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REVIEW ARTICLE

Utilization and value enhancement in palmyra palm (*Borassus flabellifer*) - A critical review

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Abstract

Borassus flabellifer, commonly known as the palmyra or "Miracle Tree," is a traditional plant with immense nutritional and economic value. With nearly 122 million palms spread across India, it holds great economic potential, as every part of the tree is useful. A wide range of value-added products-such as Neera, Nungu, Palm Jaggery, Palm Sugar, Palm Candy, Palm Fibre Composite, Palm Cola, Honey, Thavun, Muffins, Cookies, Gummy Jelly, Palm Wine, Toffee, Tuber and Palm paper can be derived from the palm. These products are not only nutritious but also support processed food industries and eco-friendly innovations. Palmyrah is a versatile plant with deep cultural and economic significance, offering considerable scope for rural development, employment generation and sustainable livelihoods. Value addition through the transformation of raw materials into high-value goods allows communities to reduce post-harvest waste, enhance income and tap into new markets. The sector's growth can be accelerated through quality improvement, innovative packaging, branding, training, infrastructure development and supportive policies. With proper intervention, the palmyra industry can become a vital driver of inclusive and resilient economic growth in palm-abundant regions. This study aims to evaluate the sector's potential to enhance sustainable livelihoods and regional development, focusing on the role of strategic enhancements in packaging, branding, training, infrastructure and regulation in unlocking its broader economic contributions of palmyra.

Keywords: composite; miracle tree; muffins; neera; palm sugar; palm paper, palm cookies; palm fibre

Introduction

Palmyra and other tropical palm trees naturally occur in various regions of East Africa, Malaysia, the Philippines, Indonesia and India. It is widely distributed throughout India, particularly in Kerala andhra Pradesh, Odisha, Bengal, Bihar and along the whole west coast (1). It is especially prominent in the southern Indian state of Tamil Nadu, where it was named the state tree in 1978. Climbing the tree and manually detaching fruit bunches using sickles is the major harvesting techniques followed. A dioecious perennial that grows slowly, the palmyra tree can reach a height of 30 m and a lifespan of 150 years. It can only be found in regions of Africa, Southeast Asia and Tropical Asia. It can resist any unfavourable weather conditions and bears fruit after 15 years of full development (2). The Greek word that originally described the fruit's leathery covering is "borassus," but the word "flabellifer" means "bearer of fans" (3). India is one of the major producers of palmyra palms nearly 122 million per year (4). With 33 % of the world's palm oil demand coming from Malaysia, it is the world's second -largest palm oil exporter. Almost 800 uses exist for palmyra trees, including those in food, drink, medicine, fibre and lumber (5).

Palmyrah, scientifically known as *Borassus flabellifer* L., is a tall, dioecious palm belonging to the family Arecaceae. It typically grows up to 30 m in height and is characterized by a robust, unbranched trunk topped with a crown of fan-shaped leaves. The leaves are large, leathery and costapalmate with a diameter ranging from 1 to 2 m. The palm produces male and female flowers on separate trees; male inflorescences are long and catkin-like, while female inflorescences are shorter with large ovaries that develop into round, black, fibrous fruits (6). Each fruit contains one to three seeds and the tender endosperm is translucent and jelly-like when immature. According to the report on the worldwide market trajectory and analysis of palm sugar, the market was estimated to be worth USD 1.7 billion in 2020 and projected to reach USD 2 billion by 2021. The sap produced from the Palmyra palm trunk is a versatile resource that is used to make gur (molasses) and palm sugar, highlighting the tree's economic relevance in tropical countries (7). This liquid, when processed, yields significant sweeteners, emphasising the Palmyra palm's importance in local economics and culinary traditions (8). The only named palmyrah variation is Srivilliputhur 1, a dwarf palm released in 1992 by Palm research station Srivilliputhur. Additionally, Borassus includes steroidal saponins known as flabelliferrins, which are bitter compounds (9). It was estimated that approximately 20000 tons of palmyra fruit pulp would be available in Sri Lanka each year during fruit season; however, only about 10000 tons of pulp are used annually because of its limited applications, mostly because of the Bitter substances called flabelliferins have not undergone extensive testing prior being incorporated into a range of consumer-focused, enticing value-added products (10).The various edible uses of the palm the sweet sap tapped from the inflorescence for making palm sugar is of prime importance. The endosperm of the young fruit, like tender coconut, is a delicacy in summer. The petiole fibre and leaf blade are used to make products such as brushes and handicrafts. The tree serves as a source of raw material for several cottage industries. In India, there is no standard palmyra palm variety, although there is a great deal of variation among the regional varieties (11). With around 800 applications, including food, drink, fibre, medicine and lumber, it is known as the tree of life (7).

