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Revitalizing traditional knowledge and mechanization for *Capparis decidua* (Kair) cultivation in arid zones: A review for sustainable approach to nutrition and livelihood

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Capparis decidua (Forsk.) Edgew., generally referred to as Kair, is a significant native shrub that can be found growing around barren land regions, wastelands, *gochars* (local grasslands), *orans*, and farm boundaries. It has a wide distribution in the land of semi-arid and arid regions of India. This shrub possesses the inherent potential to offer numerous nutritional and health benefits, and enhance the nutritional levels of rural communities. In addition to its numerous advantages and copious stores of vital nutrients, this species is not currently produced for commercial purposes. Unfortunately, compared to other exotic fruit produces, research efforts focusing on value addition for this fruit are significantly lacking. This review comprehensively examines the species' ecological adaptability, botanical and nutritional profile, therapeutic significance, and current cultivation practices. Focus on mechanized harvesting should be given for fruit quality, quantity and timeliness harvesting. To ensure sustainable farming practices in hot arid regions, it is crucial to develop a comprehensive cultivation tools, package and guidelines specifically tailored for this fruit to boost mechanization. The paper also emphasizes integrating traditional knowledge with scientific research to foster sustainable cultivation, enhance rural livelihoods, and ensure ecological restoration. The findings underscore that with focused mechanization, adaptive research, and policy support, *C. decidua* can emerge as a cornerstone of desert agroforestry, contributing significantly to nutrition, income, and environmental resilience in resource-scarce regions.

Keywords: Endangered plant, Kair mechanization, Medicinal plants, Traditional knowledge

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The perennial woody plant *Capparis decidua* (Forsk.) Edgew. (CD), sometimes referred to as the caper tree, Karira, Kair, or Ker, is belongs to the caper family (*Capparaceae*). By way of the Greek word *kapparis* and the species name *deciduous*, which means not persisting, falling-off, or deciduous, the genus Capparis is named after the Arabic word '*kabar*' for capers[1]. Capers have been utilized as a condiment for about 5,000 years. The family consists of 30 genera and 600 species of small shrubs and trees, which are primarily found in warm temperate and tropical climates[2-4]. These species include shrubs, trees, and woody climbers. Of these, India has records of 26 species[1,5-7]. The somatic chromosome number of kair is 26 (2n = 2x), indicating it is a diploid species, type of fruit is berry and edible portion is mesocarp and epicarp[2]. According to studies, it thrives in soils with reduced sodicities (pH 9, ESP 35, ECe 4dS/m)[6-8]. It favours sandy, gravely, alkaline soil with a pH between 6.5 and 8.5[9]. With a mean annual temperature of 25-41°C and a mean annual rainfall range of 100-750 mm, Kair may be found in the 300-1200 m altitude range[3,8,10,11]. It is typically found as a 4-5 m tall shrub with thick tufts, but it can also occasionally be found as a small tree[1,3,8,11,12] that can grow up to 7 m tall[3,9].

It was a plentiful species fifty years or more ago, but due to escalating human and cattle populations, it has been excessively exploited, eradicated by tractor ploughing, and grazed all nearly to extinction. Due to a shortage of planting material, the people got concerned and initiated research on its growth and propagation[9]. Currently, patches of kair plants can be found on wastelands, *gochars*, and *orans*. They mainly appear on bunds or agricultural boundaries in farmers' fields[6,7,13]. It covers around 3,540 km^2 of

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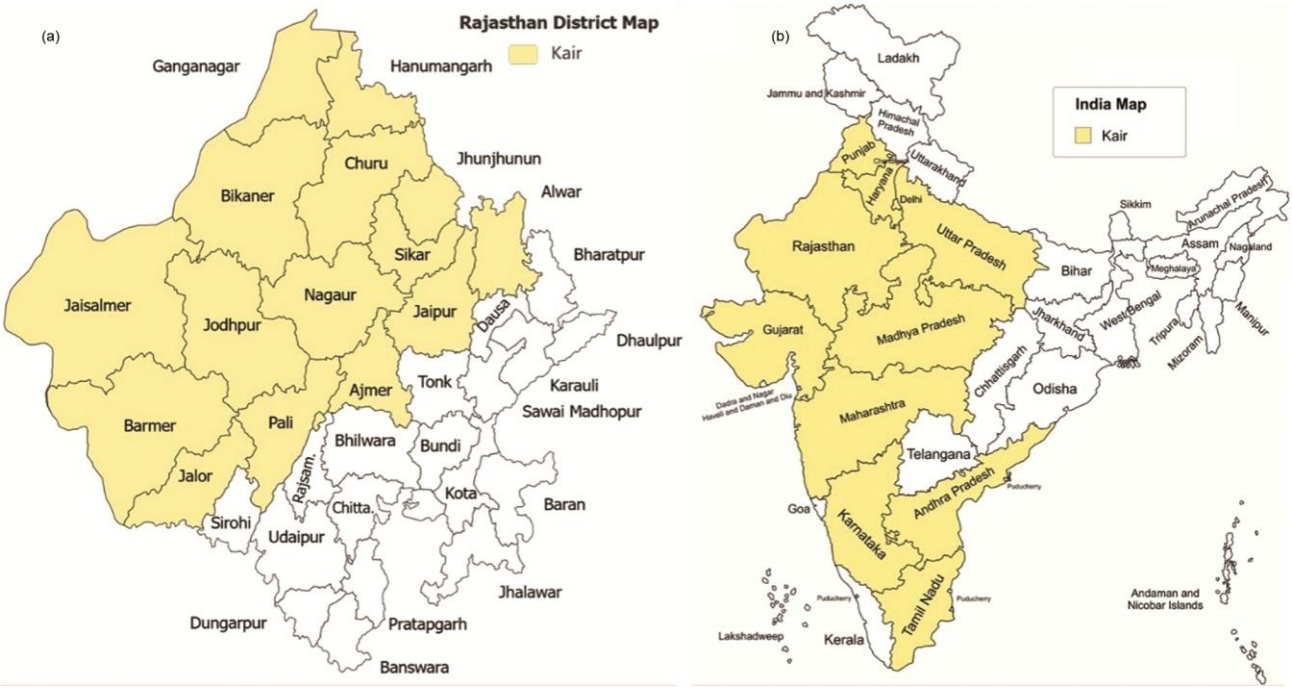

