Review of indigenous fruit crops status and their scenarios existence, conservation and utilization in the Bundelkhand region of India

ABSTRACT

The contemporary era witnesses a significant demand for nutrient-dense fruits to enhance human health from both nutritional and metabolic perspectives. Consequently, the cultivation of commercial fruit crops is increasingly reliant on inputs to mitigate losses attributed to biotic and a biotic stress. Concurrently, a diverse array of underutilized crops, predominantly cultivated, commercialized and consumed locally, emerges as a viable alternative. These underutilized fruits exhibit notable advantages in terms of cultivation feasibility, resilience to climatic variations and nutritional richness compared to major commercially grown counterparts. Moreover, they boast an abundance of essential phytochemicals and possess medicinal properties. Consequently, integrating these fruits into local diets holds promise for addressing the nutritional deficiencies prevalent among rural populations inhabiting fragile arid and semi-arid regions globally. Additionally, local communities possess profound knowledge regarding the nutritional and medicinal attributes of these crops, emphasizing the imperative for rigorous investigation into their conservation and nutritional profiles. This review delves into the ethno botanical significance, medicinal and nutritional values, biodiversity conservation and utilization strategies of 20 underutilized fruit crops prevalent in Bundelkhand region of India. These include Indian jujube, Indian gooseberry, lasora, bael, kair, karonda, tamarind, wood apple, fig, custard apple, jamun, jharber, mahua, pilu, khejri, mulberry, chironji, manila tamarind, timroo and khirni, collectively enriching the spectrum of available foods with enhanced functional and nutritional attributes.

Keywords: Bundelkhand, climate resilient, underutilized fruit, nutritional quality.

Introduction

"At present, the global population stands at 7.87 billion and is experiencing an annual growth rate of 1.03%, poised to reach approximately 9.6 billion by 2050. Among these numbers, India, with 1.38 billion inhabitants, constitutes 17.5% of the world population while occupying a mere 2.4% of the world's surface area. The foremost challenge confronting humanity today is the provision of stable, safe and nutritious food for this burgeoning populace. Currently, India ranks 101 out of 116 countries in the Global Hunger Index (GHI), indicating a somber reality in the battle against malnutrition, which inevitably hampers socio-economic progress" (Anonymous, 2013) [1]. Recognized by the World Health Organization (WHO) as the most pressing global issue, hunger affects countries worldwide, with a particularly pronounced impact on African nations and India. Consequently, 195 nations have committed to adopting sustainable development goals (SDGs) aimed at addressing severe malnutrition issues through a comprehensive approach by 2030.

"Increasing consumer awareness regarding the health benefits of fruits has significantly boosted their regular consumption as part of a balanced diet. The global demand for nutrient-dense fruits has surged in recent years, not only for their role in enhancing nutritional status but also for their positive impacts on immune and metabolic health. In India, major fruit crops like mango, banana, citrus, guava and apple occupy over 72% of the total fruit crop area, while

indigenous varieties contribute a mere 6.56% of the area with relatively high productivity"(Vikram*et al.,* 2014) [32].However, climate change poses a formidable challenge, manifesting in rising temperatures, increased UV radiation and more frequent extreme weather events, exacerbating issues such as salinity, mineral deficiency/toxicity and crop diseases and pests, particularly in arid or semi-arid regions.Consequently, climate change poses a significant threat to sustaining the production of major commercial fruits.

"In light of these environmental pressures, ensuring consumer choice and nutritional food security at an affordable and sustainable level emerges as a critical concern for researchers and growers alike. Under these circumstances, leveraging specific growing areas to harness the potential of underutilized crops capable of producing edible fruits becomes imperative to meet local food and nutritional demands. Exploring resilient native underutilized fruit crops that can withstand climatic variations and adapt to diverse agro-climatic conditions is essential" (Gora *et al.,*2019)[2]. "These indigenous fruit crops not only demonstrate superior adaptability to environmental conditions but also boast significant nutritional value. Nevertheless, limited research has been conducted on developing production protocols and utilizing these underutilized fruit species. Additionally, constraints such as the scarcity of identified varieties, inadequate availability of quality planting materials and insufficient cultural and post-harvest management practices continue to impede the systematic cultivation of these crops" (Ngwenya*et al.,*2010) [15].

"Arid regions harbour a plethora of edible fruit-bearing and food-producing species, with around 30 plant species in the Indian arid zone known for their various edible uses, 19 of which bear edible fruits of horticultural importance. Many underutilized fruit crops not only serve as fresh fruit but also find application in culinary and medicinal contexts, providing vital nutrients and often possessing ornamental value" (Kumar *et al.,* 2005) [5]. Local communities recognize their medicinal and nutritional properties, with indigenous underutilized fruit crops like ber, kair, aonla, lasora and phalsa exhibiting higher mineral content, antioxidants and phytonutrients compared to commercial varieties. Despite their nutritional richness, these underutilized fruits remain unpopular and are sold at low prices in local markets due to factors such as limited awareness of their nutritional value, consumption habits, insufficient research and government policies hindering their exploitation.

Given the significance of these tree crop species in traditional medicine, their nutritional richness and broad adaptability, the Government of India, through its centrally sponsored scheme, the Mission on Integrated Development of Horticulture (MIDH), previously known as the National Horticulture Mission (NHM), has prioritized the establishment of orchards featuring underutilized fruit species since 2022–2023. This paper undertakes a comprehensive review of 19 underutilized fruit crops indigenous to Indian arid and semi-arid conditions, elucidating their adaptation mechanisms to stress conditions, genetic diversity, ethno botany, medicinal and nutritional values and proposing strategies for their conservation and potential exploitation to enhance the nutritional and socio-economic security of the regions.