Functional roles of plant parts and their derivatives in ecosystems

Nungu - Endosperm

In southern and eastern India, the tender palmyra fruit endosperm is a summertime treat. On sweltering summer days, it soothes the parched throat. The delicate fruit endosperm, which is abundant throughout the summer, is high in riboflavin, calcium, iron, vitamin B and niacin. It is used to treat heat rashes, ulcers and urinary tract infections, which mainly happen in the summer (12). The sweet, gelatinous endosperm lies within the outer fibrous layer of the palmyra delicate fruit. Because it is made of living tissues, fresh tender endosperm is perishable and extremely vulnerable to postharvest losses from spoiling. Throughout the marketing process, these tissues need to be maintained in a living and healthy state (13). For most commodities, post-harvest losses are influenced by several factors. These comprise the main causes, which are mechanical wounds, physiological alterations and environmental elements including humidity and temperature. Inadequate facilities for harvesting, handling, postharvest treatments, packaging, transportation and storage are secondary issues that contribute to produce deterioration. Ripe pulp is also processed into various value-added products like jams, toffees and soft beverages (14). Edible products of Palmyrah are represented in Table 1.

Table. 1. Edible products of Palmyrah

Parts used	Edible products
Inflorescence	Toddy, Jaggery, Sugar, Honey, Wine, Sap
Fruit	Toffee, Spread, Jam, Pickle, Sweets (Burfi), Beverages (RTS, Squash, Nectar)
Kernel	Canned product

Neera – Palm nectar

Neera, a delicious beverage created from palm sap, is rapidly going viral in both rural and urban India. The beverage has a high nutritional value, a nice flavour and medicinal properties in addition to being refreshing. It is cool, nutritious and helps improve general health, especially when taken as a supplement by people who are deficient in vitamins and iron (15). Neera is a widely consumed beverage in several nations, including Africa, Malaysia, Indonesia, Thailand, Myanmar and Sri Lanka. With more calories and a high content of vitamin C and vitamin B complex, which help prevent diabetes, cancer, electrolyte imbalance and even hair loss, this drink has the potential to be both therapeutic and healthful. Neera is a great source of minerals, micronutrients and carbohydrates (16). Neera is a popular food in several nations, including Africa, Malaysia, Indonesia, Thailand, Myanmar and Sri Lanka. Because it contains more calories and is a strong source of vitamins B complex and C, it has the potential to be a health and therapeutic beverage which battle against diabetes, cancer, electrolyte shortage and even hair fall. Neera is an abundant source of minerals, micronutrients and carbohydrates (13). Tapping techniques for extracting sap from palm inflorescences vary based on the flower's sex and developmental stage. In male flowers, the Aripanai method involves removing the sheath of a two-week-old inflorescence, allowing it to dry for three days, then attaching a pot and making a fresh cut to collect sap without touching or caressing the inflorescence. The Vallupanai technique uses one-month-old inflorescences, where three to six male spikes with sessile flowers are bundled, wrapped in palmyra leaves and placed in a pot to collect sap during blossoming. For female inflorescences, Tattupalai involves softening the immature tissues and pricking the main axis with a fork and iron rod to form a small press at the former fruiting site for sap collection. In the Kaivetty method, the sap is extracted by slicing mature fruits aged two to three months, typically from July to November (17).