Fig. 1 — Availability of Kair in (a) Rajasthan (Source: https://paintmaps.com/map-charts/263c/Rajasthan-map-chart), (b) India (Source: https://www.mapchart.net/india.html)

pediment plains in the districts of Jodhpur and Bikaner of Rajasthan, India, with an assessed yearly output of 7,000 tonnes of fruits[11,13,14]. Its density ranges from 9 to 170 plant ha^{-1} in various landforms in Rajasthan's *Thar* Desert[3,7]. It is a dominant shrub with remarkable climate adaptations that may be found in Rajasthan's desert region[15]. It is the finest species for stabilisation of sand dune in the region of *Thar* Desert of India[3,16]. The diversity of morphological features is measured from an area getting 200 mm of rainfall per year (Barmer and Jaisalmer Districts of Rajasthan) in north-western region of the Rajasthan[3]. Different Kair prominent districts of Rajasthan and states of India are depicted in Figure 1.

Under natural conditions, *C. decidua* is mostly propagated via its seeds and root suckers[3,17]. Growing gregariously with dense spherical crowns, kair is a green, twiggy-looking shrub or small tree that is spiky and heavily branched. When young, the stem bark is smooth and green; as its ages, it turns grey. Small, succulent, caducous leaves only develop on fresh shoots for a maximum of one month[9]. Very few, 2 mm long and 1-3 mm wide[11,12] leaves appear on immature branches[1,3]. Stipular spines on branches can be up to 5 mm long[18]. In the Rajasthani area of Jaisalmer, yellow blooms on kair were found.

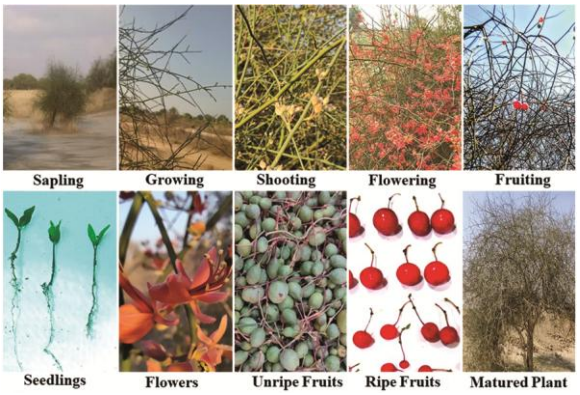

Fig. 2 — Different growth stages and fruits of Kair

Globose fruits that are green when immature and crimson or pink when ripe are carried on long stalks[9]. Different growth stages and fruits of Kair are shown in Figure 2. When the monsoon season ends, or around the beginning of autumn (October), new growth begins and lasts till the end of June, or the start of the subsequent monsoon season[9]. Winters from November to January saw the emergence of new leaves[8,11,12,19]. The months of January to March, June to July, and October, which are also known as winter foliation, summer foliation, and pre-winter foliation, respectively, are when *C. decidua* populations can foliate[8]. February marks the beginning of flowering, which lasts through November. It blooms in three

Table 1 — Some *Capparis* species related to arid/semi-arid South Asia & West Asia

Accepted name	Common names	Key traits	Native range / habitat	Notable uses
Capparis decidua (Forssk.) Edgew.	Kair/Ker, Karira	Leafless (aphyllous) green twiggy branches; stout spines; pinkish-red berries	NW India-Arabian Peninsula; hot arid zones, dunes & rocky plains	Edible fruits; fodder; traditional uses
Capparis spinosa L. (complex)	Caper bush	Rounded leaves; large white-pink flowers; caper buds	Mediterranean to W & Central Asia; xeric rocky sites	Culinary (capers); medicinal
Capparis zeylanica L.	-	Climbing shrub; elliptic leaves; axillary spines	India–Sri Lanka; deciduous forests/dry thickets	Ethnomedicinal
Capparis sepiaria L.	-	Spiny shrub; leaves present (not aphyllous); small white flowers	India–SE Asia; dry scrub	Hedge; ethnomedicinal

seasons: *Ambe Bahar* (February to March), *Mrig Bahar* (July to August), and *Hast Bahar* (October to November)[3]. Most blooms are produced by shoots older than a year[3]. Pink flowers featuring red-veined petals grow in tiny clusters across leafless shoots and are carried in the axils of the spines as many-flowered corymbs from aged branches or short lateral shoots[3,8,20].

