nutrient soil [45]. It is deciduous, medium-sized, slender, gum bearing with a cauliflorous fruiting habit, deep taproot system, bold thorny branches and trifoliate leaves [46]. Its trifoliate leaves resemble a trident, so people offer them to Lord Shiva Lingam to get rid of worry and suffering [47]. Bael can be used as avenue and ornamental trees (golden color ripen fruit); shells of the dried fruit after removing pulp are used as fashioned cups, small containers, ornamental pills, snuff boxes, etc. [48].

The bael fruit is a rich source of riboflavin used to cure beriberi, and unripe fruit is suggested to treat diarrhea and dysentery, whereas the marmelosin in fruit has therapeutic properties being a good remedy for stomach ailments [49]. However, all plant parts of bael contain various compounds with medicinal values, e.g., coumarins, alkaloids, sterols and essential oils, that have analgesic, antipyretic, anti-inflammatory, anti-antifungal, microfilaria, hypoglycemic, anti dyslipidemic, antiproliferative, wound healing, insecticidal and anti-fertility abilities [50]. Bael fruit is consumed only in processed products, such as powder, preserve, nectar, toffee [51]. These products have had high market demand during the COVID-19 pandemic period due to its ayurvedic medicinal values. Their current price in the market is high and for this reason, bael is becoming a remunerative crop for farmers of arid and semi-arid areas.

2.5. Kair [Capparis decidua (Forsk.)]

*Capparis decidua* Forsk belongs to the *Capparidaceae* family, and it is locally known as Kair, Ker, KarilTeent, Della, and Neptiin. It is an indigenous, multipurpose small woody perennial much-branched, leafless bushy shrub widely grown without much care on farm boundaries, orans, gochars and wastelands tracts of arid and semi-arid regions [52]. Its xerophytic characteristics, such as deep root system, scanty foliage, mucilaginous sap and tough conical spine, make it an ideal plant for stabilizing sand dunes and controlling soil erosion by wind during the hot desiccating summer in the Thar desert of western Rajasthan [53]. However, it easily survives in desert conditions characterized by temperatures ranging from −8 to +48 °C or more, drought, saline and poor nutrients soil ecological conditions [54]. In general, kair is naturally propagated through seeds, root suckers, hardwood cuttings and tissue culture, but the plant survival rate is very low [55]. Kair plants produce pink, red and white flowers in the axil of the spine three times a year, but the main flowering flush occurs in March–April, and fruit matures just before the monsoon [56].

The kair fruit is used as a vegetable, pickles and condiments. Dried fruit is an important ingredient of a traditional vegetable of Rajasthan known as ‘*Panchkutta*’. Its fruit is rich in proteins, carbohydrates, fiber and minerals (Ca, P and Fe). It is used in medicine for sedation, anticonvulsant asthma, inflammation and cough, since it contains isocodonocarpine, α- and β-amyrin, taraxasterol, erythrodiolalkaloids in plant organs [57].

2.6. Karonda (Carissa carandas L.)

Karonda is a plant of Indian origin, belonging to the family *Apocynaceae* and locally known as Christ’s thorn. Karonda is a hardy, evergreen, spiny, low-growing bushy multiple branched shrub grown for bio-fencing/live-fencing in gardens, orchards or in very small-scale plantations in Rajasthan, Gujarat and Uttar Pradesh [58,59]. Its drought-hardy nature is due to xerophytic features, and the plant offers 5–8 kg fruit yields without much care and management in arid and semi-arid regions. Karonda produces flowers in January–February and June–July and fruit ripe in 60–90 days after fruit set. Depending on the genotypes, white, green, purple and pinkish-red colored fruits are common, due to which it is also used as an ornamental plant in gardens [38]. Immature fruit is usually used for producing pickles
and chutney but occasionally is used as a vegetable, while fully ripe fruit is consumed fresh or processed to produce candies and colored extracts used as natural food colorant [60].

Karonda fruit is considered the richest source of iron (39 mg per 100 g), contains a fair amount of vitamin C and is used to cure of anemia and scurvy [61]. In addition, they are a good source of calcium, magnesium and phosphorus and have high antioxidant activity [62]. The mature fruit is suitable for making pickles and jellies due to the high content of pectin. They can also be exploited for making jams, squashes, syrups and chutneys, which have high market demand.

2.7. Tamarind (Tamarindus indica L.)

*Tamarindus inidica* is a dicotyledonous, monotypic, long-lived, semi-evergreen fruit plant belonging to the family *Leguminosae* [63]. It has a wide range of adaptability, and it is an ideal tree for avenue plantation as a roadside, backyard and agroforestry systems. It bears terminal and lateral drooping bisexual flowers in May–June and forms fruit as pendulous pods ten months after fruit set [64]. Tamarind fruit pulp and seeds contain tartaric acid, reducing sugar, tannin, pectin, cellulose, fiber, potassium, calcium phosphorous and other minerals, such as sodium, iron and zinc [65]. The fruit pulp is the chief source for souring sauces, curries, chutneys, beverages, food colorants and it is considered a great delicacy [66]. All its parts are valuable for food, fodder, timber, fuel, textile, nutritional and pharmaceutical industries, such as fluoride remover [67,68]. Tamarind trees are planted as roadside avenue trees in the Banaras Hindu University, Varanasi, the largest university campus of India.