Palm jaggery

Jaggery is a naturally occurring sweetener that is produced by concentrating fresh palmyra neera, purging it to get rid of contaminants and heating it evenly in an open pan. Because jaggery is complex in structure and contains longer chains of sucrose than sugar, it digests more slowly than sugar and releases energy gradually rather than all at once, giving the body energy for a longer amount of time without being hazardous (18). This product is delicate and susceptible to various circumstances, ranging from the gathering of neera to the preparation and preservation of jaggery. Due to some technological limitations in its export-quality processing and storage, the jaggery business is still at a cottage level (19). Temperature and relative humidity in the atmosphere have a major impact on how well jaggery stores. Because jaggery is kept in godowns, home kitchens and inexpensive storage systems where hygienic conditions are not properly maintained, it attracts a variety of pathogenic and non-pathogenic microorganisms. As a result, India's producer and farmer level jaggery storage facilities are quite poor (20). Fresh palmyra palm pulp is gathered using pots that had been laced with 1.0–3.5 % lime. After that, the sap was boiled in an aluminium pan with a flat bottom and filtered through fine muslin cloth. Samples were clarified, settled and filtered before boiling in a pan. Six samples were treated at 90 °C to 140 °C with lime at near optimal concentration). In the optimization of the concentration of lime, heating was done at a temperature range 100-120 °C; the process was continued until striking. It took around 180 min. Then, during the optimisation of temperature, the lime was applied at the previously found optimum level. Heating time depended on the temperature required to reach the striking point (150-200 min) (18).

Palm honey

Fresh neera is heated for 2 hrs to attain honey like consistency and it is transferred to mud pots. Mature, dry and dehulled tamarind fruits seedless are added to this boiled syrup about 1 Kg of tamarind for preparing 10 litres of syrup is required. The pot is covered by cloth and vessels are kept in a shock proof, cool dry place for 130 -180 days (21).

Fermented products

Toddy

Toddy is obtained through fermentation of neera/sap due to wild yeasts and bacteria that get exposed to sap after tapping. This is an uncontrolled natural fermentation by number of different strains of yeast and bacteria. The alcohol content in naturally fermented toddy is reported to be 5 % (22). But fermentation of palmyra sap by using pure yeast culture gives about 7.8 % alcohol content under laboratory conditions. The primary sugars that are present in partly fermented toddy is sucrose, glucose and fructose but these will be gradually converted into ethyl alcohol during the process of fermentation (23).

Palm vinegar

The palmyra sap is fermented into acetic acid by acetic acid bacteria to produce vinegar. In addition to carbs and proteins, palmyra vinegar contains a high concentration of carotene, vitamins and minerals. This medicine can be used to treat bladder infections, urinary tract infections, skin disorders, headaches and bodily pains. It has also been reported to improve memory (24).

Palmyra wine

Sterilized neera (unfermented sap) can be fermented using selected yeast strains to produce palm wine. Sterile sweet toddy with pH 6-7 has also been inoculated by beneficial yeast to produce a very clear straw colour wine. The wine prepared by this method show a good palatability which masks the unique aroma and characteristic sour acidity due to different acid species present in toddy (25).

Palmyra spread

The fruit pulp is first extracted using a 1:1 water solution and heated to 70 ° C for 10 min to maximize pulp recovery. Together with sugar, skim milk powder, a little cardamom and citric acid, the extracted pulp is cooked over a low flame while being constantly stirred until the TSS reaches 65^0 to 68^0 Brix (26).

Preparation of palm spread

To make palm spread, combine 1 kilogram pulp, 1 kg sugar, 100 g skim milk powder, 4 tiny cardamoms and 5 g citric acid. This was utilized with a little variation (26). The extracted pulp was combined and cooked at 40 °C with continuous stirring until the total soluble solid (TSS) reached 65-68° Brix. After cooking, the material was transferred to sterilized broad-mouth bottles, labelled and kept at room temperature.

Palmyra thavun

During germination, the basal part of the embryo expands to form cotyledon structure known as Haustorium. This haustorium delivers these nutrients to the embryo. So, haustorium will be more nutritious as it consists of sugars and essential amino acids and other micronutrients and bio active compounds useful for our health. It is eaten and grown fresh in the rural parts of our world. It has been demonstrated by scientific accounts that an excess of this haustorium provides additional advertising for health and wellbeing as well as illness prevention benefits. Haustorium transfers the nutrients to tubers in turn responsible for producing valuable plants (27).

The development of a fragile, spongy haustorium, or Thavun, occurs during seed nut germination. Palmyrah seeds start to sprout after two to three weeks; at this stage, the spongy endosperm of the nut is accessible. The haustorium and cotyledon are the two parts of a palmyra seed's embryo. The cotyledon changes into a radicle and then goes on to build a new plant, even though the haustorium transfers the nutrients from the endosperm to the cotyledon. In order to fuel its growth, the haustorium absorbs the nutrients when they enter the endosperm and breaks them down into simpler forms, such as simple sugars, amino acids and so on. This process takes a few weeks (28). Palmyra plant seed embryos are rich in macro and micronutrients as well as antioxidant qualities. There is a lot of moisture and fibre in this spongy haustorium. It is considered a cooling agent and is used in traditional remedies for kidney stones and stomach ulcers. The underappreciated, unloved, perishable, seasonal palm product palmyra thavun has a short post-harvest shelf life (1).