Characteristics and Prospective Applications of Indigenous Underutilized Fruit Crops

"Abiotic stresses induced by environmental factors stand as the predominant limitations on global yield across major fruit crops, accounting for up to 70% of yield losses. Delving deeper

into these stresses, specific potential yield reductions due to varied climatic adversities are discerned: 40–50% for high temperatures, 20% for salinity, 17% for drought and 15% for low temperatures. Regions characterized by arid and semi-arid climates emerge as focal points for abiotic stresses, encompassing extreme temperatures, intense solar radiation, salinity, drought and nutrient deficiencies" (Singh, 2003) [23]."Within such climatic realms, the integration of underutilized fruit crops native to arid zones presents a more viable strategy to sustain crop productivity amidst stress. This is attributed to their inherent morphological, physiological, anatomical and biochemical xerophytic traits, facilitating optimal performance under harsh conditions" (Mallik *et al.*,2010) [8]. Consequently, adaptive traits geared towards bolstering resilience and resistance to suboptimal environmental conditions do not necessarily incur a yield penalty. Rather, they ensure stability in yield under specific conditions, with fitness primarily gauged in terms of fertility, fruit and seed production.

"To confront abiotic stresses, underutilized fruit crops from arid zones, such as ber (*Zizyphus spp*.), aonla (*Emblicaofficinalis*), bael (*Aegle marmelos*), jamun (*Syzigium spp*.) and wood apple (*Feronia limonia*), have evolved modified organs to sustain vital morpho-physiological functions. These adaptations include a robust deep root system and a high root-to-shoot ratio to tap into deeper moist soil layers for enhanced water and nutrient uptake. Moreover, certain crops, like ber, bael, lasora (*Cordiamixa*) andpilu (*Salvadora persica*), possess rounded, thick and bark-covered stems to facilitate water storage and reduce cuticle transpiration. Synchronized flowering and rapid fruit development during seasons characterized by ample moisture availability are observed in crops like kair (*Capparis decidua*), lasora, aonla andpilu" (Satyanarayana *et al.*,2008) [19]. Additionally, crops such as ber, phalsa, fig and bael exhibit leaf shedding or dormancy to minimize water loss in summer and protect against frost in winter.

"Furthermore, various underutilized crops exhibit morphological adaptations, including spines instead of leaves (ber), sparse foliage (kair), spiny cladodes (prickly pear), mucilaginous sap for reduced transpiration loss (kair, lasora, pilu, bael, etc.), small-sized and thick leaves and fur/hairiness with a waxy coating on the leaf surface"(Meena *et al.*, 2022) [11]."These adaptations, along with sunken and deep stomata, enable water-saving by reducing transpiration rate and mitigating heat shocks. Selective or reduced absorption of certain ions (Na^+, Cl^-, SO_4^{-2}) is also noted, along with the accumulation of osmolytes and the biosynthesis of antioxidants, heat shock proteins and drought-responsive genes to maintain cell turgor and enhance survival in arid and semi-arid environments.Moreover, understanding the genetic underpinnings of these adaptive traits holds promise for future breeding programs, potentially leveraging novel tools like genome editing" (Singh *et al.*,2001) [24]. These underutilized fruit crops thus emerge as the vanguards of future agricultural practices, capable of bolstering farmers' income through sustainable production systems, even amid scenarios of climate change.

Aonla (*Emblicaofficinalis* G.)

The Indian gooseberry, scientifically known as *Emblicaofficinalis* G., stands as an indigenous and significant minor fruit within India. It holds its place within the family Euphorbiaceae and thrives in a variety of soil and climatic conditions across the country. Revered for its medicinal and therapeutic qualities, the aonla is often referred to as the 'amritphal' or the miracle fruit for health. Comparatively, the aonla fruit boasts 3 times the protein content and a

staggering 160-fold increase in vitamin C when measured against apples(Vikram *et al.*,2016) [31]. Remarkably, it stands as the second richest source of Vitamin C among fruits, following the Barbedos cherry, with a content ranging from 500 to 1800 mg per 100 g. Furthermore, its abundance in leucoanthocyanins, polyphenols, pectin, iron, calcium and phosphorus renders it a staple ingredient in Ayurvedic medicines, notably in the formulations of Triphala and Chyavanprash (Vikram and Sikarwar, 2018) [29].Through extensive research efforts initiated at the onset of the 21st century and the subsequent development of 30 distinct varieties, the aonla fruit has transitioned into a commercially viable crop within select regions. Its adaptability to arid ecosystems has been particularly notable, showcasing resilience, productivity and profitability even under minimal management in drought-prone and saline environments. Despite its highly perishable nature and inherent acidity and astringency, consumers have embraced its versatility in processed food products. From preserves and candies to jellies and pickles, the aonla fruit finds its way into an array of delectable offerings (Vikram and Sikarwar, 2018) [30]. Moreover, it serves as a key ingredient in beverages, including squash, juice and cider, as well as in the production of dried powders and renowned Ayurvedic tonics like Chayvanprash, Makar Prash, Triphala, Aonla Ki Rasayan, AmritKalash and AonlaBhashm.

Bael (*Aegle marmelos* L.)

