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Feasibility analysis of multi-cropping jackfruit trees with rubber plantation: An Indian perspective

Ajju R. Justus[1]* and E. Raja Justus[2]

[1]*Department of Mechanical Engineering, Sree Chitra Thirunal College of Engineering, Thiruvananthapuram 695 018, Kerala, India*
[2]*Manonmaniam Sundaranar University, Tirunelveli 627 012, Tamil Nadu, India*

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Abstract

Increase in demand for rubberwood and rubber-based products has led to widespread rubber monocropping in India. Studies show that multi-cropping can effectively mitigate the negative impacts of monocropping. Once a neglected cash crop, jackfruit cultivation now witnesses revival and value addition in states where rubber plantations are predominant. It is worth exploring the integration of the jackfruit tree as a multi crop in rubber plantations based on how well it can replace rubber trees in its applications. The paper reviews existing literature on the jackfruit tree to identify such potential areas of substitution. Jackfruit latex though unsuitable for most applications, shows promise as an alternative to natural rubber in adhesive-based applications. The timber also exhibits better structural properties than rubberwood. The root system and tree spacing are briefly reviewed. This review will pave the way for further studies in integrating jackfruit trees as a multicrop which will help reduce monocropping and encourage jackfruit cultivation.

Keywords: Multi-cropping, jackfruit, latex, natural rubber, timber, value addition

Introduction

Many consider natural rubber to be the fourth most vital resource in the world, as it is essential in the manufacture of more than 40,000 products. The global production of natural rubber reached 13.87 million tonnes in 2018 and is predicted to increase annually by 3 to 6% (Hang, 2020). In 2020, rubber was grown on 14.1 million ha worldwide (Gitz et al., 2020) with India's share of 0.822 million ha producing 712000 tonnes of natural rubber (Annual Trends, 2021). In India, the southern states of Kerala and Tamil Nadu are the traditional regions where rubber plantations have been the principal cash crop for decades. In 2019-20, rubber plantations in Kerala and Tamil Nadu occupied 551030 ha and 28358 ha (District Statistical Handbook, 2020; Economic Review 2020 and 2021) which represents a national share of 67% and 3.4%, respectively. Financial benefits justify converting large tracts of agricultural and forest areas into rubber plantations. However, the increasing population, and land requirement for residential, commercial, and industrial purposes constrains the area available for cultivation.

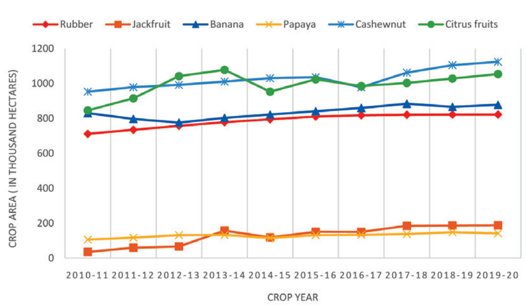

Figure 1. Cultivation area of some common crops and plantations in India.

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* Author for Correspondences: Phone + 91-9633702955; Email: ajurjustus@yahoo.co.in

Therefore, the readjustment of cultivable areas among the crops as per demand is a conspicuous agricultural practice in India. Data from the Ministry of Agriculture & Farmers Welfare (Horti Crops, 2019), graphically represented in Fig. 1, highlights the increasing trend of the natural rubber crop area. It contrasts with the random fluctuations in the crop area displayed by all other crops.