In other regions of the world, such as Morocco and Egypt, March to April is the fruiting season, however in Pakistan, the fruiting season is from May to July, with maximum flowering occurring in two weeks before the season of monsoon[8,12]. Yellow flowers on kair were spotted during a recent survey in Rajasthan's Jaisalmer district[9,14]. Approximately 3-4 kg of green, fragile fruits is produced by a mature plant (6-8 years old). The plant produces more fruit as it ages. Late flowering fruits are often lacking quality and are not useful for veggies or pickling.

Consequently, many trees yielded green fruits once, twice, or thrice annually, and the patterns within individual trees were inconsistent over time[1,11]. Fruits are tiny (11.42-22.63 mm), ovoid or subglobulous, numerously seeded (>5), somewhat mucronate, and turn blackish when dried[1,3,8,20]. Kair fruits range in weight from 1.18 to 7.3 g. Flowering in February-March generates higher fruit production (for per plant up to 20 kg fruits)[21]. Fruit yield ranges for per plant from 2 to 20 kg depending on life span, genetic potential, and flowering season[1,3,8]. Green, tender fruits are well-priced in the neighbourhood market, even at roadside stands (for Rs. 100-250 per kg). 1,600 kg amount of green fruits, when processed, can provide 320-400 kg of dried fruit. At the current estimated market price of Rs. 250 to 300 per kg of the dried fruit, it can generate an estimated income of Rs. 80,000-96,000 per hactare[13]. Smaller fruits have generally 1 to 2 large-sized seeds while larger fruits have many (>30) little seeds[1,3]. Immature green kair with diameters of 6.022 to 9.275 mm were found to have sphericity values of 0.92 and 0.96, respectively[22]. The root is thick and deep, reaching depths of up to four meters. Numerous secondary roots eventually sprout from the main/primary tap root after only one tap root first forms[3]. Through its tap root system of water uptake, the Kair plant can extract water from the earth up to a depth of 4 m[11,12]. Some genus and species are mentioned in Table 1.

However, there is currently no commercial production of this species. As a result, the species plant habitat characteristics, distribution, morphology, phenology, multipurpose use (Table 2), morphological diversity, medicinal significance, and nutritional aspects in terms of nutrient chemical compositions (Table 3) of the kair plant should be reviewed.

Nutritional value and chemical composition of Kair

Additionally, it is understood that the plant may be a good source of essential minerals and nutrients that contribute to its nutritional advantages. Plants with higher calcium and potassium levels, for example, are appreciated for both cattle feed and human diet[12,29-31]. Ca is an essential element that contributes to human bone strength[30,31]. Being high in K and low in Na improves the cardiovascular system since the two are interrelated and work together to maintain smooth blood flow[30]. A biochemical examination of mature fruits revealed that they are extremely nutritive[9,32]. The immature berry-shaped fruit produce is high in carbs, proteins, and minerals[9,28]. Protein gradually decreases with the maturity of fruit[33]. Carotene levels in kair fruits and fruit husk were also high (210 mg kg^{-1})[11,34]. Quantitative analysis of kair's fuel wood attributes including moisture, calorific value, fuel wood

Table 2 — Multiple uses and services of different Kair parts

Uses	Stem/Bark/Branch/Root	Leaves	Flowers	Fruits
Fodder[1,3,5,6,8,23,24]	• In arid regions, source of fodder (Avg. 1.10 kg/year). • Camel and goats enjoy young branches, especially in the post-winter season.	• Grass supplement for camels, sheep, goats, and many animals during times of grass scarcity.	-	• Relished by camels and goats.
Food[1,3-9,14,15,22,25,26]	• In Sudan, the major source of camel food. • Gums (Stem exudation used as food)	-	• Flower buds are cooked, pickled, and consumed as vegetables (*Sakpuspa*).	• Consumed by people in Sudan. • The unripe fruit is pickled • Green fruit is the famous 'Panchkoot' mixtures of dry vegetables of Rajasthan.
Fuel Wood[3,5-8,15,27]	• Used in firewood (C.V. 625-775 kg/m^2). • In charcoal preparation and additional income from timber. • Used in *hawan*.	-	-	-
Miscellaneous and services[3,6-9,15,25,28]	• Used in the construction of water troughs and pipes. • Ethnic cultures use it for aesthetic purposes. • Small rafts, beams, boat knees, axles, cartwheels, shelters, fences, tool handles, agricultural equipment, and even combs are all possible. • Erosion control and environmental benefits. • In Sudan, it is preferred as a shade tree and shelterbelt. • Used as a 'Toran' in a wedding ceremony. • Use in silvopastoral systems as a woody component. • Spoon-shaped utensils, dohi's, ghatti, furniture, doors, and windows are used for roof thatching. • Fruits utilized in a variety of ethnic applications. • Dried branches are utilized to fence in their crops and around their residences.			

index, carbon, silica, ash-biomass ratio, density, and volatile matter found that it has the best fuel wood characteristics[6,7,27]. The dry matter (DM) content of *C. decidua* varied from 12.19 to 73.62%, whereas Root > stem bark > shoot > flower > fruit have 67.25, 65.02, 47.99, 25.81, and 12.19% dry matter, respectively[30].