Bael, scientifically known as *Aegle marmelos* L. (Correa), stands as the singular species within the genus Aegle, affiliated with the Rutaceae family. It boasts a venerable heritage as one of India's ancient indigenous fruits, known by diverse monikers across the country including billi, Bengal quince, stone apple, golden apple and Japanese bitter orange. Bael thrives across a broad spectrum of edaphic-climatic settings, owing to its remarkable resilience against heat, drought and impoverished, low-temperature soils (Sharma *et al.*,2007)[20]. Exhibiting deciduous tendencies, it assumes a medium stature with slender proportions, characterized by gum-bearing attributes, a cauliflorous fruiting disposition, a robust taproot system, formidable thorny branches and trifoliate foliage reminiscent of a trident, a feature that prompts its presentation to Lord Shiva Lingam to alleviate worry and suffering. Bael serves dual roles as both avenue and ornamental specimens, particularly prized for their golden-hued ripened fruits, while the desiccated fruit shells, stripped of their pulp, find utility as crafted vessels, petite receptacles, decorative adornments and snuff containers.The bael fruit emerges as a veritable font of riboflavin, instrumental in the treatment of beriberi, with its unripe variant prescribed for mitigating diarrhea and dysentery. Marmelosin, a constituent of the fruit, offers therapeutic efficacy against assorted gastric maladies. The multifaceted medicinal attributes of bael extend throughout its entire anatomy, comprising an array of bioactive compounds such as coumarins, alkaloids, sterols and essential oils, which confer analgesic, antipyretic, anti-inflammatory, antifungal, microfilarial, hypoglycemic, antilipidemic, antiproliferative, wound-healing, insecticidal and antifertility properties(Singh *et al.*, 2011) [21]. Bael fruit finds consumption primarily in processed forms such as powder, preserves, nectars and toffees, owing to its esteemed status in Ayurvedic medicine. The burgeoning demand for these products has propelled bael into a lucrative crop for farmers inhabiting arid and semi-arid regions, resulting in a commensurate rise in market prices.

Chironji (*Buchananialanzan*)

Chironji, scientifically known as *Buchananialanzan*, is a member of the Anacardiaceae family, originating from the lush landscapes of the Indian subcontinent. Thriving effortlessly, it exhibits remarkable adaptability to various soil types and climates, predominantly inhabiting the arid and semi-arid forests spanning across Jharkhand, Chhattisgarh, Madhya Pradesh, Rajasthan, Gujarat and Uttar Pradesh. This medium-sized botanical wonder presents itself as a blend of subdeciduous and evergreen traits, boasting a straight, dignified trunk adorned with coriaceous leaves. Its genetic makeup, characterized by high heterozygosity and a penchant for cross-pollination, often leads to alternating periods of abundant fruiting(Roy *et al.,* 2015) [17]. The fruit of the Chironji tree offers a dual culinary delight, fit for consumption both in its raw form and after a gentle roasting. Encased within its kernel lies a treasure trove of essential nutrients, including 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 various vitamins. Beyond its nutritional prowess, Chironji demonstrates promising medicinal properties, revered for its potential in combating a spectrum of ailments. From the venomous sting of a serpent to the discomforts of dysentery and the shivers of a cold, Chironji's extracts have been lauded for their efficacy. Furthermore, its therapeutic reach extends to alleviating symptoms associated with asthma, fever, ulcers and even the ravages of Alzheimer's disease. Noteworthy is its documented anti-diabetic and antihyperlipidemic activities, marking it as a multifaceted healer in the realm of traditional medicine.

Custard Apple (*Annona squamosa* L.)

"Custard Apple (*Annona squamosa* L.) thrives as a resilient fruit plant belonging to the family Annonaceae, primarily cultivated in specific regions of the Indian Deccan plateau. It flourishes under optimal conditions of light, gravelly soil and small pebbles. The plant is characterized by small, semi-deciduous shrubs with simple leaves, cauliflorous flowering, bisexual and protogynous flowers, superior ovary and fruit etaerio of berries, presenting a distinctive botanical profile. Flowering predominantly commences in new flushes from March to August, reaching its peak in April–May. The fruit, displaying a climacteric nature, may appear as symmetrically heart-shaped, lopsided, or irregular, with the spaces between the protrusions transitioning to yellow upon full maturity" (Mitra *et al.,* 2011) [13]. The demand for custard apple fruit is steadily escalating in both domestic and international markets, driven by its sensory pleasures, therapeutic advantages and nutritional abundance. Custard apple fruit is rich in essential vitamins such as A, B, C, E and K1, along with crucial minerals, antioxidants and polyunsaturated fatty acids. Its medicinal prowess encompasses antimalarial, antifeedant, immunosuppressive and cytotoxic attributes, with certain compounds harnessed in HIV treatment. Moreover, the cosmetic industry has leveraged the attributes of custard apple, introducing a variety of products including perfumes, soaps, pimple creams, essential oils, hair lotions, ayur slim capsules, cold balms, anti-stress massage oils and body care creams.

Fig (*Ficuscarica*)

Fig, scientifically known as *Ficuscarica*, belongs to the Moraceae family. Their origin traces back to ancient times, with historical roots embedded in various civilizations. Cultivating figs in Bundelkhand requires a meticulous understanding of the local climate and soil conditions, making it a skillful practice passed down through generations. Botanically, figs are characterized

by their unique enclosed inflorescence structure, known as a syconium, which contains numerous tiny flowers (Meghwal and Kumar, 2009) [9]. This fruit is not only delicious but also offers substantial nutritional benefits, rich in fiber, vitamins and minerals. In Bundelkhand, where agriculture plays a vital role in sustaining livelihoods, the cultivation of figs serves as both a source of sustenance and a connection to tradition, weaving together the threads of history, botany and nutrition in the fabric of the region's agricultural landscape. In the Bundelkhand region, the cultivation of figs holds significant importance, not only for its agricultural value but also for its cultural and nutritional significance.

Indian jujube/Ber(*Ziziphusmauritiana* L.)