Palmyra sprout cookies

The cookies are incorporated with palmyra sprouts a rich source vitamin - E. They are mainly gluten free and are called “Gluten free cookies” and have less amount of fat. They offer high nutritional value and are economically accessible. Gluten free cookies can be consumed by patients having Celiac disease (29). The increased spread ratio of the cookies was more desirable. The author reported that there is a decrease with increase in spread ratio of the biscuit with the incorporation of makhana flour into the wheat. The spread ratio of the cookies was analysed at 2.63 ± 0.32 mm (30). The gluten-free diet is used for several objectives, including as managing NCGS (non-celiac gluten sensitivity), IBS, diabetes, DH, inflammation and obesity. The gluten-free diet is becoming more popular and consumers, health experts and food producers are all influencing it (31). The team discovered that biscuits made with refined wheat flour and quinoa had 482 and 465 calories per 100 gram, respectively. The greater calories in the cookies were related to the higher fat content (32). The fat level of the Palmyra sprout-incorporated cookies was determined to be 8.53 g. The author reported that the wheat enriched biscuit with citrus peel powder had a fat content of 11.98 g.

Palmyra muffin using sprout flour

Diablisss sugar was used instead of commercialized white sugar. Major carbohydrates present in shoot flour are starch and other major sugars are glucose, fructose and sucrose (33).This is the antidiabetic herbal cane sugar excellent for controlling blood sugar as it has a low glycaemic index (GI). Flax seeds are added to enrich the product with omega-3 fatty acids thus making the muffins a healthier snack choice (34) It improves nutritional value of muffins like fibre rich muffins, sugar free muffins, antioxidant rich muffins and fat-free muffins (4). This experiment revealed significant differences in the proximate composition of commercialized refined wheat flour and palmyrah sprout flour. This investigation found that wheat had a crude fiber level of 0.52 %, which was similar to the 0.51 % reported before (35).

Gummy Jelly

Palmyra fruit (1-2 kg) is weighed, washed and de-mesocarped. Fruit pulp is extracted after the seed is removed manually. Palmyra palm fruit juice was obtained by sieving the extract to get rid of the insoluble pulp. After being pasteurised for 5 min at 65 °C, the juice was kept at -18 °C until it was needed (36). Glucose syrup, sucrose, high methoxyl pectin, sodium citrate, fructose, water, palmyra palm fruit juice, 50 % citric acid are the major ingredients. The mesocarp of ripe palmyra fruit was mixed with water (at a 1:1 w/w ratio) to create the fruit juice and the insoluble pulp was subsequently extracted (37). Because the palmyra palm fruit contains a lot of sugar and carbohydrates, the pulp needs to be removed with water, which dilutes the fruit juice and lowers the amount of carbohydrates in the finished product (14, 38).

Palmyra tuber flour

Palmyra tubers are edible shoots that develop from germinated seeds in loose soil. Many people consume tubers straight from the fire after removing the outer layer. Palmyra tubers are high in fibre and starch, which helps manage several illnesses, particularly diabetes. Frequent ingestion of palmyra tuber flour improves physical strength, decreases appetite and when combined with other nutrients, helps prevent malnutrition (26). Palmyra tuber flour's primary carbohydrate is starch. The starch has a low gelatinisation temperature and viscosity, but it has good settling properties for a food starch. Similar to potato starch, palmyra tuber flour starch has a grain size of 40 µm and lacks bitterness, which is an intrinsic feature of the tuber (8).

Palm toffee

The ingredients for palm toffee include fruit pulp, sugar, glucose, maida, starch and skim milk powder. The mixture is boiled for up to 40 min while being constantly stirred and the end point is ascertained by a drop test in water. After removing the container from heat, put the toffee mixture on an aluminium pan and smear with oil or butter and left in the air overnight. After that, the toffees are cut to the appropriate size and form, wrapped in butter paper and kept at room temperature. It can be stored for about 2-3 months (39).