Kair has a variety of chemical elements such as alkaloids, fatty acids, flavonoids, glycosides, saccharides, steroids, terpenoids, and volatile oils, all of which have significant therapeutic potential. The plant is high in alkaloids, fatty acids, terpenes, sterols, fibre, and oils[15]. The chromatographic analysis of ethyl alcohol: water (90-10v/v) extract showed that it contains glucose, raffinose, sucrose, maltose, mannose/fructose, serine, threonine, glutamine, alanine, aspartic acid and glutamic acid[35]. Whereas, unsaturated seed contains 68.6% and saturated seed contains 31.4% of fatty acid[3,8] with 20% oil content[8,9,14,36]. Seed of kair also has sugar (1.7%) and protein (17%)[3,36]. Vitamin C also reported in fruit pulp (7.8 mg per 100 g of pulp weight)[8]. Flowers contain phytic acid (680 mg per kg) and oxalic acid (1 mg per kg)[11,34]; lipid (0.37%), ash (7.8%), folic acid (300 µg), thiamine (490 µg) and riboflavin (160 µg)[35]. Unripe Fruits have fat (7.43%)[6,7,32]; ether extract (7.43%), crude fibre (12.32%), carotene (0.05%), Mn (0.02%)[3,32]; ash (5.96%)[6,7]; digestible carbohydrates (59.4% DW basis)[32]. The detailed composition of kair fruits is given in Table 3.

Medicinal values of Kair

The plant has a significant amount of important bioactive and phenolic antioxidants and is well-known in South Asian native medicine systems for its folk medicinal uses, particularly in the treatment of infectious disorders[30,40-42]. It has emmenagogue,

Table 3 — Detailed composition of Kair fruits

Chemical composition	Stem/Bark/Branch	Flowers	Fruits		Root
			Ripe	Unripe	
MC, %[3,6,7,12,22,30,35]	34.9	73.40	56-72.45	65-69	32.7
Sugar, %[8,37]	-	-	1.7-3.0	-	-
Protein, %[4,7,9,28,32,35,36,38]	8.9	11.5	8.6	23.3-44.38	8.6
Oil, %[9,36]	-	14	14	-	-
Carbohydrate, %[6-8,12,35,38]	-	18.11	-	63.06	-
Ascorbic acid (mg/kg)[3,6,7,11,32,34,35]	-	1190	7.81	66.0 (0.12%)	-
surface wax, %[9]	-	14	14	-	-
Ca, (mg/kg)[3,12,30,32,35,38,39]	166.2	298.2	322 (0.05%)	400 (0.09%)	312.2
K, (mg/kg)[4,8,30,35]	1496.0	5813.0	3.23	11690.0	3588.0
Na, (mg/kg)[12,30,35,38]	283.3	957.5	675-916	160.64-661.7	232.5
P, (mg/kg)[3,12,32,35,38]	-	191.88	176.8	219	-
Mg, (mg/kg)[3,12,30,32,35,38]	12.2	26.4	-	110.97	13.5
Zn, (mg/kg)[3,30,32]	173.7	28.5	-	15.3 (0.02 %)	58.1
Fe, (mg/kg)[3,12,30,32,38]	110.4	306.0	-	260.4 (0.04 %)	151.1
Cu, (mg/kg)[3,30,32]	3.62	4.26	-	9.41 (0.01 %)	11.67
Cd, (mg/kg)[30]	0.43	0.00	-	0.00	0.15
Co, (mg/kg)[30]	0.50	-	-	-	0.95
Ni, (mg/kg)[30]	1.07	1.07	-	-	3.56

carminative, alexipharmac properties, tonic, stimulates appetite, aphrodisiac, and is beneficial for cough, asthma, rheumatism, lumbago, and hiccough[20]. In Sudan, kair is used to treat swellings, jaundice, and joint infections[8]. *Peganum harmala* and kair young shoots can be combined as an antifertility medication[9]. Bark is akheteric, antihelminthic, analgesic, laxative, diaphoretic, and useful for ulcers and boils, cough and vomiting, piles, asthma, and all inflammations[6,7]. The bark is astringent, narcotic, laxative, diaphoretic, alexeteric, and anthelmintic[14]. Flower buds can also be used as herbs. The hydrocarbons nonacosane and triacontane are found in flowers[8]. Phosphoric acid is found in flowers and fruit husk[35]. Fruits have anti-diabetic properties. Alcoholic extracts of root bark and fruit pulp have anthelmintic properties[15]. Unripe fruit and shoot extracts employed as hypocholesterolemic agents[43] result in faecal excretion of cholesterol and also bile acids[44]. The fruit contains a harsh hot taste that is astringent to the bowels, eliminates biliousness, foul breath, and urinary purulent discharges, and is beneficial in cardiac problems (Ayurveda). *C. decidua* is said to have diuretic and anti-diabetic effects. The seeds oil contains nitrogen and sulphur. Alcoholic extract of the root bark provides antifungal and antibacterial properties[45,46]. Ethanolic extract of aerial portions exhibited analgesic action[47] and anti-inflammatory[3,47]. It inhibited cell cultures of *V. cholera Inaba*, *Vibrio cholerae Agave*, and *V. cholera Eltor*[8,45]. The detailed medicinal use of kair plant is given in Table 4.