The Indian jujube, scientifically known as *Ziziphusmauritiana* L., belongs to the family Rhamnaceae and is often referred to as the king of arid-zone fruits or the poor man's apple. Characterized by a fast-growing nature and a spreading canopy, the ber tree features a short bole with slender, downy branches adorned with pairs of brown, bold spines. Its remarkable drought-hardiness stems from a deep taproot system and xerophytic traits, including dormancy (leaf shedding) during the scorching summer months to prevent excessive transpiration, as well as waxy and hairy leaves and a thick bark. Thriving even in marginal or poor soils where other commercial fruit trees struggle, the Indian jujube boasts seeds containing saponins, jujubogenin andobelin lactone. Beyond its utility in fuel and charcoal production, jujube wood, along with its leaves, serves as fodder for livestock. The fruit itself, characterized by a spongy, sweet andflavorful pulp, serves as an excellent source of various vitamins, including C, A and B, as well as carotenoids, protein and essential minerals such as calcium, phosphorus and potassium. Notably, its sugars, including fructose, glucose and galactose, contribute to its nutritional value. Additionally, the smoke from burning its leaves is utilized in traditional remedies for skin ailments, coughs and colds. Given its short shelf life, typically limited to 4–5 days after harvest, there's a pressing need to develop value-added products either at the farmer-field or industrial level. Furthermore, there's a growing recognition of the necessity to diversify and popularize jujube products (Singh *et al*., 2015) [28]. Notably, the Indian jujube stands out as a fruit crop capable of yielding substantial returns even under rainfed conditions, owing to its adaptability to a wide range of soils, water availability and climates, barring heavy frosts, in arid and semi-arid regions. Beyond its nutritional and economic significance, certain jujube cultivars such as Dragon, Mushroom, So and Teapot are prized for their aesthetic qualities, including unique fruit shape, color and tree structure. Consequently, we find a place in gardens and backyards, dwarf habit and compact canopy.

Jamun (*Syzygiumcumunii*)

Jamun, scientifically known as *Syzygiumcumunii*Skeels, is a resilient evergreen fruit tree native to the Myrtaceae family, thriving particularly in neglected and marshy terrains. Ideal for cultivation, it requires deep loamy, well-drained soils and thrives best in dry weather during both its flowering and fruiting stages. During the months of March to April, Jamun showcases its delicate flower panicles, emerging elegantly at the leaf axil. The fruit, borne in clusters ranging from 10 to 40, presents itself in round or oblong shapes, each containing a single seed and following a unique sigmoid development pattern. Interestingly, Jamun fruits are classified as non-climacteric. Jamun stands out for its rich reservoir of biochemical compounds, including

anthocyanins, myrecetin, ellagic acid, isoquercetin andkaemferol. These compounds confer various health benefits, such as anti-inflammatory, neuropsychiatric, antimicrobial, anti-HIV, nitric oxide scavenging, anti-fertility and antiulcerogenic properties. Moreover, the seeds of Jamun contain glycosides, notably jambolin or antimellin, which are believed to possess anti-diabetic qualities by impeding the conversion of starch into sugar. Beyond its medicinal uses, ripe Jamun fruits are widely utilized in diverse culinary applications. They are transformed into a plethora of delectable products including squashes, juices, jam, jelly, pickles and wines. Interestingly, in regions like Goa and the Philippines, the fermented fruits of Jamun are employed in the production of Brandy and a unique distilled liquor named jambava, showcasing the versatility and cultural significance of this remarkable fruit.

Jharber[**(*Ziziphusnummularia*) Burm. f.**]

Jharber [(*Ziziphusnummularia*) Burm. f.] is a resilient shrub, standing 1–2 meters tall, characterized by its perennial nature, deciduous foliage and thorny branches that gracefully arch. Thriving in the harsh environments of extremely arid regions, it finds its place in various habitats including crop and grazing lands, sandy-saline expanses, rocky terrain and degraded pastures. Its anatomical features, notably the presence of papilla, crypt stomata, epidermis fortified with a thick outer wall and a substantial cuticle, along with its deep taproot system, equip it with unparalleled tolerance to drought, salinity and high-temperature stresses, thereby rendering it adaptable to the most extreme arid climates. The blooming period of jharber occurs in July–August, with fruit maturing by November–December (Singh, 2007) [25]. The fruits, small-sized drupes with a globose-ovoid shape, exhibit a deep red hue and contain minimal edible pulp with a subtly acidic taste. Dried jharber fruit harbors triterpenoids, alkaloids and saponins, possessing medicinal properties utilized in the treatment of various ailments including cancer, gastric issues, sedation, blood purification, obesity, fever, pain relief, cooling effects, respiratory conditions, anemia, vomiting and wound healing. Locally known as ‘Pala’, jharber leaves serve as valuable fodder for camels, cattle, goats and sheep, owing to their richness in crude fiber, crude protein, calcium and phosphorus. Moreover, different parts of the plant find application in traditional medicine: leaves are utilized in poultices for wound healing and treatment of asthma, fever, gum bleeding and liver disorders; bark is employed to alleviate diarrhea; roots are brewed into decoctions for fever reduction and powdered for ulcer and wound management; fruit acts as a laxative and antiemetic; and seeds offer sedative properties.

Kair[***Capparis decidua* (Forsk)**]

Kair, scientifically known as *Capparis decidua*Forsk, is a member of the Capparidaceae family and is recognized locally by various names such as Ker, KarilTeent, Della and Neptiin. This indigenous, multipurpose small woody perennial, with its much-branched, leafless bushy shrub form, is commonly cultivated with minimal attention along farm boundaries, orans, gochars and wastelands in arid and semi-arid regions(Mahla, *et al.*, 2012) [7]. Its xerophytic traits, including a deep root system, sparse foliage, mucilaginous sap and robust conical spines, render it well-suited for stabilizing sand dunes and mitigating soil erosion caused by hot, desiccating summers in the Thar desert of western Rajasthan. Despite harsh desert conditions encompassing temperatures ranging from -8^{o}C to + 48 ^{o}C or even higher, prolonged drought, saline soils and nutrient-poor ecological settings, Kair thrives effortlessly. Primarily propagated naturally through

seeds, root suckers, hardwood cuttings and occasionally through tissue culture, Kair exhibits a notably low survival rate. The plant boasts pink, red and white flowers, which appear in the axil of the spines three times annually, with the primary flowering period occurring during March–April, culminating in fruit maturation just before the monsoon season (Singh and Singh, 2011) [22].Kair fruits find versatile applications, serving as a vegetable, pickles and condiments. When dried, the fruit becomes a crucial component of a traditional Rajasthan vegetable dish known as 'Panchkutta'. Rich in proteins, carbohydrates, fiber and essential minerals such as Calcium (Ca), Phosphorus (P) and Iron (Fe), Kair fruit also holds medicinal value, offering relief in conditions like sedation, asthma, inflammation and cough, courtesy of its constituents like isocodonocarpine, α- and β-amyrin, taraxasterol anderythrodiolalkaloids present in various plant organs.