2.8. Wood Apple [Feronia limonia (L.) Swingle]

Wood apple is an indigenous fruit tree that is also known as kainth, elephant apple and monkey fruit [69,70]. Systematic block plantation in the form of orchards of wood apple is uncommon, whereas it is mostly found in isolation as a stray plant in the plains of Southern Maharashtra, Uttar Pradesh, West Bengal, Madhya Pradesh and Chhattisgarh states of India. The wood apple is a small-to-moderate size, glabrous, deciduous tree with thorny branches, rough and spiny bark and it is able to grow on saline, poor and neglected lands normally unsuitable for fruit cultivation [71]. It is the only species of the *Citrus* family that can tolerate both drought and salinity stress. Its flowering starts from February to May, and fruit matures October to December depending on the moisture availability [14,72].

The fruit of wood apple is a berry with rough, hard-shelled, large, globose, woody pericarp and sweetish aromatic edible pulp [73]. Several organs of the *F. limonia* tree have excellent therapeutic and functional properties: leaves (diuretic, anti-microbial and stomach disorders), roots and bark (insecticidal and snakebite), spines (liver and menorrhagia), gum (diarrhea and diabetes) and fruit pulp (skin cancer, diarrhea, sore throat, Jaundice and gastropathy) [74–76]. The fruit is processed as powder, preserve, squash, sherbet, beverage, jam, cream, leather, wine, toffee, candy, RTS, pickle and capsules [77,78].

2.9. Custard Apple (Annona squamosa L.)

Custard apple is one of the drought-hardy fruit plants belonging to the family *Annonaceae*, which is commercially cultivated in a limited area of the Indian Deccan plateau region. The light, gravel and small pebbles soil is also suitable for its cultivation. Custard apple plants are small, semi-deciduous shrubs with simple leaves, caulisferous flowering, bisexual and protogynous flowers, superior ovary, fruit etaerio of berries [79]. Its flower is borne mostly in new flushes after the shedding of old leaves commencing from March to August with a peak in April–May [80]. The fruit is climacteric, it may be symmetrically heart-shaped, lopsided or irregular, and the interspaces between the protuberances become yellow at full maturity [81].

The demand of custard apple fruit is increasing in domestic and international markets thanks to their sensory, therapeutic and nutritional properties, as well as their pleasant flavor. Custard apple fruit contains vitamins A, B, C, E, and K1, essential minerals,
antioxidants and polyunsaturated fatty acids. They are antimalarial, antifeedant, immuno-suppressive, cytotoxic, diterpenes and are used to treat HIV [82,83]. Moreover, a range of cosmetic products using custard apple is available in the market, such as perfumery, soaps, pimple creams, essential oils, hair lotions, ayur slim capsules, cold balms, anti-stress massage oil, pain massage oils, and foot care creams [84].

2.10. Jamun (Syzygium cumumii Skeels)

Jamun belongs to the Myrtaceae family is an Indigenous evergreen hardy fruit tree that naturally grows in neglected and marshy areas. Deep loamy, well-drained soils and dry weather during the flowering and fruiting period are ideal conditions for its cultivation. Jamun flower panicles emerge at the leaf axil during March–April. Fruit is borne in clusters (10–40 fruit) and are round or oblong, single-seeded berries with a single sigmoid type development pattern, and are non-climacteric [85].

Jamun is rich in biochemical compounds, e.g., anthocyanins, myrecetin, ellagic acid, isoquercetin, gluscode, kaemferol, and it is used for its anti-inflammatory, neuropsycho, anti-microbial, anti-HIV, nitric oxide or free radical scavenging, anti-fertility and anti-ulcerogenic activities [86]. Glycosides in the seed, jambolin or antimellin, are considered to have anti-diabetic properties by halting the conversion of starch into sugar [87,88]. Ripe jamun fruit is used to prepare many products, such as squashes, juices, jam, jelly, pickles and wines. In Goa and the Philippines, the fermented fruit of jambolans is used to produce Brandy and a distilled liquor called ‘jambava’ [89].

2.11. Jharber (Ziziphus nummularia Burm. f.)

Jharber is a 1–2 m tall, perennial, deciduous and thorny shrub with drooping branches that in nature occupies almost all the habitats of extremely arid environments (crop and grazing lands, sandy-saline, rocky, degraded pastures) [10]. Anatomical features, such as the presence of papilla, crypt stomata, epidermis with a thick outer wall and thick cuticle and deep taproot system provide the best tolerance to drought, salinity and high-temperature stresses, making this species adaptable to extreme arid regions [90,91]. It flowers in July–August, and fruit ripens in November–December; the fruit is small-sized drupes with a globose-ovoid shape, dark red color and little edible pulp of sub acidic taste [22].

The jharber dried fruit contains triterpenoids, alkaloids and saponins and are used in medicine for their anticancer, stomachic, sedative, blood purifier, anti-obesity, antipteryetic, anodyne, refrigerant, pectoral, anti-anemia, vomiting and styptic properties [92]. Leaves of jharber, locally called ‘Pala’, are often used as fodder for camels, cattle, goats and sheep, being rich in crude fiber, crude protein, calcium and phosphorus [93]. In addition, some plant organs have local medicinal uses. For instance, (a) the leaves are used to obtain poultices to heal wounds or they are used to cure asthma, fever, gum bleeding and liver problems; (b) the bark is used to treat diarrhea; (c) the roots are used as a decoction to cure fever, whereas its powder is adopted to treat ulcers and wounds; (d) the fruit is laxative and antiemetic; (e) the seeds are sedative [94].