SWOT analysis of Kair

There have been no systematic efforts to collect and protect plants displaying this variety, or to conserve or promote the most desirable variations. There is a requirement to determine acceptable types in order to pick plants with large fruit size and high production[8]. Scientific efforts to generate genetically superior strains and standardise acceptable cultivation practices may boost production and thus farming income from plantation in dry places where arable cropping system is not very profitable[3]. If suitable selection from available diversity is made, kair can become a superb crop for the extreme dry region of Gujarat and Rajasthan states, where only a very few species used to survive and it can be domesticated[6,7]. Because of its rich nutritional profile and therapeutic characteristics, it merits special attention for conservation and enhancement in semi-arid and arid regions of India and iso-climatic zones around the world[3]. These advantages make kair agriculture both economically and environmentally viable. The detailed SWOT analysis of kair is highlight in Table 5.

Table 4 — Medicinal use of plant parts of Kair

Parts	Diseases	Specified method to cure diseases
Bark / Stem[1,3,5-8,14,48-50]	• Arthritis	• Bark ash is administered to the knee joint.
	• Cough	• Powdered coal with cane sugar with water 10 g for 5 days
	• Cuts	• Wet steam heated on fire juice is used for bleeding and early healing
	• Bolls	• Aqueous bark solution applied to bolls
	• Dental	• A fresh branch extract is applied to the teeth to relieve toothache.
	• Eczema	• Wet stem coated with oil and set ablaze. The extract produced following the burning process is applied to the affected area.
	• Eye problem	• Fresh stem extract applied on eyelids to cure cataract
	• Gynaecological	• Powdered stem coal combined with sugar candy and consumed orally with water. It lessens the flow of blood during menstruation.
	• Injury	• Powdered stem coal combined with vegetable oil and administered orally to treat old injury
		• Fresh extract of stems is applied to wounds to promote early healing.
	Miscellaneous use including ayurveda and veterinary use	
	• The plants' bark has also been used to treat asthma, ulcers, inflammation, diabetes, cough, and gout.	
	• Wood coal is used in muscular injuries	
Leave[6,7,49,50]	• Dental	• To ease discomfort, a spiny tipped section of young leaves is placed between the teeth.
	• Blister	• Powder of top shoots and young leaves are made
	• Eczema	• Eczema treated with aqueous paste of young leaves
	• Pain relief	• Fresh young leaves crushed are immersed in water. Then water is drained out. The residue is dried and solidified. A small slice is eaten with butter.
	• Fracture	• Powdered coal of stem mixed with half cup sesamum oil and administered orally to the patient
	• Gastritis	• In a gaseous condition, a wood extract is given orally with water
	• Tuberculosis	• Young leaf paste is produced and sieved through a muslin cloth. For five days, some water is put to the filter and is taken orally twice a day.
	Miscellaneous use including unani and veterinary use	
	• They are also used as antidote to poison, anti-fertility, drug, Appetizer, cardiac troubles and also in afflictions of the joints	
Flower[6,7]	• Cough	• Aqueous paste with sugar with water
	• Jaundice	• Powdered flower taken orally with water
Fruit[3,6-9,15,42,51]	• Ashtma	• Powder mixture with *heraheeng, pipli, joharad,* sugar candy, after meal twice a day
	• Constipation	• Powder with rock salt, small *harad* with water at night
	• Gastritis	• Powdered fruit with wateris taken orally
	• Tuberculosis	• Mixture is prepared by mixing fruit of this plant with 10 g dried ginger, 100 g amla fruit, 10 g alum (white), 200 g sugar candy, 10 g turmeric powder, powder, 10 g big *pipli* and 10 g big *harad*. 10 g (each dose) mixture taken 2 times a day in morning before meal.
	Miscellaneous use including veterinary and ayurveda use	
	• The immature fruits are beneficial for anthelminthic, constipation, asthma, laxative, coughing, worms, hysteria, and other psychological issues.	
	• The fruits and other plant components have been claimed to offer various medicinal characteristics in the treatment of biliousness, cardiac, gastrointestinal, and diabetic problems.	
	• Astringent to the bowl, destroying biliousness, foul breath, and urinary purulent discharge, and aiding in the treatment of cardiac problems.	
	• Karai powder is used to treat diabetes and alloxan-induced oxidative damage.	
	• The seeds and fruits of the karai tree are used to cure dysentery, cholera, and urinary purulent discharges. Fruits cooked as vegetables with pure ghee and red chilli powder, coriander powder, and turmeric powder. This is consumed twice daily for 90 days.	
	• The fruit has a harsh spicy taste that is astringent to the bowels, removes biliousness, foul breath, and urinary purulent discharges, and is beneficial in cardiac problems (Ayurveda). This is used to treat skin conditions.	

(Contd.)