Karonda (*Carissa carandas* L.)

Karonda, scientifically known as *Carissa carandas* L., originates from India and is a member of the Apocynaceae family, commonly referred to as Christ's thorn. It thrives as a robust, evergreen shrub adorned with spines, boasting a low-growing, bushy appearance with multiple branches (Singh *et al.*, 2014) [27]. Primarily cultivated for bio-fencing or live-fencing purposes, particularly in gardens, orchards, or small-scale plantations across Rajasthan, Gujarat and Uttar Pradesh, Karonda exhibits remarkable resilience to drought conditions, attributed to its xerophytic characteristics. In these arid and semi-arid regions, it yields between 5 to 8 kilograms of fruit with minimal care and management. The flowering season of Karonda spans from January to February and June to July, with fruits ripening within 60 to 90 days post-fruit set. Its genetic diversity results in fruits of various hues including white, green, purple and pinkish-red, rendering it a favored ornamental addition to gardens. Typically, the immature fruits find utility in pickle and chutney production, occasionally serving as a vegetable. Fully ripe fruits, on the other hand, are enjoyed fresh or undergo processing to yield candies and natural food colorants. Karonda fruits stand out as an abundant source of iron, boasting 39 milligrams per 100 grams, alongside a notable presence of vitamin C, making them valuable in addressing anemia and scurvy (Mishra, 2007) [12]. Moreover, they offer substantial levels of calcium, magnesium and phosphorus while exhibiting significant antioxidant properties. Due to their high pectin content, mature Karonda fruits are ideal for pickle and jelly making, while also finding application in jams, squashes, syrups and chutneys, catering to a burgeoning market demand.

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

Khejri, scientifically known as *Prosopis cineraria* (Druce.) L., belongs to the Leguminosae family and is revered as the marvel of nature, a precious boon, the monarch of the desert and the gilded emblem of arid landscapes. This desert-adapted arboreal species thrives as the cornerstone of existence in the Indian Thar desert, its every facet contributing to the enhancement of the socio-economic fabric of local communities. Characterized by its evergreen demeanor and leisurely growth, the Khejri tree presents exfoliating bark, a domed canopy, diminutive yet viscous foliage and a robust taproot system delving to remarkable depths (exceeding 53 meters) (Pareek, 2002) [16]. Renowned for its resilience, it withstands drought and salinity (ranging from 10.0 to 25.0 EC dSm^{-1}). Indigenous to Arabia and the Indian Thar desert, its presence sprawls across Rajasthan, Haryana, Gujarat, Punjab and Delhi. A versatile botanical entity, Khejri bestows upon humanity a bounty of vegetable pods, flour, fodder for livestock, fuel,

timber, gum, resin and medicinal extracts. Its utility extends to serving as fencing and windbreaks, embellishing avenues, delineating farm perimeters in arid regions, sculpting topiaries and bonsai and adorning home gardens while facilitating forest rejuvenation in parched terrains. Elevating soil fertility through nitrogen fixation and litter accumulation, Khejri fosters an environment conducive to organic enrichment, augmented levels of soluble calcium and available phosphorus and a mitigated soil pH. Furthermore, it serves as a catalyst for productivity in intercropping and companion cropping schemes, rendering it indispensable in agroforestry ventures within arid and semi-arid landscapes (Singh, 2007) [25]. Endowed with leaves rich in nutrients—boasting crude protein, fiber, nitrogen-free extracts, ash, ether extract, calcium and phosphorus—Khejri sustains nutritional adequacy in challenging environments. Its unripe pods, known as 'Sangri,' serve as a vital component of the Panchkutta vegetable, offering a nutritional profile abundant in protein, fat, carbohydrates, fiber, phosphorus, calcium and iron. These pods find utilization in culinary preparations ranging from fresh and dried vegetables to pickles and flour. Each component of the Khejri tree holds therapeutic potential: from flowers yielding anti-diabetic compounds to leaves alleviating oral ulcers and from pods and seeds addressing malnutrition and mineral deficiencies to combatting ailments such as asthma, piles and leprosy.

Khirni (*Manilkarahexendra* L.)

Khirni (*Manilkarahexendra* L.) belonging to the Sapotaceae family, stands as a native gem of India, characterized by its evergreen foliage, moderate stature and unhurried growth. Thriving in arid to semi-arid climates, this species adorns landscapes as an avenue tree and its compact size lends itself to bonsai cultivation, boasting a lush canopy that persists year-round. Its floral display graces the landscape from February to March, followed by the ripening of its fruits in May to June. Khirni serves not only as a picturesque addition to the scenery but also as a practical resource, particularly as a rootstock for sapota, leveraging its resilience to salinity and drought. Rich reservoirs of tannins, oil and vitamin A reside within its bark, seeds and fruit, respectively, enriching both culinary and medicinal sector Vishalnath*et al.*,2000) [33]. Khirni's fruits and bark are esteemed for their diverse medicinal applications, ranging from alleviating fevers and digestive maladies to treating skin conditions, ulcers and respiratory ailments like bronchitis. Such versatility underscores Khirni's significance beyond mere ornamentation, casting it as a botanical treasure trove deeply intertwined with human well-being.