2.12. Mahua [Madhuca longifolia (Koenig)]

Mahua is an indigenous deciduous tree belonging to the family Sapotaceae and is characterized by medium-to-large-sized canopy, grey-black cracked bark, milky and short trunk and many-branched [95]. The flowers are grouped in dense clusters with long pedicels and have a coriaceous (leathery, stiff and tough) calyx and a tubular, cream-colored, scented caduceus corolla. The fruit is a pinkish-yellow berry with 1–4 recalcitrant seeds [96]. The trees are heterozygous and cross-pollinated. It is a multipurpose tree, which fulfills the three basic requirements of tribal people (food, fodder and fuel) [97]. Mahua flowers are edible and highly nutritive, being a good source of sugars, vitamins, proteins, minerals and fats, and they are used as a sweetener to prepare numerous traditional dishes, such as barfi, kheer, halwa and meethi puri, in the tribal belts of Madhya Pradesh, Rajasthan,
Gujarat, Orissa, Jharkhand, Chhattisgarh and Andhra Pradesh [98,99]. Mahua dry flowers are also fermented to produce wine, brandy, ethanol, acetone and lactic acids [100]. Mahua is also used in medicine for its hepatoprotective, antiburn, anti-skin disease and wound healing, emollient, bone healing, swelling gum, anti-ulcer, anti-snake bite, milk production stimulation in lactating women, anti-bronchitis, anti-diabetic, diuretic, immune system stimulating, digestive, antioxidant, energetic and glucose booster activities [101,102].

2.13. Pilu (Salvadora persica L.)

Pilu is also known as kharijal, meetajal, mustard or salt bush, toothbrush tree, and belongs to the family Salvadoraeeae. It is a perennial, evergreen, large, much-branched shrub or tree widely found in Gujarat, Rajasthan, Haryana and Punjab and is suitable for the forestation of ravines, saline and alkaline lands as shelterbelts/windbreaks due to its hardy xerophytic nature [103,104]. Pilu possesses a number of potentially therapeutic compounds, namely salvadoricine, salvadourea, β-sotisterol, trimethyl amine, thioglucoside, di-benzyl thiourea, rutin, potash, chlorine, sulfur, etc. [105].

Pilu’s fibrous branches are a natural toothbrush (Miswak) and thus are used for oral hygiene [106]. They are also used in a number of important medicines, e.g., antiseptics, abrasives, dentrifices, fluoride, enzyme inhibitors, dental diseases, anti-tumors, anti-leprosy, anti-ulcers, anti-gonorrhoea, and antiscorbutic products [107–109]. Moreover, the fruit is a source of sweeteners and are used for producing fermented drinks; the tender shoots are eaten as a salad, and the seeds are rich in C12 and C14 acids used in the soap and detergent industry [110].

2.14. Khejri [Prosopis cineraria (Druce.) L.]

Khejri or Jand/shami belongs to the Leguminosae family and is considered as the wonder tree, nature’s gift, the king of desert and the golden tree. It is a desert dwelling tree that is the lifeline tree of the Indian Thar desert because each and every part of the tree is used to improve the socio-economic life of the local people [111,112]. Khejri is an evergreen, slow-growing tree with exfoliated bark, rounded canopy, small and mucilaginous leaves and a strong deep taproot system that can reach extraordinary depths (up to 53 m or more). It was reported to be drought and salinity tolerant (10.0 to 25.0 EC dSm$^{-1}$) [113,114]. It is native to Arabia and the Indian Thar desert [115], and it is extensively distributed in the Thar desert of the Indian states of Rajasthan Haryana, Gujarat, Punjab and Delhi [116].

It is a multipurpose tree as it provides a vegetable pod, flour, cattle fodder, fuel, timber, gum, resin and medicine [117]. It is also used as fencing/windbreak, avenue tree, on farm boundaries in water deficit areas, topiary, bonsai and screening trees in home gardening, and forest restoration in arid landscapes [38,118]. It is a high litter accumulating tree and improves soil fertility through fixing atmospheric nitrogen, and these effects result in the increase in the soil content of organic matter, soluble calcium and available phosphorus and in a reduction in soil pH [119,120]. Moreover, the Khejri tree is considered a productivity booster in inter-cropping and companion cropping systems thus it is highly suitable for agroforestry systems in arid and semi-arid regions. Khejri green leaves have a very high nutritional value containing crude protein (11.9–18.0%), crude fiber (13–22%), nitrogen-free extract (43.5%), ash (6–8%), ether extract (2.9%), calcium (2.1%) and phosphorus (0.4%) [121]. The unripe pods (‘Sangri’), an important ingredient of the Panchkutta vegetable, is nutritionally rich in crude protein (18%), fat (2.0%), carbohydrate (56%), crude fiber (26%), phosphorus (0.4%), calcium (0.4%) and iron (0.2%), and is consumed as a green or dry vegetable, pickles and flour [122]. All the organs of Khejri have therapeutic properties: flowers (Patuletin glycoside patulitrin, rutinisitosterolluteolin and prosogerin A and B) are used for their anti-diabetic activity and for treating Lewis lung carcinoma [123]; leaves (spicigerine, campesterol and Tricosan-1-α) for mouth ulcers [124]; pod and seed (Prosogerin, linoleic acid and prosophylline) for preventing protein malnutrition and calcium iron deficiency in blood, asthma, piles and leprosy, etc. [112,125,126].
2.15. Mulberry (Morus alba L.)