Preparation of palm toffee

500 g pulp; 500 g sugar; 200 g skim milk powder; 50 g glucose; 50 g maida; and 100 g starch. To make palm toffee, combine fruit pulp and ingredients, heat at 70 degrees and stir for 40 min. The termination point was selected using a drop test in water. After removing the pot from heat, spread the toffee mixture on an aluminium tray sprayed with oil/butter. Allow to air dry overnight before cutting into 3×1.5 cm pieces and wrapping in butter paper. Store at room temperature (26).

Palm sugar

Palm sugar serves as a natural alternative to cane sugar. Neera is filtered through wire mesh to remove any debris before being boiled in an alloy kettle to make palm sugar. After evenly boiling the neera liquid is allowed to cool. The sediments must all be eliminated. It is then allowed to cool and run through a crystalliser after being heated to 110 °C for 2 hrs to a consistency similar to honey. Following the formation of sugar crystals, the sugar is collected by centrifugation, dried and then pulverised for storage (40). Inedible products of Palmyrah edible are represented in Table 2

Table 2. Inedible products of Palmyrah

Parts Used	Inedible products
Leaf	Mats, Baskets, Fans, Hats, Umbrellas, Buckets, Writing Material, Fence, Fibre extracted is used to make brushes and handicrafts
Fruits	Fibre extracted is used to make toys and fancy items
Stem	As poles for shed construction and as timber source.

Value addition - Non-edible products

Palmyra leaves

The light ivory colour tender leaves harvested from Palm tendered into thin strips which can be used to make toys, flowers, garlands and fancy goods. While the older leaves are used to mould containers. The harvested leaves have midrib that can be used for making of the brooms (41).

Palmyra Timber

The most valuable application of palmyra wood is in the building of village homes, however it is occasionally used for beams and rafters. Additionally, palmyra palm wood is utilised for firewood.

Palm fibre

Palmyra fibre has garnered significant international recognition, evidenced by its robust export market in countries such as Japan, Australia and the United Kingdom, thereby underscoring its global demand and economic importance. The fibrous substance called "Naar" is extracted from the frond stalk. Karukku are longitudinal splits that can be utilised for tying. They are produced by soaking the stalks after the petiole's sharp, serrated edges have been removed (41).

Petiole fibre reinforced polyester composite

ASTM D3822

"Standard Test Method for Tensile Properties of Single Textile Fibers" - used for determining tensile strength, elongation and modulus of individual palm fibres, the composites are created by reinforcing both untreated and treated palmyra palm petiole fibre. Their mechanical and dielectric qualities are rigorously examined. Palmyra palm petiole chemically treated FRP composites had the maximum tensile strength of 56.69 MPa and 1052.83 MPa. The composites reinforced with chemically treated fibre exhibit improvements in flexural strength and modulus of 3.16 % and 34.76 %, respectively, in comparison to the FRP composites made from palmyra palm petioles. The palmyra palm petiole fibre reinforced composites have an impact strength of 97.07 % higher than the unreinforced specimen. The designer will be encouraged to use an insulating material that is relatively low in weight based on the dielectric strength vs fibre content statistics (42).

In order to characterise the physical, chemical, mechanical, thermal and electrical properties of various natural fibres (both with and without chemical treatment) and matrices (thermoplastic, thermosetting plastic, etc.), numerous researchers have worked to create composites. Among those, several writers have concentrated on (43). In the order of *Borassus* fruit, short, short hybrid, long and long hybrid palmyra palm fibre reinforced polymer composites, the following describes the creation and characterisation of the composites reinforced with short palmyra palm fibrous waste, stem, stem long, palm/jute, palm/banana and *Borassus* fruit .The following describes the creation and characterisation of the composites reinforced with short palmyra palm fibrous waste, stem, stem long, palm/jute, palm/banana and *Borassus* fruit fibre in various fibre in various matrices (44). In the instance of *Borassus* fruit fibre reinforced polyester composites, Sudhakara et al. obtained greater tensile strength, modulus, flexural strength, modulus and impact strength for alkali treated/MAPP composites by 4.5, 17, 17.2, 9 and 10 %, respectively.

The palmyra palm fibres were separated from the stem (45) and also chemically by soaking in a 1 % NaOH solution. According to their findings, palmyra fibres up to 50 mm in length in polyester composites exhibited an increasing trend in flexural strength before thereafter declining. When the fibres are 50 mm long, the composites showed a maximum tensile strength of 42.65 MPa, after which it started to decline (46).