The jackfruit tree (*Artocarpus heterophyllus*) is part of the Moraceae family native to India. It is an evergreen tree with a height of 8 to 25 m. It has a rough straight stem with a 1.25 cm thick green or black bark protecting it. It has broad, elliptic, thick leaves, and the bark exudes milky latex. It grows in tropical and subtropical regions and can survive cooler and drier climates. The ideal growing conditions encompass an altitudinal range of 0-1600 m above sea level, a temperature range of 19 to 29 °C, and warm, humid weather with evenly distributed rainfall in the range of 1000 to 2400 mm (Prakash et al., 2009). Well-drained alluvial soil with modest nutrient content and a pH range from slightly acidic to neutral is conducive to growth. However, it shows moderate tolerance to drought and flooding and can grow even in malnourished lateritic, sandy, or stony soils (Kunhamu, 2011). It predominantly finds application as timber, traditional medicine, and as a source of edible fruit. Jackfruit is a staple food in India. Its immense nutritional value and mineral content is utilized as vegetable or fruit and is informally known as the poor man's food in India, Bangladesh, and Southeast Asia. It is a traditional medicine for fever, diarrhea, ulcers, helminths, syphilis, snakebite, glandular swellings, anemia, asthma, dermatitis, cough and skin diseases (Balbach and Boarim, 1992; Heyne, 1987; ICUC Report, 2003; Perry, 1980). The heartwood of the jackfruit tree boiled in water, produces a natural tone dye with significant medical properties. It offers protection from fungal infections, skin disorders and foul odor (Salguero, 2003). India is referred to as the "land of jackfruit" (Rana et al., 2018). In India, jackfruit is predominantly grown in Kerala, Assam, Tamil Nadu, Karnataka and Maharashtra. Jackfruit is also the official fruit of Kerala.

Table 1. National ranking of jackfruit crop area in predominant rubber growing states for 2015-16 (Area, Production and Productivity of Rubber Plantations in Tamil Nadu, n.d.; Crop Statistics, 2019; Rubber Production, n.d.; Statistics, n.d.; Pradeep et al., 2020).

State	*Hevea brasiliensis*		*Artocarpus heterophyllus*	
	Crop area (in ha)	National ranking	Crop area (in ha)	National Ranking
Kerala	550840	1	59850	1
Tripura	74335	2	10070	6
Assam	55990	3	22000	2
Karnataka	41366*	4	5200	8
Tamil Nadu	27608	5	2760	10

* Linearly interpolated using 2012-13 and 2018-19 values.

It is evident from Table 1 that states with predominant rubber plantations also cultivate jackfruit as a local crop. Rubber plantations grown as a mono crop negatively impacts the sustainability of other local crops and results in a loss of biodiversity. Multi-species plantations are more productive than mono-species plantations (Erskine et al., 2006). Every part of the jackfruit tree has its benefits. Therefore, if the jackfruit trees can substitute for a notable percentage of the rubber plantation, it will improve the commercial value and utilization of jackfruit and its products. It will accelerate the jackfruit industry's development and offer better financial security to growers through product diversification. It will act as a financial cushion when natural rubber prices fall and also help reduce rubber monoculture, thereby improving productivity and biodiversity.

For such a reallocation to happen, jackfruit must exhibit properties that can substitute natural rubber in some, if not all of its applications. Identifying other potential uses for jackfruit trees adds to its commercial value. The present study reviews the latex characteristics of the jackfruit tree and its ability to substitute or blend with natural rubber in specific applications, compares its timber with rubberwood, and identifies possible areas of concern in introducing the jackfruit tree as a multi crop. An in-depth examination of these concerns present promising avenues for future research.

Comparison of jackfruit latex with natural rubber

The possibility of jackfruit tree latex as an alternative source of natural rubber to *Hevea brasiliensis* latex has been investigated by many researchers (Bhadra et al., 2019; Buranov and Elmuradov, 2010; Mekkriengkrai et al., 2004). Both the tree latex and the fruit gum composition are the same, with a high waxy matter content. It also contains α-artostenone in the form of enol wax esters (Balakrishna and Seshadri, 1947). There is ambiguity in using the term *Artocarpus integrifolia* as a synonym for jackfruit tree or Jack tree. (About the Lectin, n.d.; Khare, 2014) support the usage while (Elevitch and Manner, 2006) oppose it, arguing that it represents a different species, champedak. The present study considers literature that mentions the tree as “jackfruit tree” or “Jack tree.”

The characteristics of latex, such as molecular weight, distribution, adhesion, chemical composition and contact angle, determine its nature and potential applications. The molecular weight and its distribution significantly influence the rubber properties. For example, density, melting point, and viscosity are directly proportional to the molecular weight (Kovuttikulrangsie and Sakdapipanich, 2005). Comparing jackfruit latex with Hevea brasiliensis latex is essential for assessing potential substitutions or blending in natural rubber applications.