Mulberry belongs to the Moraceae family, is native to South-West Asia and has wide geographical distribution from temperate to tropical climates [127]. The Morus genus comprises 16 deciduous species out of 24 species, and Morus alba, M. nigra, and M. rubra are mainly grown in commercial orchards [128]. It is a perennial, woody, fast-growing, deciduous tree with alternate, simple and often lobed leaves, catkin inflorescence and composite sorosis fruit [129]. Most of its commercial cultivation has aimed to produce silk and shelterbelts rather than fruit. However, the latter are rich in vitamins, minerals, dietary fiber, sugar, amino acids, carotenoids, flavonoids and phytosterols. They are used as a functional food in the forms of masala, herbal tea, marmalades, juices, yogurt, biscuits, smoothies, capsules or as natural dyes, cosmetics oil and dietary food products, such as pekmez, kome and pestil [130,131]. The various suggested pharmacological uses are for obesity, cardiac diseases, diabetes, hypercholesterolemia, tumors, oxidative stress, brain damage and for their anti-fungal, anti-aging, anxiolytic and hepato-protective activities [132–135].

2.16. Chironji (Buchana nialanzan)

Chironji belongs to the family Anacardiaceae, which originates from the Indian sub-continent [136]. It has no specific requirements in terms of soil and climate, and it is naturally found in the arid and semi-arid forests of Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan, Gujarat and Uttar Pradesh [137]. Chironji is a medium-sized, sub-deciduous/evergreen plant with a straight trunk and coriaceous leaves [138]. It is a highly heterozygous, cross-pollinated plant with a strong tendency to alternate bearing [138]. The fruit can be eaten both raw and roasted. Its kernel contains fats (59.0%), proteins (19.0–21.6%), carbohydrates (12.1%), fiber (3.8%), phosphorus (528.0 mg), calcium (279.0 mg), iron (8.5 mg) and vitamins [139]. It has the potential capacity to cure various diseases, such as snakebite, dysentery, diarrhea, asthma, burning sensation of body, fever, ulcers, cold and Alzheimer’s, and it has anti-diabetic and anti hyperlipidemic activity [81,140–142].

2.17. Manila tamarind [Pithecocellobium dulce (Roxb.) Benth.]

Manila tamarind is commonly known as Madras thorn Monkey pod and Jungle jalebi and belongs to the Fabaceae family. It is a multipurpose, fast-growing, medium-sized thorny tree used as live fencing, animal fodder, hardwood timber, windbreak and a potential source of lac culture. Its fruit has a sweet acidic taste and high content of dietary fiber, proteins, Ca, Fe, P, unsaturated fatty acids and antioxidants [143–145]. Manila fruit is used to treat toothaches, mouth ulcers, sore gums, dysentery, chronic diarrhea, stress, aging symptoms and dark skin spots [146–148].

2.18. Timroo (Diospyros melanoxylon Roxb.)

Timroo or tendu belongs to the family Ebenaceae and is native to India and Sri Lanka [36]. It is found in endemic conditions within limited areas of Gujarat, Madhya Pradesh, Rajasthan, Jharkhand, Bihar, Chhattisgarh and Tamil Nadu [149]. It is a long-lived, deciduous, dioecious, seedless parthenocarpic berry fruit. Its leaves are commercially used for bidis making (indigenous, traditional cigarette), agricultural implements and furniture. Most importantly, it is used as an indicator for high sulfur dioxide concentration [150,151]. Timroo fresh fruit has high total phenolic content, flavonoids, scavenging activity, antioxidants and β-carotene content as equal or more to guava, plum, star fruit, mango, kiwi and apple fruit [152–154]. Its bark extracts are used to treat dyspepsia, diarrhea, and smallpox (burnt bark) by ethnomedicine practitioners [155–157].