The mechanical qualities of palmyra/banana fibre reinforced composites exhibited optimally enhanced properties at 2 cm fibre length when compared with 3 cm (49). The use of fibrous waste that is produced when palmyra palm leaves are separated from the stem base to create polyester composites reinforced with palm fibre waste (pfw). In order to compare the outcomes of the short fibre composites without hybridisation, they have also created pfw/glass FRP composites. Impact strength increased with the addition of PFW, however tensile and flexural strength could not be achieved with an increase in the fibre content of the composite(47).

Materials used

Others used borassus fruit, palm fibre waste and palm leaf stalks among the different fibres listed, while palmyra palm tree sprout leaves and palm fruit. Srinivasababu was the first to develop empty fruit bunch fibres (48). He described the fibre and its composites under mechanical and dielectric loadings and the findings have been published elsewhere. The palmyra palm tree is the source of a new natural fibre called palmyra palm petiole, which is used in the current study. It displays the dried fibre that was extracted. The palmyra palm petiole fibre can be successfully extracted using the pure splitting method, which is used and which has been documented elsewhere. Ecmalon 4413 unsaturated polyester resin supplied by Ecmas resins private Ltd., Hyderabad is used in the present work for fabricating composites for tensile, flexural, impact and dielectric test specimens (49).

Chemical treatment

For 12 hrs the palmyra palm petiole fibre is steeped in a tub filled with 0.625 M NaOH. The treated fibre is then thoroughly cleaned with water and allowed to dry at room temperature until the moisture is naturally eliminated. This is now referred to as palmyra palm petiole-CT.

Testing and manufacturing

The untreated and chemically treated palmyra palm petiole fibres exhibit tensile strengths of 98.14, 156.13 MPa and 1.17, 1.84 GPa (43). The composites reinforced with palmyra palm petiole CT fibre at a fibre volume fraction of 26.11 % achieve the maximum flexural strength, modulus and flexural strength of 62.61 MPa and 8.14 GPa. The tensile and flexural tests of the composites following chemical treatment demonstrate strong adhesion between the fibre and matrix. Only tension causes most of the fibres to fail and some untreated fibres separate from the polyester matrix. This could be because the fibre has a smooth exterior that makes it easy for it to breach the weak contact and slip out of the matrix. Bending alone is the reason why the outermost layer of the chemically treated FRP composites fails.

Hemp, sisal and flax are processed to make floor panels, setback linings and door cladding. Additionally, flax fibres are utilised in place of asbestos fibres in automobile disc brakes.

Coconut fibre is used to make seat bottoms, back cushions and head restraints. Cotton is used to provide sound proofing; it was embedded in phenolic resin and used in the body of the East German Traban car; the first production car manufactured with natural fibres.

Abaca is used in underfloor body panels. Wood fibres are used in many applications in decks, docks and window frames and moulded panel component. Kenaf is used in door inner panels (50).

Palmyrah palm fruit paper

Palmyra palm fruit fibres have the qualities to be utilised as a substitute raw material for cellulosic pulps in the production of paper. Fibre strands from palmyra palm fruits were analysed for their chemical makeup, including cellulose, holocellulose, pentosan, lignin and extractives. The soda process is the most widely used pulping method for non-wood fibres (51) .

A novel pulping technique called nitric acid-water alters the Kurschner–Hoffner method for producing paper pulps. To extract the fibre the ripening meat was compressed. Water was used to wash the pressed fibres connected. After drying each of these samples, the moisture content was calculated for the experiment that followed. They were kept in cold storage in plastic bags. The TAPPI standards for ash content (T211 om-93), cellulose content (T203 om-93), lignin content (T222 om-98), hot water soluble (T207 om-88), 1 % sodium hydroxide soluble (T212 om-88), ethanol-benzene extractable (T204 om-88) and pentosan (T223 om-84) were used to determine the samples' chemical composition. Holocellulose underwent analysis using the peracetic technique (52).

Pulping of palm fruit

The alkali and acidic procedures were used to pulp the crushed fibres. They were cooked in a digester autoclave with a liquid-to-wood ratio of 10:1. Liquor preparation for the alkaline treatment the concentration of sodium hydroxide pellets was measured after they were dissolved in water.