Gel Permeation Chromatography (GPC) in serial combination measures the molecular weight of jackfruit latex. It depends on factors such as tree age, clone, soil, climatic conditions, and tree parts used in the latex generation. Molecular weight distribution depends on the tree age and is narrower in jackfruit latex. The molecular weight of the polymer proportionally influences its decomposition temperature. Jackfruit latex has a high surface free energy of 0.0516 N/m. Its resin content varies from 61-70%. Its tensile strength, young’s modulus, and shear strength are 0.08 , 0.01 and 0.08 N/mm^2 respectively (Nepacina et.al, 2020). Jackfruit latex shows very high elongation with the elongation at break being much more than that of Hevea brasiliensis latex. It can also be vulcanized like

Table 2. Comparison of jackfruit latex with natural rubber latex.

Property	Natural rubber latex	Jackfruit latex	Reference
Chemical composition	cis-1,4 polyisoprene	trans-1,4 polyisoprene (65.6%) cis-1,4 polyisoprene (34.4%)	(Bhadra et al., 2019)
Rubber content (%)	35	Fruit 1	(Bhadra et al., 2019; Martín-Martínez, 2002)
	30	Trunk 0.65 Ripe Fruit 0.45	(Mekkriengkrai et al., 2004)
Molecular weight distribution	Bimodal with a high polydispersity index	Unimodal with a narrow polydispersity index	(Bhadra et al., 2019; Mekkriengkrai et al., 2004)
Particle size (μm)	0.01-5	0.5-5.8	(Martín-Martínez, 2002; McMahan & Whalen, n.d.; Mekkriengkrai et al., 2004)
	1.18		(Sakdapipanich et al., 2002)
Number averaged Molecular Weight (M_n)	120000-320000	5254	(Bhadra et al., 2019; Kovuttikulrangsie & Sakdapipanich, 2005)
	Young tree 83000 Mature tree 243000	Trunk 87000 Ripe fruit 118000	(Mekkriengkrai et al., 2004)
Weight averaged Molecular Weight (M_n)	680000-2900000	10915	(Bhadra et al., 2019; Kovuttikulrangsie & Sakdapipanich, 2005; Martín-Martínez, 2002)
	Young tree 300000	Trunk 177000	(Mekkriengkrai et al., 2004)

natural rubber showing promise for applications that require vulcanizable elastomers.

The low molecular weight of jackfruit latex means it cannot replace natural rubber in many applications. However, its chemical composition and properties show promise for adhesive-based applications. The next section will explore its feasibility as a commercial adhesive, independently or in combination with natural rubber.

Bio-adhesives

The global rubber adhesive market in 2018 was estimated to be US$ 56.59 billion and is likely to reach US$71.99 billion at a Compound Annual Growth Rate (CAGR) of 4.93% by 2023 (Rubber Based Adhesives, 2020). Rubber-based adhesives (Elastomeric adhesives) have a wide range of industrial and domestic applications. Reports estimate rubber-based adhesives to represent one-third of adhesives available in the market (Martín-Martínez, 2002). This is due to the extensive growth of the packaging, automobile, and electronics industries. Rubber-based adhesives are categorized into pressure-sensitive, contact, hot-melt, and structural adhesives. It contains an elastomer that acts as the base material. Other constituents like tackifier resin, antioxidants, and other additives might be required based on the application. The capability of jackfruit tree latex as a mucoadhesive and starch-based adhesive and its blend with natural rubber latex as an additive in adhesive applications is explored.

Pressure Sensitive Adhesives (PSA)

Pressure Sensitive Adhesives, commonly known in the market as self adhesives, are pressure-induced non-structural adhesives. It is a viscoelastic material with adequate adhesion and cohesion to form a good bond with the surface without any adhesive film breakage. Ease and safety of use, high utility, no solvent or chemical reaction requirement, and bonding at room temperature are its advantages. It typically consists of an elastomer and a modifying resin (tackifier). Many other constituents are present based on the application. The Pressure Sensitive Tape Council requires the adhesives to have permanent tackiness, insignificant pressure requirement, robust binding force, sufficient cohesion, adhesion, and elasticity for proper bonding. It should also not have any water, solvent, or heat activation requirements.