2.19. Khirni (Manilkara hexendra L.)

Khirni/rayan belongs to the Sapotaceae family, and it is a native to India, evergreen, medium-sized, slow-growing fruit plant with a spreading canopy [36]. It is a wild plant found in the arid and semi-arid to tropical climate as an avenue tree and can be used
as bonsai due to the evergreen, dense foliage and dwarf habit [158]. It bears flowers in February–March, whereas fruit ripen in May–June, and it is commercially used as rootstock for sapota to exploit its tolerance to salinity and drought [159]. Its bark, seeds and fruit are rich sources of tannins, oil and vitamin A, respectively [160]. Khirni fruit and bark are used for numerous medicinal purposes, such as curing fever, flatulence, stomach disorder, leprosy, ulcers, opacity of the cornea, dyspepsia, urethrorrhea and bronchitis [161,162].
| Common Names | Species | Drought Tolerant | Marginal/ Poor Soils | Vitamins | Mineral Elements | Antioxidants | Medicinal Properties | Shelf-Life | Consumed Form |
|--------------|---------|------------------|----------------------|----------|------------------|--------------|----------------------|------------|----------------|
| Aonla (Indian Gooseberry) | *Emblica officinalis G.* | Yes [163] | Yes [163] | C [31] | Ca, Fe, P [30,32] | Leucoanthocyanins, gallic acid, ascorbic acid [30,32] | Yes [30] | Perishable [33] | Raw, processed |
| Bael | *Aegle marmelos L.* (Correa) | Yes [45] | Yes [45] | B1, B2, A, C [164] | Fe, Ca, K, P [165,166] | Marmelosin, psoralen [50,166] | Yes [49,50] | Very low perishability [167] | Processed [51,168] |
| Ber (Indian Jujube) | *Ziziphus mauritiana L.* | Yes [23,42] | Yes [53] | C, A, B [11,72,85] | Ca, P, K, Rb, Br, La [45,48,74] | Carotenoids [102] | Yes [8] | Perishable [68,89] | Raw, dry, processed [1,26,103] |
| Chironji | *Buchanania lanzan* | Yes [137] | Yes [137,169] | B1, B2, C [170] | P, Ca, Fe [139] | Polyphenolics [170,171] | Yes [81,141,142] | Highly perishable (fruit) very low perishability (kernel) [172] | Raw, processed [139] |
| Custard apple | *Annona squamosa L.* | Yes [173] | Yes [173] | A B1, B2, B3, C, E [82,83] | K, Mg, Ca, Zn, Fe [174] | Carotenoid, flavonoids [83,84,174] | Yes [82,83] | Perishable [175] | Raw, processed [84] |
| Jamun | *Syzygium cumini Skeels* | Yes [176] | Yes [176] | C, B, E [177,178] | K, Na, Mg, Ca, Fe [179] | Ascorbic acid, phenolics [86,178] | Yes [87,88] | Highly perishable [176] | Raw, processed [89] |
| Jharber | *Ziziphus nummularia* Burm. f. | Yes [10,91] | Yes [10] | C, B group, A [22] | K, P, Ca, Fe, Na [180] | Phenolics and ascorbic acid [92] | Yes [92] | Very low perishability [22] | Raw, dry [22] |
| Kair | *Capparis decidua* (Forsk.) | Yes [53,54] | Yes [52] | A, C, E [57,181] | Al, P, Na, Mg, Fe, Ca [57,182] | Rutin, tocopherols, carotinoids [182-184] | Yes [57] | Very low perishability [56] | Processed [56] |
| Common Names | Species | Drought Tolerant | Marginal/Poor Soils | Vitamins | Mineral Elements | Antioxidants | Medicinal Properties | Shelf-Life | Consumed Form |
|--------------|---------|------------------|---------------------|----------|------------------|--------------|----------------------|------------|----------------|
| Karonda      | Carissa carandas L. | Yes [185,186] | Yes [187] | C, A [61,62] | Fe, Ca, Mg, P [61,62] | Phenolics, flavonoids, anthocyanins [61,62] | Yes [188] | Moderately perishable [186,187] | Raw, processed [60] |
| Khejri       | Prosopis cineraria (Druce.) L. | Yes [113,114] | Yes [113,114] | K1, A, C [189] | Ca, P, Fe, Zn [121,122] | Phenolics, carotenoids, saponin [123] | Yes [123,126] | Moderately perishable [126] | Dry, processed [126] |
| Khirni       | Manilkara hexandra L. | Yes [159] | Yes [158] | A, C, E [160] | Ca, Fe, Zn, Cu, Se [189] | Quercetin, myricetin, rutin [160] | Yes [161,162] | Highly perishable [190] | Raw, processed [191] |
| Lasora       | Cordia myxa L. | Yes [192] | Yes [193] | C [10] | Ca, P, Zn, Fe [41,194,195] | Polyphenols, flavonoids [41,194,196] | Yes [197] | Perishable [198] | Processed [39,199] |
| Mahua        | Madhuca longifolia Koenig | Yes [200,201] | Yes [200] | C, A [201] | Ca, P [202] | Ascorbic acid [98] | Yes [101,102] | Very low perishability [201] | Processed [99,100] |
| Manila       | Pithecellobium dulce (Roxb.) Benth. | Yes [148] | Yes [148] | C, B6, B1 [203] | K, P, Ca, Fe, Zn [204] | Anthocyanins, polyphenolics [145,205] | Yes [146,147] | Moderately perishable [206] | Raw, processed [207] |
| Mulberry     | Morus alba L. | Yes [127] | Yes [127] | C, E, K [208] | Fe, Cu, Mg, K, Se, Na [208] | Zeaxanthin, resveratrol [208] | Yes [132,135] | Highly perishable [208] | Raw, processed [130,131] |
| Pilu         | Salvadora persica L. | Yes [103,104] | Yes [103,104] | E, C, A [209] | K, Cl, Na, S, Fe [210] | Polyphenols, flavonoids, carotenoids [209] | Yes [105,108] | Highly perishable [110] | Processed [110] |
| Common Names | Species | Drought Tolerant | Marginal/Poor Soils | Vitamins | Mineral Elements | Antioxidants | Medicinal Properties | Shelf-Life | Consumed Form |
|--------------|---------|-----------------|---------------------|----------|-----------------|-------------|---------------------|------------|----------------|
| Tamarind     | *Tamarindus indica* L. | Yes [211] | Yes [211] | C, K, B₈ [65] | K, Ca, P, Na, Fe, Zn [65] | Polyphenols, flavonoids, carotenoids [67,68] | Yes [67,68] | Very low perishability [66,212] | Raw, processed [66] |
| Timroo       | *Diospyros melanoxylon* Roxb. | Yes [213] | Yes [213] | C, A [214] | K, Ca, P [214] | Polyphenolics, beta-carotene [152–154] | Yes [155,157] | Perishable [214] | Raw, processed [215] |
| Wood apple   | *Feronia limonia* L. | Yes [71] | Yes [71] | A, B₂, C [216] | Ca, P, Fe [216] | Phenolics [216,217] | Yes [74–76] | Very low perishability [218] | Processed [77,78] |
3. Diversity and Conservation of Genetic Resources of Indigenous Underutilized Fruit Crops

India is regarded as a mega-diverse country, as it houses 11.18% of the world’s recorded plant species and over 2.4% world’s surface area [219]. Out of 34 global biodiversity hotspots, India shares four biodiversity hotspots (Western Ghats and Sri Lanka, Himalayas, Indo-Burma, Sundal) and one-third of the higher plant species present in these areas are endemic. The conservation and management of this biodiversity is considered to be mandatory for the use of humankind [220].