Table 4 — Medicinal use of plant parts of Kair (*Contd.*)

Parts	Diseases	Specified method to cure diseases
Root[6–8,49,50]	• Pain killer	• A 2–3-year-old plant's roots are close to some warmed sand. Pregnant ladies with backaches are advised to lie on it for a few hours. (Coal made from root material is taken internally with ghee and milk for three to four days to treat body pain. Peel the top layer off an equal number of Capparis and Prosopis cineraria fresh roots. Currently, lightly sauté in mustard oil before spreading on the floor. A person with a backache is permitted to rest for a few days).
	• Skin problem	• Cut-up roots that have been cooked in water. Its filtrate is used to treat urticaria by soaking in it.
	Miscellaneous use including Veterinary and ayurveda use	
	• Charcoal of roots mixed with sesamum oil is provided orally to animals for faster healing of damaged bones.'	
	• Utilised as renal disinfectants, diuretics, tonics, and for arteriosclerosis, as well as eye compresses.	
	• Root bark and stem infusion is used as a febrifuge and diuretic.	
	• The root bark and roots are aromatic, bitter, and used to cure intermittent fever and rheumatism.	
	• Used as an anthelmintic and purgative	
	• Used in the treatment of fever, coughs, asthma, and swelling.	
	• Pyorrhea and alveolaris	
	• Cut-up roots that have been cooked in water. Urticaria can be treated by bathing in its filtrate.	

Table 5 — SWOT analysis of Kair in India

Strengths	Weaknesses	Opportunities	Threats
• Vast area of semi-arid and arid region.	• Lack of experience in plantation development and management.	• Nature friendly.	• Because cuttings are challenging to root, emphasis has shifted to micropropagation methods[9].
• None unit is engaged in mechanization of kair.	• Difficulty in field establishment[9].	• Both ecological and economic significance[22].	• Poor quality of farm machines.
• Alkalinity reduction and increase of organic carbon[6,7,16].	• Slow growing species.	• Because cuttings are challenging to root, emphasis has shifted to micropropagation methods.	• Lack of manufacturing hub in the state.
• Best species for shelterbelts.	• Stagnation in the crop yield.	• Decrease inflow of labour towards specific plant.	• Scarcity of farm labour.
• Control wind erosion[6,7,9,16].	• Less market values.	• Developing the skills of scientists, engineers, manufacturers, and farmers.	• Farmers eagerness to accept new technology.
• Stabilisation of sand dune in the *Thar* desert[6,7,9,16].	• Lack of quality control and standardization		• Climate change and sustainability of agriculture.
			• Survival of seedlings in nurseries was low[9].

Identified mechanization requirement for kair production

Agricultural labour scarcity is one of the utmost problems in agricultural sector due to rapidly increasing trends of migration to city in search of better employment opportunities and income which also increased wage rates in rural areas. This in turn ultimately resulted in difficulty in getting agricultural labourers in right time as well as additional burden to women, elderly and children, creating imbalance in family and social lives. Women are increasingly taking on many tasks and responsibilities, including agricultural work.

Kair mechanization is a crucial input to improve efficiency in kair production as well as to emerge farmers from subsistence farming. Primarily, it should start from small hand tools to more sophisticated powered machines and equipment. Because of its various applications and tolerance to germinate in various soil types in desert places with very little and unpredictable rainfall, kair has commercial potential on marginal lands with very little irrigation[9]. Various kair operations such as planting, irrigation, fertilization, pruning and training in commercial cultivation. Whereas harvesting and post-harvest require special attention in traditionally grown kair plants on barren land and as well also required in commercial cultivation. With little improvements to existing traditional growing technology, it should be possible to profitably utilise the abundant fruits[9].

Planting

The planting media was made up of dirt mixed with FYM in a 3:1 ratio[3]. The seeds can be planted in polyethylene tubes (200-gauge, 10 cm x 25 cm size) filled with a comparable mix of clay, sand, and powdered farmyard manure (FYM). Germination takes roughly 15 to 20 days and can last up to 40 days. After one year of sowing, the survival rate for seedlings ranged from 36.1 to 64.3%[3]. Seedlings exhibit a gradual growth rate, requiring a year of growth in the nursery prior to being appropriate for field planting just before the subsequent rainy season[9]. For a year following planting, the plants must be watered every 15 days, excluding the rainy season. They then establish themselves firmly in the ground and stop needing irrigation. Although it is possible, artificial propagation by root suckers is frequently unsuccessful[9]. After a period of five months the seedling develops to a height of 20.0 cm[3].

Seedlings can be cultivated under strict nursery conditions, but early mortality is high. August is the greatest month for sowing. The seedlings are suitable for transplantation after six to seven months. This is commonly performed in early March or July-August, and in the beginning of the monsoon season[8]. A hectare of land may produce 1,600 kg of immature green fruits (at 4 kg per plant) from the methodical planting of the species at spacing of 5 m by 5 m[3].

Strategies for quality planting materials

It has been demonstrated vegetative propagation techniques, such as stem cuttings treated with half strength MS medium supplemented indole-3-butyric acid (IBA 1000-2000 ppm) and in vitro micropropagation using nodal explants cultivated on Murashige and Skoog (MS) medium enriched with 5 mg l^{-1} 6-benzylaminopurine (BAP), have shown promise for true-to-type and high-performing genotypes[2,9]. The establishment of *C. decidua* as a climate-resilient, livelihood-supporting species in India's arid ecosystems can be strengthened by the adoption of decentralized propagation units, certification procedures, and participatory varietal selection (PVS), which can guarantee the steady supply of high-quality planting materials[8,9].