Sealants

Sealants (Caulkants) have been around for a long time, with data indicating the earliest known use of sealants back to 1500 BC. It is continuously evolving according to the requirements of modern applications. Modern aircraft, ships, automobiles, buildings, and furniture all require sealants. Though indistinguishable from each other, a slight distinction is made between adhesives and sealants based on their application. Adhesives hold the surfaces together, whereas sealants fill or bridge a gap permanently. The bond line of a sealant is much larger compared to that of an adhesive. Sealant formulation is almost entirely based on elastomeric material as the amount of elongation before failure is a vital classification parameter (Pocius, 2012). Sealant elongation, Hardness, Peel, and weathering are some of the parameters that must be satisfied by a standard sealant.

Starch-based adhesive

These are water-soluble adhesives derived from natural sources. Starch is readily available, cheap, and biodegradable. It can be processed into a thermosetting polymer for improved properties like heat resistance. Additives improve application-specific properties. It may use fillers like calcium carbonate and tackifiers like borax. Starch adhesives are suitable for gluing joining paper-based materials like packing boxes, cardboard, stationery items, paper cartons, and bottle labels (Ebnesajjad and Landrock, 2015; Emblem and Hardwidge, 2012).

Jackfruit latex as a bio-adhesive

Commercial adhesives and sealants are generally expensive. Moreover, studies show that many of its constituents have serious environmental concerns.

For example, Isocyanates, perfluoroalkyl, 1-butyl glycidyl ether are toxic and pose a grave threat to humans and the environment (Annex XV Restriction Report, 2019; Polyfluoroalkyl Substances (PFAS) Contamination, n.d.; Glenn et al., 2021; Goldenman et al., n.d.; Rusyn et al., 2019).

Due to the above-stated effects, it is worthwhile to look at bio-adhesives and sealants made from natural rubber latex. Natural rubber-based adhesives are already present in the market. However, adding a natural binder or tackifier improves its binding and elastomeric properties and limits the quantity of rubber required. Jackfruit latex enhances the binding and elastomeric properties of rubber-based adhesives. The reasons in favor of considering jackfruit latex are listed below:

- Jackfruit latex contains 60-70% resin and is used in varnishes. It is incredibly sticky and finds use as an adhesive in birdlime. Heated latex finds application as household cement to mend porcelain and earthen articles and as a caulking agent in boats and buckets (Morton, 1987).
- Adding jackfruit latex to a rubber base creates hydrophobic and other desirable properties of a sealant (Diamante and Carpo, 2019).
- Hydrophobic nature, flow property, compressibility, and low reactivity of jackfruit resin (Jitendra et al., 2014) make it a valuable constituent in adhesives.
- Jackfruit latex significantly increases wet skid resistance and carbon black dispersion in rubber compounds (Bhadra et al., 2019). Carbon black is a reinforcing agent that increases the holding power of the Adhesive (Pocius, 2012).
- Its high elongation to failure is a requirement in sealant applications. It can undergo extreme elongations at a very low-stress value, a desirable property in thermoplastic adhesives.
- Jackfruit latex has a low molecular weight. The number of entanglements per unit volume significantly reduces by adding low molecular weight resin. It increases flow and compliance properties (Poh et al., 2008).
- Jackfruit tree has flavonoid and tannin content. The average flavonoid and tannin content is 5.57 mg/g and 2.14 mg/g. It reduces gel and pressing time and accelerates the curing of resin (P. S. S. Devi et al., 2021; Jahanshaei et al., 2012).
- Jackfruit latex contains CH_3 and OH groups. It is required for chemical interactions between the polymer and the filler material (Bhadra et al., 2019).
- Jackfruit latex has a high work of adhesion and a low contact angle (less than 90 °C) that results in good wetting and spreading of the adhesive on the surface and is an indicator of a good adhesive (Bhushan, 1996; Rudawska, 2012).
- Jackfruit latex has high free surface energy. It results in high stickiness.
- Fourier Transform Infrared (FTIR) Spectroscopy matches the latex to Ethylene-vinyl acetate, a thermoplastic adhesive (Nepacina et.al, 2020).