Lasora (*Cordiamyxa* L.)

Lasora (*Cordiamyxa* L.), also known locally as Gonda, Lasora, Lehsua, Indian cherry, Assyrian Plum, or Bird’s Nest Tree, belongs to the Boraginaceae family and is cultivated throughout India, excluding high hills and temperate climates. Cordia, characterized by its fast growth and stunning inverted dome/umbrella crown, serves as both an avenue tree and ornamental furniture (Nagar *et al.*,2013) [14]. Its ovate, alternate and stalked leaves are utilized as fodder during hot summers when green grasses are scarce, as well as for rearing lac insects.In March, these trees bear white hermaphrodite flowers, followed by drupaceous green unripe fruit that is harvested from April to June. The fruit, predominantly consumed as green fresh vegetables and pickles, fills the void during lean periods when conventional vegetables are scarce. Rich in antioxidants such as carotenoids, ascorbic acid, phenols and minerals, Cordia fruit provides essential nutrients crucial for human health and the treatment of various ailments including

improved digestion, birdlime, anti-tumor properties, anti-helminthic effects, diuretic capabilities, demulcent features, expectorant qualities and enhanced hair growth.

Mahua (*Madhucalongifolia*)

Mahua, scientifically known as *Madhucalongifolia* (Koenig), is an indigenous deciduous tree that falls under the family Sapotaceae. It boasts a medium-to-large-sized canopy and features grey-black cracked bark, along with a milky and short trunk that branches out extensively. Its flowers form dense clusters with long pedicels, characterized by a coriaceous calyx and a tubular, cream-colored, fragrant caduceus corolla. The fruit it bears is a pinkish-yellow berry containing 1–4 recalcitrant seeds. These trees are heterozygous and rely on cross-pollination for reproduction.Mahua serves as a multipurpose tree, meeting the fundamental needs of tribal communities: food, fodder and fuel. Its flowers, which are edible and highly nutritious, offer a rich source of sugars, vitamins, proteins, minerals and fats(Mahla and Singh, 2013) [6]. They are commonly utilized as a sweetening agent in various traditional dishes like barfi, kheer, halwa andmeethipuri across the tribal regions of Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujarat, Orissa, Jharkhand, Chhattisgarh and Andhra Pradesh.Additionally, Mahua dry flowers undergo fermentation processes to yield wine, brandy, ethanol, acetone and lactic acids. Furthermore, Mahua finds applications in medicine due to its hepatooprotective, antiburn, anti-skin disease, wound healing, emollient, bone healing, swelling gum, anti-ulcer, anti-snake bite, lactation stimulation in women, anti-bronchitis, anti-diabetic, diuretic, immune system stimulating, digestive, antioxidant, energetic and glucose-boosting properties.

Manila tamarind [*Pithecellobiumdulce* (Roxb.) Benth]

Manila tamarind, scientifically known as *Pithecellobiumdulce* (Roxb.) Benth., is renowned under various colloquial names such as Madras thorn, Monkey pod and Jungle jalebi, all within the expansive Fabaceae family. This versatile, swiftly growing, medium-sized tree is characterized by its thorny branches, finding extensive utility in applications ranging from live fencing to the provision of animal fodder, as well as serving as a source of hardwood timber and a barrier against wind. Additionally, it holds promise as a potential medium for lac culture (Wallnofer, 2001) [35]. The fruit of the Manila tamarind offers a juxtaposition of flavors, boasting both sweetness and acidity, while also packing a considerable punch in terms of dietary fiber, proteins, calcium, iron, phosphorus, unsaturated fatty acids and antioxidants. Beyond its nutritional value, the Manila fruit has traditionally been employed in the treatment of various ailments, including toothaches, mouth ulcers, sore gums, dysentery, chronic diarrhoea, stress-related symptoms and even manifestations of aging such as dark skin spots.

Mulberry (*Morus alba* L.)

The Mulberry (*Morus alba* L.) belonging to the Moraceae family, finds its origins in South-West Asia, displaying a wide geographical presence spanning from temperate to tropical climates. Within the Morus genus, which encompasses 24 species, 16 of them are deciduous, among which *Morus alba, M. nigra* and*M. rubra* stand out as primary contenders for cultivation in commercial orchards. This perennial, woody, fast-growing tree bears alternate, simple leaves, often with lobes, along with catkin inflorescences and composite sorosis fruit.While historically cultivated predominantly for silk production and as shelterbelts, the fruit of the Mulberry tree holds substantial nutritional value, boasting a rich composition of vitamins, minerals, dietary

fiber, sugars, amino acids, carotenoids, flavonoids and phytosterols. Its versatility extends beyond mere consumption, finding utility in various forms such as masala, herbal tea, marmalades, juices, yogurt, biscuits, smoothies, capsules and even as natural dyes and cosmetics oil (Vyas *et al.*, 2009) [34]. Traditional food products like pekmez, kome andpestil also harness the goodness of Mulberries.Furthermore, Mulberries have garnered attention for their suggested pharmacological benefits, including potential applications in addressing obesity, cardiac diseases, diabetes, hypercholesterolemia, tumors, oxidative stress and brain damage. Additionally, they exhibit anti-fungal, anti-aging, anxiolytic and hepato-protective properties, further adding to their appeal beyond their culinary uses.

Pilu (*Salvadora persica* L.)