Irrigation

For the first year after planting, the plants must be irrigated after every 15 days except during the monsoon season. Then they firmly established their roots in the soil and no longer require much irrigation[9]. A noteworthy observation about plant spread was that in wild populations, the spread was generally more north-south than the east-west, depicting that greater growth occurs in the north-south direction to avoid higher amount of heat load. There was no distinct difference in spread in established populations, which can be due to regular and close spacing[11].

Harvesting

Plants produced from seed begin bearing fruits after the age of 6 to 7 years, although plants propagated vegetatively can begin fruiting after a period of 4 years[9]. It is critical to harvest fruits at the right time and level of ripeness. Harvesting fruits by hand is a frequent practice[3,9]. Because hand picking harvests only tender fruits and avoids adult ones, there is no need for additional sorting of the fruits. Furthermore, because the plants are prickly, cautious picking is essential. Harvesting the fruits with twigs attached is also seen at times, however this reduces plant vigour and subsequent fruiting[8,9]. The fruits are gathered between April and May[8].

It has been recommended that the fruits should be picked after 7 to 10 days of fruit set, when they are 5 to 8 mm in diameter, during the month of March-April, to obtain a higher market price[1,8,9]. The seeds harden as they mature, and the fruits are not suitable for food. Fresh fruits are priced at Rs. 20 to 25 per kg (US$ 0.4-0.5), while dried fruits are priced at Rs. 150 to 200 per kg (US$ 03.3-4.4)[9]. The prickly form of the plant makes hand plucking the fruits difficult, and people frequently gather the fruits by pounding the crown with wooden sticks. Fresh fruits are typically offered in local marketplaces. Because of the presence of tannins and phenolic compounds, fresh fruits are astringent[9].

Post-harvest

After removing the pulp from well-ripened fruits, seeds are removed and dried in the shade[9]. Due to their bitter flavour, unripe fruits are often not utilised as such. After processing, these fruits can be transformed into a number of by-products. The treated fruits may be directly utilized for pickling or as vegetables, or they can be dried for off-season use[3,8,37]. Fresh fruits are typically offered in local marketplaces. Because of the presence of tannins and phenolic compounds, fresh fruits are astringent[9].

The market offers three relative classes of processed *C. decidua* fruits based on size: big,

medium, and small. Smaller fruits exhibit greater delicacy and superior quality compared to their larger counterparts. Dried fruits can be preserved at room temperature for one year without any degradation in quality. One-fourth recovery, *i.e.*, 1 kg of fresh immature fruit provides approximately 200 to 250 g of processed dry fruit[3,8]. Fruits after processing are stored in jars or plastic containers, whilst processed dried fruits can be stored in flexible polybags. Fruits after drying can be preserved in polybags for one year without degradation in quality[8]. Hand picking ensures picking of selectively only immature fruit produce and hence there is no need of further grading processes.

A tentative report on *C. decidua* vegetative proliferation through rooting of stem cuttings exists, although the proportion of rooting and rate of multiplication are poor. A more efficient approach for large-scale multiplication must be devised. Tissue culture allows for the bulk clonal replication of specific tree genotypes[14,52,53]. Thus, there is still a lot to be done to enhance kair productivity.

However, there is a need to educate people about the proper harvesting stage as well as suitable curing and processing processes prior to drying. These processes have a direct impact on the product quality and shelf life of stored produce[44].

Need of kair machinery and tools for cultivation

No specific or standard mechanized tools and equipment are used for any purpose in the cultivation and management practices. Currently, the most common operations are needed nursery plantation and grafting/budding, digging and planting, plant protection, irrigation and fertigation, harvesting and post-harvest management.

Harvesting

Fruit harvesting/picking is done by hand pulling using collecting bag. Because of the thin spines, dense canopy, and small size of sensitive fruits, harvesting *C. decidua* fruits is quite difficult. An adult may only collect 10-12 kg of fruits per day[3], and because green immature fruits are harvested by rural people, it is evident that a greater number of fruits would be picked up from non-spiny open type shrubs that fruit sooner[8]. Harvesting/fruit picking is regarded as the most important and significant operations in kair production, storage, and handling the market cycle, due to the potential for fruit damage and musculoskeletal stress on the worker. Traditional picking (manual plucking, branch cutting) and post-harvest practices are to blame for lowering fruit quality and reducing postharvest shelf life. Farmers also regularly use traditional methods such as branch chopping, tree shaking, and beating with sticks for fruit harvesting[54]. These procedures are dangerous, labour-intensive, and time-consuming practices that have an impact on market quality and nutritive value of the kair.

Mechanised harvesting/picking and post-harvest processing of fruitis seen as the most viable area of intervention for addressing the growing phenomena of labour scarcity, costs, and entrepreneurial opportunity in the country's rural areas[55,56]. Around the world, mechanical harvesters like limb shaker, air blasting, trunk shaker and canopy shaker, particularly for fruits have been examined and practiced for improving efficiency and profitability of farming. But no one is specified is used or evaluated for the species. Even though, there are major issues such as the flexibility, the fruit selection ability, the damage to the fruit and trees, the design for mechanical harvester and topographical constraints which still limits the investment capability and application of the mechanical harvesters in countries[54,55,57,58].