Mooney viscosity demonstrates that the jackfruit latex polymer has a lower viscosity than natural rubber. Substrate moistening and molecular mobility positively affect stickiness (Selina andLyusova, 2012). Lower viscosity increases substrate moistening and molecular mobility. Viscosity is affected by particle size. As the particle size increases, surface area per unit volume decreases while the average distance between particles increases. It leads to the idea that latex of similar chemical composition but different molecular characteristics can be mixed to attain optimal rubber-based adhesive compositions.

An experimental study assessed the sticking strength of different combinations of natural rubber and jackfruit latex and its application as a rubber-based sealant. The study showed that jackfruit latex improves flexibility and decreases brittleness. Natural rubber and jackfruit latex in the ratio 1:2 has an allowable pressure of 626.98 kPa against 524.33 kPa of commercial sealant (Diamante and Carpo, 2019).

A study evaluated the strength of jackfruit tree sap

Table 3. Potential utilization of Natural rubber and Jackfruit tree.

Tree part	Rubber Tree	Jackfruit tree	Reference
Leaves	• No significant application.	• Fodder for cattle. • Tender leaves are cooked as vegetables. • Medicine against syphilis and helminths.	
Fruit	• No significant application.	• The unripe fruit is an excellent substitute for meat. • Value-added products like chips, juice, ice cream, jam, dehydrated Jackfruit, other snacks.	(Ranasinghe et al., 2019)
Seed	• Rubber seed oil is used in the soap, paint industry. • Potential biofuel. • Rubber seed cake is used as fodder for cattle.	• Medicine because of its antiaging, antihypertensive, anti-inflammatory, antimicrobial, anti-diabetic, anti-helminthic antioxidant, anticancer, and antiulcer properties. • It forms an integral part of the diet in roasted or boiled form. • Healthy alternative to wheat flour. • Raw material in bioplastics.	(V. M. Devi et al., 2012; Lubis et al., 2016; Mandave et al., 2018, 2018; Waghmare et al., 2019)
Wood	• It is traditionally used as firewood and in single-use packing crates. • It is not naturally durable. However, chemical treatment can be used to make furniture and in other commercial timber applications.	• Furniture and other timber applications.	
Root	• No significant application.	• Medicine to treat skin ailments, diarrhea, and asthma.	(Swami et al., 2012)

adhesive and natural rubber sap adhesive. The bio-adhesives were individually applied on Balsa wood specimen, and its strength under tensile and bending conditions was observed. jackfruit bio-adhesive showed tensile and bending strength of 19.93 MPa and 23.45 MPa, while the tensile and bending strength of rubber-based bio-adhesive was 28.129 MPa and 23.58 MPa. Thus, the strength of jackfruit-based bio-adhesive is comparable with the strength values of rubber-based bio-adhesive. Therefore, the study validates their potential as an alternative bio-adhesive (Ma'arif et al., 2019).

Jackfruit seed is also used as a starch-based adhesive with suitable property modifiers (Shetty et al., 2016). In addition, the potential of jackfruit latex as a binder in mucoadhesive drugs is widely researched (B et al., 2010; Gohain & Sahu, 2016; Rani & Madhavi, 2017; Sabale et al., 2012). Jackfruit latex gum was successfully used as an eco-friendly binder in cotton pigment printing (Kabir et al., 2018).

Timber benefits of the jackfruit tree

The inclusion of the jackfruit tree as a multi-crop with *Hevea brasiliensis* results in multiple benefits. It improves the local biodiversity, acts as a shade and wind barrier for the rubber trees, checks the depleting groundwater levels by retaining rainwater, positively affects the microclimate, and reduces global warming. Every part of the tree is valuable and offers significant income to the grower if adequately utilized (Baliga et al., 2011; Jagtap & Bapat, 2010; Nair et al., 2017; Ranasinghe et al., 2019).