Pilu, scientifically known as *Salvadora persica* L., boasts a rich tapestry of aliases including kharijal, meetajal, mustard or salt bush and toothbrush tree, firmly nestled within the Salvadoraceae family. This perennial, evergreen entity, characterized by its robust, much-branched shrubbery or arboreal stature, finds its habitat spanning across the landscapes of Gujarat, Rajasthan, Haryana and Punjab. Its robust and adaptable xerophytic nature renders it an ideal candidate for afforestation endeavors in ravines, saline and alkaline lands, where it serves as a stalwart shield against the whims of winds, as shelterbelts or windbreaks. Within Pilu's botanical arsenal lies an array of potentially therapeutic compounds, including salvadoricine, salvadourea, β-sitosterol, trimethylamine, thioglucoside, dibenzylthiourea, rutin, potassium, chlorine andsulfur, among others Singh *et al.*, 2013) [26]. Noteworthy among its attributes, Pilu's fibrous branches emerge as a natural alternative to conventional toothbrushes, often referred to as Miswak, contributing to oral hygiene practices. Beyond this, Pilu's contributions extend to the realm of medicinal concoctions, serving as a cornerstone in the formulation of antiseptics, abrasives, detergents, astringents, fluorides, enzyme inhibitors and remedies for dental diseases, tumors, leprosy, ulcers, gonorrhea and scurvy. Furthermore, the fruit of Pilu holds the key to sweetening agents and is utilized in the production of fermented beverages. Its tender shoots grace tables as a refreshing salad addition, while the seeds yield a bounty of C12 and C14 acids indispensable in the soap and detergent manufacturing sector.

Tendu or Kendu(*Diospyrosmelanoxylon*Roxb)

The Tendu or Kendu tree (*Diospyrosmelanoxylon*Roxb.), a member of the Ebenaceae family, is native to the Indian subcontinent and is locally referred to as temburini. It exhibits resilience to both drought and frost conditions but is susceptible to waterlogging. Found abundantly in the local markets of Madhya Pradesh, Chattisgarh, Jharkhand and Orissa states during the summer season, it is esteemed as a delicacy. The fruits, renowned for their high nutritional value and abundant phenols and fibers, are utilized by the tribal populations in these regions to combat the scorching loo or hot winds of summer (Jadhav *et al.*, 2009) [3]. The etymology of its generic name, derived from the Greek words 'Dios' (divine) and 'Pyros' (fruit), signifies the superior quality of its fruits. Meanwhile, the specific name, also of Greek origin, alludes to its characteristic dark wood. The fruit pulp, yellow, glutinous, soft, sweet and mildly astringent, is rich in sugars, proteins, fiber and vitamin C. Moreover, the presence of beneficial phytochemicals such as β-carotene, terpenoids, flavonoids, saponin and tannin further enhances its nutritional profile (Sahu *et al.*, 2012) [18]. Ripe tendu fruits serve as a significant source of non-

antioxidants, including unidentified oligosaccharides, fumaric acid and gallic acid. This plant holds a well-documented presence in Ayurveda, Unani texts andethno botanical records, lauded for its multifaceted utility in treating various ailments. Like cashew apples, litchis and other tropical and subtropical fruits, tendu fruits can be used to produce wine. Throughout Indian traditional medicine, they have been extensively employed in the treatment of diverse conditions such as diarrhoea, cholera, dysentery, intermittent fevers, bleeding gums, bronchitis, carbuncles, coughs, cramps, pneumonia, syphilis, tumors and more.

Tamarind (*Tamarindus indica* L.)

Tamarind (*Tamarindus indica* L.) is a dicotyledonous, monotypic, long-lived, semi-evergreen fruit plant from the family Leguminosae. Possessing a broad adaptability range, it serves as an excellent candidate for avenue plantation in various settings such as roadside, backyard and agro-forestry systems. During the months of May to June, it adorns itself with terminal and lateral drooping bisexual flowers, subsequently yielding pendulous pods ten months post-fruit setMeghwal *et al.,* 2012) [10]. Within its fruit pulp and seeds reside a plethora of constituents including tartaric acid, reducing sugar, tannin, pectin, cellulose, fiber, potassium, calcium, phosphorous, as well as additional minerals such as sodium, iron and zinc. Revered as a culinary gem, the fruit pulp stands as a primary ingredient in souring sauces, curries, chutneys, beverages and food colorants, elevating dishes to delightful heights. Beyond its gastronomic applications, every part of the tamarind tree holds value in various sectors including food, fodder, timber, fuel, textiles, nutrition and pharmaceuticals, notably for its role as a fluoride remover. Notably, the Banaras Hindu University in Varanasi, India, boasts a landscape adorned with tamarind trees, enhancing the aesthetic and ecological appeal of the largest university campus in India.

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

The indigenous fruit tree known as Wood Apple (*Feronia limonia* (L.) Swingle), also referred to as kainth, elephant apple and monkey fruit, is primarily found in isolation rather than in systematic block plantations. It thrives in the plains of Southern Maharashtra, Uttar Pradesh, West Bengal, Madhya Pradesh and Chhattisgarh states of India. Wood apple, a small-to-moderate sized deciduous tree with thorny branches and rough, spiny bark, can grow in saline, poor and neglected lands typically unsuitable for fruit cultivation. Unlike other members of the Citrus family, it possesses the unique ability to endure both drought and salinity stress. Flowering of the wood apple tree commences from February to May, with fruit ripening occurring between October to December depending on moisture availability (Jamil and Sharma, 2019) [4]. The fruit itself is a berry characterized by a rough, hard-shelled, large, globose pericarp containing sweetish aromatic edible pulp. Various parts of the *F. limonia* tree boast therapeutic and functional properties: leaves (diuretic, anti-microbial and stomach disorder remedies), roots and bark (insecticidal and antidotes for snakebites), spines (for liver and menorrhagia treatments), gum (alleviating diarrhea and diabetes symptoms) and fruit pulp (used in the treatment of skin cancer, diarrhea, sore throat, jaundice and gastropathy). Wood apple fruit undergoes processing into powder, preserves, squash, sherbet, beverages, jams, creams, leathers, wines, toffees, candies, capsules, ready-to-serve beverages (RTS), pickles and chatani.