Nitric acid (HNO3) was dissolved in water and the concentration was measured to create a nitric solution for the acidic procedure. To stop the reaction, water was used to wash the partially delignified pulps that were produced. The pulps were filtered and mechanically broken down. To exclude uncooked particles, use a flat screen with 0.25 mm slits. Subsequently, a twin-roll mill was used to pressurise the moist soda pulps for fibrillation until the fibre's freeness matched that of unbeaten acid pulp (CSF 150 mL). The filtered pulps were dried in a hot air oven at 105 °C after being centrifuged. The screened pulp yield was calculated using the pulps' oven-dry weight. The screened pulps' kappa number was assessed using the TAPPI standard (T236-cm-85). A Kajaani FS-200 device was used to measure the fibre length. The quality of the fibre sheets and the yield of screened pulp are the main outcomes of effective pulping. The charge concentration, cooking time, cooking temperature and pulping process type all have a significant impact on the yield, as can be observed. A higher alkaline or acidic charge speeds up de-lignification, as seen by a lower kappa number and a decline in pulp output from the breakdown of carbohydrates. Alkali-catalyzed processes are mostly to blame for the yield loss during the alkaline pulping of lignocellulosic (58). The removal of monosaccharide moieties from carbohydrates is done in steps. This begins at their reducing ends and proceeds throughout the polymeric chain until a competing reaction (the halting reaction) forms a stable alkali group. The acidic technique gives paper made from palmyra palm pulp a higher brightness (53). The pulp's strong light absorption is likely caused by certain extractable alkali or acid components in the raw material, as the pulp's brightness rises with increasing chemical charge. The most popular ones for directly measuring the potential strength of paper are most likely the tensile and tear indices. The pulp sheets with the highest tensile index are those composed of beaten soda pulp and 10 % sodium hydroxide cooked for 75 min (10/75/150) at 150 °C. They have respective tensile and tear indices of 13.8 Nm/g and 1.12 mNm^2/g (54). Nevertheless, the beaten soda pulp (10/75/150) and the unbeaten pulp sheets composed of acidic pulp with 8 % nitric acid at a cooking temperature of 100 °C for 30 min (8/30/100) do not differ substantially in either of these qualities. Its higher tensile strength at a certain tear index indicates that, out of all the pulps examined, its interfibrous bonding strength is the highest.

Chemical properties of Palmyra palm fruit fibres

The ash content of the fibres is 0.64 %. This is lower than those of non-wood fibres such as rice straw with 9.2 % (55), jute leaf with 8.8 % (kenaf with 4 % (56) and bagasse with 1.5 % (57). Chemically, Palmyra palm fruit fibres are rich in holocellulose (68.52 %) and cellulose (37.01 %). These are important parameters in determining the suitability of a raw material for papermaking. Lower lignin content (18.54 %) is normally found in non-wood fibres. The pentosan content in Palmyra palm fruit fibres is 28.51 %. This indicates the amount of hemicellulose, which contributes to the strength of paper pulp. A higher pentosan content is desirable.

Making of paper

The dried pulp was turned into hand sheets. The Tappi Test Method T205 om-88 was followed in the preparation of the lab sheets and a final grammage (mass of the product (80 g/m^2) per unit area. After being broken down, the screened pulps were suspended in water with a dry content of 2.04 g/L. In the hand sheet mould, the pulp suspension and 8 L of water were combined for 10 sec at 2 atm air pressure. Through the wire screen, the white water was drained. To get rid of extra water, three blotting sheets were placed over the sheet and 1 kPa of pressure was applied for 30 sec. After that, the sheet was taken off the wire screen, coated with a metal plate and blotting paper and compressed for ten min at 500 kPa to eliminate any remaining extra water. Prior testing, the sheet was lastly dried and conditioned for 48 hrs at 25 °C and 50 % relative humidity (RH). Ten hand sheets were used to assess the brightness (T452 om-92), tear index (T414 om-88) and tensile index (Tappi T494 om-88) (58).