It is observed from Table 3 that every part of the jackfruit tree has some significant application. The rubber tree is probably the only commercially exploited source of natural rubber and is grown for its latex. Rubberwood is not naturally durable. However, effective chemical treatment can make it suitable for most timber applications. Rubber seed oil is another unique product that finds application

Table 4. Comparison with jackfruit timber with rubberwood timber

Property	Jackfruit timber.		Rubberwood timber	
Visual appeal	It is ordinarily yellow/orange and changes with age to brown or dark red.		It has a characteristic light creamy color that can be dyed to imitate the color of any commercial timber.	
Treatment	No significant chemical treatment is required. It is naturally termite, fungal, and bacterial resistant and seasons without difficulty.		It must be chemically treated and seasoned for use as timber. Untreated rubberwood is not termite, borer, and pest resistant. It undergoes structural distortion on seasoning.	
Bending modulus of rupture (kg/m^2)	614.5		853.9	
Bending modulus of elasticity (kg/m^2)	59433.7		57463	
Compressive strength at limit of proportionality parallel to grain (kg/m^2)	278.9		270.3	
Compressive strength at maximum load parallel to grain (kg/m^2)	405		382.6	
Compressive modulus of elasticity (kg/m^2)	34664.8		47566.8	
Compressive strength at 2.5mm deflection perpendicular to the grain (kg/m^2)	161.7		157.4	
Radial hardness (kg)	342.3		384.2	
Tangential hardness (kg)	388.7		374.8	
Mean End hardness (kg)	558.9		554.1	
Maximum load to failure from shear strength test (kg)	2788.9		2770.7	
Tensile stress at limit of proportionality(kg/m^2)	393		435.3	
Tensile stress at maximum load (kg/m^2)	522		741.2	
Maximum shear stress (kg/m^2)	111.6		110.8	
Stress wave velocity (m/s)	2934		3573	
Heat of combustion (kJ/g dry weight)	Bark	15.25	Bark	16.17
	Sapwood	18.07	Sapwood	16.45
	Heartwood	18.64	Heartwood	16.16
	Mean	17.32	Mean	16.26
Ash content (%)	Bark	7.51	Bark	10.15
	Sapwood	1.14	Sapwood	1.87
	Heartwood	0.82	Heartwood	1.89
	Mean	3.16	Mean	4.62
Specific gravity	Bark	0.415	Bark	0.375
	Sapwood	0.534	Sapwood	0.493
	Heartwood	0.588	Heartwood	0.515
	Mean	0.513	Mean	0.461
Moisture content (%)	Bark	39.1	Bark	53.5
	Sapwood	48.3	Sapwood	50.0
	Heartwood	45.3	Heartwood	48.1
	Mean	44.2	Mean	50.5
Applications	• Make furniture, musical instruments, masts, oars, brush backs, musical instruments and carvings.		Untreated	Firewood, packing crates, and match sticks.
	.• The sawdust and wood chips are boiled to derive a rich yellow dye used for dyeing robes.		Chemically treated & seasoned.	Commercial and structural timber applications. Raw material for furniture, panels, doors.
Price	Rs 1500-2000/cft		Untreated	Rs 3500/tonne
			Chemically Treated & Seasoned.	Rs 600-900/cft

in the paint and biofuel industry. In the Indian scenario, rubberwood and rubber seed oil are grossly underutilized with inadequate value addition. Untreated rubberwood is used as firewood and to make cheap packing crates. The chemically treated and seasoned rubberwood can be used to make furniture and in other timber applications. However, the inferior quality associated with rubberwood results in low interest and subsequent underutilization in higher value-added applications (Justus and Justus, 2023). Also, the chemical treatment plants required for rubberwood and the treated rubberwood have environmental and health concerns (Dhamodaran, n.d.; Murthy et al., 2019; Onthong et al., 2011; Teoh et al., 2011). Jackfruit timber is reviewed in Table 4 (Elevitchand Manner, 2006; Ponnath et al., 2014; Shanavas and Kumar, 2003) to understand its structural properties, economic and environmental aspects.