A significant part of the flora and fauna biodiversity is threatened by many factors related to climate change [25]. The indigenous underutilized fruit resources have remained on the back foot due to the introduction of ethnic fruit species and the advancement in the cultivation of existing major fruit species. Furthermore, the ever-increasing population undoubtedly is exerting huge pressure on the degradation of biodiversity (ecosystems, genes and species), causing severe genetic losses. Most of the endangered fruit species are conserved, domesticated, improved only by traditional societies/farmers and tribal people. However, in the last decades, a systemic effort laid on the exploration, conservation and their utilization by the different institutions [221].

The main Indian statutory body responsible for plant genetic resource collection and conservation, the ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR), New Delhi, India, has conserved about 440,000 accessions of 1900 species in its gene bank and about 3520 accessions of recalcitrant species in a cryo gene bank since its inception (1976). The ICAR-NBPGR has in-situ and ex-situ conservation at its 10 regional stations and 59 designated National Active Germplasm sites (NAGS) across the country. The present status of underutilized fruit crops conservation in India is 1717 at ICAR-NBPGR and its collaborative centers (Table 2), whereas the major research institutions working on underutilized fruit crops in the country are maintaining 1127 accessions in their field gene banks (Table 3). Furthermore, 357 accessions belonging to eleven underutilized fruit species are being cryopreserved in gene banks [149].

Table 2. Status of collection and conservation of indigenous fruit species undertaken by different institutions of India.

| Crop            | No. of Accessions |
|-----------------|-------------------|
| Ber             | 487               |
| Aonla           | 159               |
| Bael            | 57                |
| Karonda         | 50                |
| Timroo          | 24                |
| Manila Tamarind | 24                |
| Mahua           | 153               |
| Khirni          | 74                |
| Phalsa          | 36                |
| Pili            | 207               |
| Jamun           | 198               |
| Tamarind        | 248               |
| **Total**       | **1717**          |
## Table 3. Underutilized fruit species’ germplasm being conserved in field gene banks at different institutions in India.

| Name of Crop | CIAH, Bikaner | RS, HAU, Bawal | NBPGR, Jodhpur | PAU, Abohar | CAZRI, Jodhpur |
|--------------|---------------|----------------|----------------|-------------|---------------|
| Ziziphus mauritiana | 318 | 47 | 26 | 34 | 40 |
| Ziziphus rotundifolia | 22 | - | - | - | - |
| Emblica officinalis | 50 | 6 | - | - | - |
| Punica granatum | 154 | - | - | - | - |
| Carissa carandas | - | 4 | - | - | 13 |
| Cordia myxa | 65 | 30 | 17 | - | - |
| Aegle marmelos | 17 | 10 | 5 | - | - |
| Grewia subinaequalis | 06 | 04 | 04 | - | - |
| Capparis decidua | 06 | 22 | 22 | - | 20 |
| Syzygium cuminii | 50 | - | - | - | - |
| Tamarindus indica | 25 | - | - | - | - |
| Madhuca latifolia | 50 | - | - | - | - |
| Buchanania lanzan | 30 | - | - | - | - |
| Manilkara hexandra | 30 | - | - | - | - |

RS: Regional station; HAU: Hisar Agriculture University, PAU: Punjab Agriculture University.

### 4. Strategies for the Improvement and Promotion of Underutilized Fruit Crops

The underutilized fruit species play a crucial role in mitigating nutritional insecurity and poverty in those rural or tribal areas of the country where the availability of fruits is either low or not accessible to them. In recent years, concerted efforts have been laid by some of the public sector research organizations in the improvement of underutilized fruit crops. As a result, some varieties have been developed through selection and hybridization for higher adaptability with good yield and quality traits under arid and semi-arid environments (Table 4). The locally adapted species serve as a reservoir of stress-related genes that are a potential source for the improvement of stress-tolerant varieties in future breeding programs. Several production technologies have been standardized by different institutions, e.g., propagation methods (rootstock selection, grafting/budding), plant spacing, canopy management, nutrient and water management, crop regulation, plant protection and post-harvest management, and value addition (Table 4).
Table 4. Recent advances made for the cultivation and utilization of underutilized fruit crops.