Pulping process

The quality of the fibre sheets and the yield of screened pulp are the main outcomes of effective pulping. The charge concentration, cooking time, cooking temperature and pulping process type all have a significant impact on the yield, as can be observed. A higher alkaline or acidic charge speeds up de-lignification, as seen by a lower kappa number and a decline in pulp output from the breakdown of carbohydrates. Alkali-catalysed processes are mostly to blame for the yield loss during the alkaline pulping of lignocellulosic (6). The removal of monosaccharide moieties from carbohydrates is done in steps. This begins at their reducing ends and proceeds throughout the polymeric chain until a competing reaction (the halting reaction) forms a stable alkali group. The acidic technique gives paper made from palmyra palm pulp a higher brighter. The pulp's strong light absorption is likely caused by certain extractable alkali or acid components in the raw material, as the pulp's brightness rises with increasing chemical charge. The most popular ones for directly measuring the potential strength of paper are most likely the tensile and tear indices. The pulp sheets with the highest tensile index are those composed of beaten soda pulp and 10 % sodium hydroxide cooked for 75 min (10/75/150) at 150 °C. They have respective tensile and tear indices of 13.8 Nm/g and 1.12 m Nm^2/g. Nevertheless, the beaten soda pulp (10/75/150) and the unbeaten pulp sheets composed of acidic pulp with 8 % nitric acid at a cooking temperature of 100 °C for 30 min (8/30/100) do not differ substantially in either of these qualities. Its higher tensile strength at a certain tear index indicates that, out of all the pulps examined, its interfibrous bonding strength is the highest.

Conclusion

Value addition in palmyrah and its diverse range of products offers immense potential for economic upliftment, rural employment and sustainable development, especially in regions where this versatile palm is abundantly available. By processing palmyra into high-value products such as Neera, Nungu, Palm Jaggery, Palm Sugar, Palm Candy, Palm Fibre Composite, Palm Cola, Honey, Thavun, Muffins, Cookies, Gummy Jelly, Palm Wine, Toffee, Tuber and Palm Paper, communities can significantly enhance income opportunities while preserving traditional knowledge and practices. These innovations not only help in reducing post-harvest losses but also create new markets through quality improvement, packaging and branding. With appropriate support in training, infrastructure and policy interventions, value addition in palmyra can serves catalyst for inclusive growth and long-term sustainability. Edible palm products like neera, palm jaggery, palm sugar, palm candy, palm chocolate, tuber flour and palmyra thavun are rich sources of vitamins and minerals, but products are not widely commercialized to date, due to the lack of value addition. The cultivation and value addition of Palmyrah palm (*Borassus flabellifer*) face several challenges today. One of the major difficulties is its long juvenile phase, often taking 12-20 years to reach maturity, which discourages farmers due to delayed returns. Its dioecious nature further complicates large-scale planting, as only female trees bear fruit and male trees are more suitable for tapping. Lackage of reliable vegetative propagation methods hampers the multiplication of elite genotypes. Mechanization is limited, making harvesting, especially tapping and climbing, labour intensive and risky. In terms of value addition, inadequate processing infrastructure, poor storage facilities for neera and limited market access restrict economic benefits. Traditional products like jaggery and fibre goods lack standardization and branding, affecting commercial scalability. Moreover, policy support and organized supply chains are lacking, leading to partial use of this multipurpose tree. Addressing these issues through research, technology and farmer engagement is critical for unlocking full potential. Crop enhancement in Palmyrah palm (*Borassus flabellifer*) is critical for increasing its economic potential, particularly in semi-arid environments. Because it is a slow-growing, dioecious plant, it is critical to choose superior genotypes with early blooming, high sap supply and improved fruit quality. Although still under investigation, vegetative propagation methods like as tissue culture can aid in the multiplication of elite lines. DNA fingerprinting and marker-assisted selection are examples of molecular technologies that can help detect and preserve desirable features. Hybridization, though challenging due to tall nature and separate sexes, holds promise for developing improved varieties. Usage of plant growth regulators may enhance early growth and sap production. Additionally, integrating improved agronomic practices, such as optimized spacing, nutrient management and intercropping, supports better yield. Conservation of genetic diversity through field gene banks and cryopreservation is vital. Participatory breeding involving farmers and institutional support can accelerate sustainable Palmyrah improvement programs in traditional growing areas.

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Authors' contributions

PA contributed to conceptualizing and supervising the review title. SSA carried out the collection of research and review papers. NS contributed to preparing the original draft review article. RJ contributed to the methodology of the review article. PM contributed technical editing of the review article. IPS clarified the doubts regarding the palmyra. Supervision and validation were done by SSJR, PY & RJ. Revision of the manuscript was done by DK & JLJ.

Compliance with ethical standards

Conflict of interest: The writers have no conflicts of interest. This attests to the fact that the text has not been submitted for publication elsewhere and is an original work. Furthermore, we attest that all references have been appropriately cited and that no information, including tables, has been taken verbatim from other publications. All authors consent to submit this manuscript to the Plant Science Today Journal

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