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Detailed descriptions of the characteristics and potential uses of 20 underutilized fruit crops native to arid and semi-arid regions are provided below, complemented by a summary of their key traits in Table 1.

Table 1 Important characteristics of underutilized fruit crops.

Sl. N.	Common Names	Improved Varieties	Mineral Elements	Propagation Technologies	Consumed Form	Value-Added Products
1	Aonla	Anand-1, Anand-2, Goma Aishwaria, Laksmi-52, NA-6, NA-7, NA-10.	Ca, Fe, P	Patch budding	Raw, processed	Candy, Chyawanpras, Shreds, Candy, Preserve, Squash, RTS, Pickle, Jelly, Leather, Toffee, aonla powder
2	Bael	Goma Aswarya, NB-5, NB-7, NB-9, Pant Aparna, Pant Shivani, Pant Sujata, Thar Divya, Thar Neelkanth, Thar Prikriti, Thar Shristhi, Thar Shivangi.	Fe, Ca, K, P	Patch budding, detopping for promotion of scion wood in mother plant	Processed	Squash, preserve, candy
3	Ber	Bhuvraj, CAZRI Ber 2018, Gola, Goma Kirti, Katha, Seb, Thar, Thar Sevika, Umran.	Ca, P, K, Rb, Br, La	T-budding, insitu budding,	Raw, dry, processed	Osmodehydrated ber, Canned ber, Jam, Pickle
4	Chironji	KatarniChironji, Local Varieties, PahadiChironji, Thar Priya.	P, Ca, Fe	Soft wood grafting, insitu grafting	Raw, processed	Dried seed
5	Custard apple	ArkaNeelanchal,Vikram, ArkaSahan, Balanagar	K, Mg, Ca, Zn,Fe	Whip grafting	Raw, processed	Puree, jam, RTS, Juice, Frozen pulp
6	Fig	Conadria, Dianna, Poona Fig, Excel, Dinkar, Chalisgaon	K, Ca, Na, Mg, P, Fe, Mn,Zn,Cu	Hardwood cutting	Dry, processed	Dried fruit
7	Jamun	Arka Anmol, Black Pearl, Goma Prinynka, Jyoti, Kala Jamun, Krishna Jamun, Thar Kranti, Konkan Bahadoli, Jamwant, Paras, Rajamun,	K, Na, Mg, Ca,Fe	Patch budding and soft wood grafting	Raw, processed	Jamun Juice, RTS, Squash, Nectar, Jam, Vinegar,Wine, Jelly, Cider, Syrup

		Rajendra, Jamun-1, Jamwant.				
8	Jharber	Geronimo, JK Kuber, Jomon, Monroe	K, P, Ca, Fe, Na	Seed	Raw, dry	Churan, Bar, Toffee
9	Kair	CZJK-3 and CZJK-5	AI, P, Na, Mg, Fe, Ca	Patch budding, soft wood grafting	Processed	Vegetable, Pickle panchkutta
10	Karonda	Thar Kamal, Konkan Bold, Maru Gaurav, Pant Manohar, Pant Sudarshan, PantSuvarna	Fe, Ca, Mg, P	Cutting/air layering	Raw, processed	Murabba, Jam, Jelly, Pickle, Chutney
11	Khejri	Thar Sobha, Thar Amruta	Ca, P, Fe, Zn	Patch budding	Dry, processed	Vegetables, Pickle, Biscuits
12	Khirni	Thar Rituraj	Ca, Fe, Zn, Cu, Se	Cleft grafting	Raw, processed	Dehydrated fruit, fruit bar, RTS, Jam
13	Lasora	Thar Gold, MaruSamaridhi, Karan Lasora, Puskar Local, Paras Gonda	Ca, P, Zn, Fe	Patch budding	Processed	Pickle, Beverage, Chutney
14	Mahua	Thar Madhu, NM-2, NM-4, NM-7, NM-9	Ca, P	Soft wood grafting	Processed	Alcohol, Bakery, Vinegar, Syrup, Wine
15	Manila tamarind	PKM 1	K, P, Ca, Fe, Zn	Cutting,Micro propagation	Raw, processed	Dried seed, Oil extraction
16	Mulberry	Thar Lohit, Thar Harit, Delhi Local,Saharanpur Local-1, Saharanpur Local-2, China White	Fe,Cu,Mg, K, Se, Na	Cutting	Raw, processed	Squash, RTS
17	Pilu	Local-1	K, Cl, Na, S, Fe	Seed	Processed	Squash, RTS, Miswak
18	Tamarind	Periyakulam-1, PKM-1, Prathisthan, Urigam, Ajanta, Yogeshwari, Anant Rudhira, Goma Prateek	K, Ca, P, Na, Fe, Zn	Root/stem cutting, wedge Grafting	Raw, processed	Jam, Jelly, Syrup, Pulp Powder, Candy, Seed kernel powder
19	Tendu	Wilde, Local	K, Ca, P	Seed	Raw, processed	Fresh, juice and jam
20	Wood apple	Thar Guarav	Ca, P, Fe	Soft wood grafting	Processed	Chutney, Pickle, Frozen puree, sauce

Source: websites of ICAR-Central Institute for Arid Horticulture, CHES, Godhra, Gujarat, ICAR-NBPGR, New Delhi and ICAR-CAZRI, Jodhpur.

Conclusion

It is concluded that the incorporation of these fruits into local diets shows potential in combating the prevalent nutritional deficiencies among rural populations residing in fragile arid and semi-arid regions worldwide. Furthermore, local communities hold extensive knowledge about the nutritional and medicinal properties of these crops, underscoring the necessity for thorough exploration into their conservation and nutritional characteristics. This review explores the ethno botanical importance, medicinal and nutritional benefits, biodiversity preservation and utilization approaches of underutilized fruit crops commonly found in the Bundelkhand regions

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1.

2.

3.

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