| Species | Improved Varieties | Production Technologies | Major Value-Added Products | Ornamental and Other Values | Institute Involved |
|---------|--------------------|------------------------|----------------------------|---------------------------|--------------------|
| Aonla   | NA-7, NA-10, NA-6, Anand-1, Anand-2, Laksmi-52, Goma Aishwaria [222,223] | Standarization of propagation (patch budding), high-density planting, canopy management, value addition, integrated nutrient management [223] | Candy, Chyawanprasad, Shreds, Candy, Preserve, Squash, RTS, Pickle, Jelly, Leather, Toffee, aonla powder [34,35,223] | Avenue plantation | ICAR-CIAH, Bikaner; ANDUAT, Ayodhya |
| Bael    | Goma Yashi, NB-5, NB-7, NB-9, Pant Aparna, Pant Sujata, Pant Shivani, Thar Divya, Thar Neelkanth, Thar Shristhi, Thar Prikriti, Thar Shivangi [224] | Standarization of propagation (patch budding), detopping for promotion of scion wood in mother plant, planting geometry and high-density planting, plant architectural engineering, water and nutrient management, fruit drop and cracking management, bael-based cropping system [224] | Squash, preserve candy [51,223,225] | Avenue plantation, windbreak plantation [48] | ICAR-CIAH, Bikaner; ANDUAT, Ayodhya; GBPUAT, Pantnagar |
| Ber     | Gola, Umran, Goma Kirti, Katha, Seb, Thar Sevika, Thar Bhuvraj, CAZRI Ber 2018 [22,226] | Standarization of propagation (T-budding), insitu budding, top-working, pruning and training system, high-density planting system, water and nutrient management, fruit fly and stone weevil management [22,227] | Osmodehydrated ber, Canned ber, Jam, Pickle [22] | Ornamental purpose, windbreak, bio-fencing, furniture [27,28] | ICAR-CIAH, Bikaner; NBPGR, New Delhi; HAU, Hisar; ICAR-CAZRI, Jodhpur |
| Chironji| Thar Priya [228,229] | Standardization of propagation (soft wood grafting), insitu grafting, training and pruning, nutrient management, processing, value addition [228] | Dried seed [139] | Avenue plantation [137] | ICAR-CIAH, Bikaner (Raj); NIFTEM, Sonipat (Haryana) |
| Species      | Improved Varieties                                      | Production Technologies                                                                 | Major Value-Added Products                                      | Ornamental and Other Values                          | Institute Involved                                      |
|-------------|--------------------------------------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------|
| Custard apple | Arka Neelanchal Vikram, Arka Sahan, Balanagar [230] | Standardization of propagation (whip grafting), high-density planting system, canopy management, flower regulation, processing, value-added products [230–232] | Puree, jam, RTS, Juice, Frozen pulp [233,234] | Kitchen gardening [230] | ICAR-IIHR, Bangalore                                    |
| Jamun       | Goma Prinynka [235]                                    | Standardization of propagation (patch budding and soft wood grafting), high-density planting system, canopy management, processing, value addition [235–237] | Jamun Juice, RTS, Squash, Nectar, Jam, Vinegar, Wine, Jelly, Cider, Syrup [236,237] | Avenue and windbreak plantation [236,237] | ICAR-CIAH, Bikaner (Raj); ICAR-CAZRI, Jodhpur; ICAR-IIHR, Bangalore |
| Jharber     | -                                                      | Dehydrated products [238]                                                               | Churan, Bar, Toffee [238]                                      | Bio-fencing, wind break, forest and soil restoration [238] | ICAR-CIAH, Bikaner                                     |
| Kair        | CZJK-3 and CZJK5 [239]                                  | Standarization of propagation (root cutting and tissue culture), post-harvest management, value addition [35,56,239] | Vegetable, Pickle panchkutta [240]                              | Bio-fencing, wind break, forest and soil restoration, ornamental value [52,53] | ICAR-CIAH, Bikaner; ICAR-CAZRI, Jodhpur               |
| Karonda     | Thar Kamal, Konkan Bold, Maru Gauray, Pant Manohar, Pant Suda rshan, Pant Suvantra [185,241] | Standardization of propagation (cutting/air layering), high-planting system, training and pruning, nutrient and water management, value addition [185,241] | Murabba, Jam, Jelly, Pickle, Chutney [185,241,242] | Bio-fencing in kitchen garden, orchards, windbreak, ornamental [38,38,59] | ICAR-CIAH, Bikaner (Raj); ICAR-CAZRI, Jodhpur; GBPUAT, Pantnagar (UK) |
| Khejri      | Thar Sobha, Thar Amruta [243]                          | Standardization of propagation (patch budding), water and nutrient management, canopy management, khejri-based model (HBCPSMA) [243,244] | Vegetables, Pickle, Biscuits [122]                              | Bio-fencing, wind break, forest and soil restoration, bonsai [38,118] | ICAR-CIAH, Bikaner                                     |
| Species          | Improved Varieties                          | Production Technologies                                                                 | Major Value-Added Products                              | Ornamental and Other Values                                | Institute Involved                                      |
|------------------|---------------------------------------------|----------------------------------------------------------------------------------------|--------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------|
| Khirni           | Thar Rituraj [245]                          | Standardization of propagation (cleft grafting), plant spacing, canopy management, cropping system, value addition [225,245] | Dehydrated fruit, fruit bar, RTS, Jam [225]            | Avenue plantation [158]                                  | ICAR-CIAH, Bikaner(Raj)                                 |
| Lasora           | Thar Bold, Maru Samaridhi, Karan Lasora [246–248] | Standardization of propagation (patch budding), canopy management, defoliation, integrated pest management, value addition [246–248] | Pickle, Beverage, Chutney [39]                        | Avenue and border plantation as windbreak [37,38]        | ICAR-CIAH, Bikaner; ICAR-CAZRI, Jodhpur; SKNAU, Jobner  |
| Mahua            | Thar Madhu [249]                            | Standardization of propagation (soft wood grafting), canopy management, nutrient and water management, post-harvest management, value addition (alcoholic beverage) [249] | Alcohol, Bakery, Vinegar, Syrup, Wine [98–100]        | Avenue and ornamental plantation [249]                  | ICAR-CIAH, Bikaner (Raj); NIFTEM, Sonipat (Haryana)    |
| Manila tamarind  | PKM 1 [250]                                 | Standardization of propagation (cutting, micropropagation), value addition [250,252] | Dried seed, Oil extraction [207]                      | Bio-fencing, windbreak and shelterbelts [252]           | ICAR-CIAH, Bikaner(Raj); TNAU, Tamilnadu               |
| Mulberry         | Thar Lohit, Thar Harit, Delhi Local [253]   | Standardization of propagation (cutting), mixed farming system, nutrient management, training and pruning system by Tamil Nadu Agriculture University [253,254] | Squash, RTS [130,131]                                | Avenue plantation, furniture [128]                     | ICAR-CIAH, Bikaner                                      |
| Pilu             | -                                           | Value-added products [106,110]                                                         | Squash, RTS, Miswak [106,110]                         | Avenue, wind break, forest and soil restoration [103,104] | ICAR-CAZRI, Jodhpur                                    |
Table 4. Cont.