Post-harvest management

In India, most of the kair grading and sorting work are done manually based on visual observation. For optimal fruit packaging, saving transport resources, and increasing marketability, an automated, precise grading system can increase operational efficiency, and minimize labour requirements[59]. Attempts have been made by CAZRI to develop manual fruit graders for multi fruits such as apples, mandarin, lemon, pears and sweet orange, which are still in the research phase and yet to be commercialized. But in case of kair fruit there no such effort has been made in this area. Few imported high capacities Chinese or developed grader are also presently seem to be used in cooperatives farm/private industry through subsidy program but very limited.

Challenges and constraints of fruit mechanization

No specific field and commercial cultivation, smallholder subsistence and rainfed farming system, no farms, lack of roads to most of the fields and physical constraints of dessert topographic limit the machinery introduction and promotion.

Inadequate research, development and extension activities on kair mechanization

In India, work on kair mechanization research is inadequate and extension program is negligible.

Institutions for education, research, and extension are very weak and have given less priority for kair mechanization work. Arid mechanization research related institutes such aslack adequate resources, expertise and infrastructure facilities for proper work on kair mechanization and technology generation. Coordination among education, research and extension looks very poor. Major agricultural extensions and educational institutions also lack well established arid mechanization disciplines and manpower. In addition, to promote sustainable arid/kair mechanization programs there is also need to recruit trained manpower (agricultural engineers) in the institutions related to arid/kair mechanization/ modernization in India.

Lack of kair related policies and practices

Specific policy and practices for kair development (Orchard establishment and management policy, kair fruit processing policies, nursery policy, kair export and import policies etc.) are still lacking behind in the country.

High harvest and post-harvest losses

There is lot of harvesting losses (not measured), still a high postharvest loss of kair due to the lack of proper harvesting, grading, sorting, storing, inappropriate packaging materials, and means of loss transportation.

Unproductive plants

Most of the old plants give less production due to poor and no management practices such as nutrient, training and pruning or might be due to global warming or climate change effect. Farmers are destroying plants and shifting towards cultivation of other agriculture and horticulture crops which also lead to decrease in machinery use and productivity.

Future aspects, way forward and recommendations

C. decidua can be an ideal crop for India's severe dry zone, where just a few species may have survived and be domesticated[3]. Furthermore, the species is a formidable contender for application in plantation forestry and agroforestry (as a woody element), as well as horticulture in the arid tropical regions of the Indian subcontinent and other global ecoclimatic areas[9]. However, scientific investigation is required to assess the compatibility and economic viability across different resource scenarios[8,22]. Comprehensive research initiatives are necessary to optimize the production, propagation, and utilization of this species to promote rural livelihoods and improve desert land.

Research activities encompass the following: the setting up a germplasm bank for kair seeds or suckers from diverse dry regions of India to preserve the diversity of plant's genetic; the formulation and advocacy of intensive farming practices for the sustainable production and uses of kair; the creation of techniques for cloning selected germplasms via vegetative means, as seed-raised plants may not consistently exhibit true-to-type characteristics; and the advancement of methods for cloning specified germplasms through vegetative propagation. The seeds possess limited viability duration; hence, the seed propagation of this plant is ineffective. Nonetheless, vegetative propagation through stem cuttings is considered difficult and necessitates further investigation other alternatives like adding honey bees (*A. mellifera* L.) to natural pollination significantly increased the amount of kair fruit produced[60].

In fact, operations *vis*. mechanization of kair including transplanting of saplings, pit making and harvesting of fruits etc. are prime need of current situation. Adoption and validation on different models of nursery house based on agro-ecological zones, climatic parameters, farmer’s acceptability and economical aspects need to be given priority in applied or adaptive research. Training and wider dissemination work on farm management machinery tools is needed to have proper training of kair plants and pruning of older trees which is very important operation to increase quality production. Detailed research work on kair is recommended to have proper vision on technical, environmental and financial benefits of technology before promoting and recommending to farmers or growers, but in practice (except in a few cases) it is rarely followed[61,62].

Conclusion

Capparis decidua offers a viable solution to ecological, nutritional, and livelihood challenges in arid regions. Reviving its traditional value through scientific cultivation, efficient propagation, and context-specific mechanization is essential for its sustainable utilization. Addressing existing constraints via research, infrastructure, and policy interventions can transform kair into a commercially valuable and environmentally sustainable crop. Pruning tools can rejuvenate kair plants by removing unwanted shoots for fresh

canopy growth. Its integration into agroforestry systems holds the promise of rural empowerment and ecological conservation, marking it as a key species for the future of traditional desert agriculture. Thus, we must promote small-scale mechanization of kair equipment and machinery.

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Conflict of Interest

The authors have no conflict of interest.

Author Contributions

Conceptualization: PD, PP. Literature Search: PD, AK. Writing – original draft: PD, PP. Writing – review & editing: PD, AK.

Ethics Statement

Traditional knowledge has been documented in accordance with code of ethics.

Informed Consent

Prior informed consent was obtained before documenting the local knowledge from the informants.

Data Availability

Supporting data are available from the corresponding author upon reasonable request.

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