| Species       | Improved Varieties       | Production Technologies                                                                 | Major Value-Added Products                      | Ornamental and Other Values                      | Institute Involved                      |
|---------------|--------------------------|-----------------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------|
| Tamarind      | Periyakulam 1 (PKM1)     | Standardization of propagation (root/stem cutting, wedge grafting), water and nutrient  | Jam, Jelly, Syrup, Pulp Powder, Candy, Seed     | Avenue plantation, wind break, ornamental as     | TNAU, Tamilnadu, ICAR-CIAH, Bikaner      |
|               |                          | management, insect-pest management, processing, value-added products                     | kernel powder [66]                              | bonsai purpose [255]                              |                                          |
|               |                          | [255–257]                                                                               |                                                 |                                                 |                                          |
| Timroo        | -                        | -                                                                                       | -                                              | Avenue tree [149]                                | ICAR-CIAH, Bikaner(Raj)                  |
| Wood apple    | Thar Guarav [258]        | Standardization of propagation (soft wood grafting), high-density planting system,      | Chutney, Pickle, Frozen puree, sauce           | Boundry plantation of farms [258]                | ICAR-CIAH, Bikaner                      |
|               |                          | processing, and value addition [258,259]                                               |                                                 |                                                 |                                          |
In addition to the medicinal and nutritional value of fruits, these underutilized fruit crops have multipurpose utilities, such as ornamental, avenue tree, rootstocks, bio-fencing, windbreak/shelter tree, furniture, screening in backyard gardening, forest restoration and as social and economic plants [28,38]. The promotion of these underutilized fruit crops can be accelerated by providing training and demonstrations of the developed technologies to the end-users. Emphasis needs to be directed towards the developmental activities, such as the establishment of planting nurseries for ensuring the supply of quality planting materials and processing units for scale-up of their values added products at commercial levels through entrepreneurship or self-help groups or farmer producer organizations (FPO), etc. The adoption of these crops can be promoted by planting them on community lands, in the premises of religious places, gardens, parks, etc., where, besides providing recreation or ornamental values, these would provide nutrient-rich fruits to the people (Table 1). The government, through its various schemes, such as MIDH, tribal sub-plan (TSP), scheduled caste sub-plan (SCSP), are providing quality planting materials for the establishment of commercial orchards of different fruit crops, including underutilized fruits. These crops are less prone to insect pests and diseases. Pesticide application is almost negligible; thus they can be fitted well into organic farming. The underutilized fruit crops are expected to get special attention under the recently launched centrally sponsored scheme ‘Prakritik kheti’ (Natural farming) that aimed at promoting the cultivation of crops and fruit species in their natural habitats. Furthermore, in order to promote the importance of indigenous species, the government has been giving major emphasis through a slogan ‘vocal for local’.

In addition, it is required that the development of policies for incentives to on-farm conservation of biodiversity, and the recognition through felicitation and monetary supports to the people and societies involved in the conservation and utilization of such important indigenous underutilized fruit species. Furthermore, the inclusion of course curricula about indigenous fruit species at the school level will create awareness among the children. For creating awareness, extension specialists can organize special awareness camps/campaigns and exhibitions at micro and macrolevels, conveying themes of unexploited-underutilized fruit crops. Furthermore, the use of mass media, such as radios, televisions, newspapers and other printed and electronic media platforms, can play an effective role in creating awareness about the significance of underutilized fruit crops among the growers and other stakeholders, as well as consumers.

5. Conclusions

Underutilized fruit crops play an important role for their therapeutic properties due to their significant medicinal and nutritional value and can be considered as future horticultural assets to help nations assuring nutrition and food security, besides providing recreational, social and environmental significance. Being hardy and adapted locally, these species may serve the purpose of enhancing sustainable farm income under the harsh arid and semi-arid environments, such as waste lands (jharber, kair, pilu), marginal or saline soil and water conditions (ber, aonla, bael, karonda, etc.), rocky terrains (custard apple, timroo, jamun, etc.) and also in the backyard or kitchen gardening (karonda, custard apple, khejri, mulberry, etc.) and avenue plantation (tamarind, lasora, khirni, jamun, mulberry, khejri, etc.). Some fruit crops possess high significance in food processing industries (aonla, bael, karonda, tamarind, etc.). Their horticultural development is moving quite fast, and in the future, there will be greater technological adoption, extension and policy planning, both in traditional horticultural enterprises as well as in the commercial sectors. Special efforts are needed in terms of research and development of suitable specific packaging practices and of superior varieties. Considering the potential of the underutilized fruit crops, the emphasis shall be made to substantiate the efforts being made towards eradicating global malnutrition by their direct introduction in other arid and semi-arid regions of the world so as to achieve the goal of sustainable development (1 to 3) of the United Nations.
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