Jackfruit timber is a medium hardwood considered appropriate for furniture and cabinet making, music instruments, turnery, implements, oars, masts, carvings, and picture frames. High durability, termite and decay resistance, resemblance to mahogany, and high surface polish achievability are reasons for its high value. It is delicate and evenly grained, resulting in achieving a high surface finish. It is dense and has good workability making it easy to create intricate carvings and designs on it. It seasons quickly and shows an admirable response to polishing. The golden yellow timber is a visual delight. This medium hardwood is naturally termite, fungi, and bacterial attack resistant, eliminating significant chemical treatment. The jackfruit tree is valued as a conventional timber in India. Jackfruit trees as a multi-crop can increase timber availability which can bridge the increasing timber deficit in the country.

Root system and multi-crop spacing

The potential of jackfruit tree's latex as a bioadhesive and its high-quality timber make it essential to explore its productivity in rubber plantations as a multi-crop. The productivity is influenced by tree spacing, canopy cover and the root interaction between rubber and jackfruit trees. Based on the intercrop selected, rubber-based intercropping can be broadly categorized as initial intercrop, cover crops, and permanent intercrop (Zaw, 2023). Banana, pineapple, and sugarcane are some initial intercrops grown during the gestation period of the rubber tree. They require sunlight and are suitable in the initial years when the canopy cover is not closed and sunlight penetration is significant. Cover crops are usually leguminous cropsthat provide land cover.Ginger, turmeric, tea, cocoa, mahogany, teak are some permanent intercropsgrown for herbs, fruits, and/or timber for the entire lifecycle of rubber trees. Rubber plantations achieve significant canopy closure in 4-5 years (Ibrahim, 1991) and have full canopy development in nine years (Rodrigo et al., 2005). Rubber plantations have a 25-year rotation cycle. Jackfruit trees can be a permanent intercrop as it has a canopy closure duration similar to rubber trees and requires time to bear fruit and develop timber. The intensity of the intercrop root competition with that of the rubber tree determines the intercrop type and spacing (single or double row). The root system of a rubber tree consists of a main tap root with several lateral roots and fine rootlets. The taproot can go beyond 2.5 m in depth. The lateral roots are majorly concentrated within a soil depth of 0.3 m and can go up to 0.8 m with a horizontal spread over 9 m during its lifecycle (Carr, 2012; Samarappulli, 1996). This means that the roots commonly grow through the adjacent planting rows of rubber. Ramification occurs when the roots from the adjacent rows meet and root density evens out horizontally. Another study (Srinivasan et.al., 2004) suggests that 70% of the rubber tree roots lie in the zone of 3 m lateral spread and 30 cm soil depth indicating the zone of root competition. If the majority of the multicrop's roots also are at the same soil depth, interspacing may be increased (double row) and the intercrop should be planted at the same time as rubber. Otherwise, if the root activity is concentrated at a different depth, the spacing may be adjusted accordingly. The jackfruit tree also has a long taproot system (Love and Paull, 2011).

However, the authors failed to find any comprehensive study of its root distribution system. Only one case study in Thailand was available on the economic profitability of rubber agroforestry with jackfruit trees for its fruit (Somboonsuke et al., 2011). Though the paper provides limited details, it indicates the feasibility of jackfruit tree as a multicrop. Detailed studies on the root system of the jackfruit tree, economic feasibility and crop management of jackfruit with rubber are unexplored areas for future research. Additionally, exploring optimal intercropping methods such as boundary, relay, block or strip intercropping is another area for potential research.

Results and Discussion

The present study highlights the following criteria in favor of the jackfruit tree as an intercrop in rubber plantations, crop area, conduciveness of climatic and geographic conditions for growing, market and infrastructure facilities, financial stability insurance. India's national ranking based on crop area shows its considerable presence in the predominant rubber-producing states. It indicates the conduciveness of climatic and geographic conditions for growing jackfruit in such states. The market for jackfruit is already present. Therefore, integrating the jackfruit tree as a multi-crop does not require creating a new market. It only involves the improvement of the existing market and infrastructure facilities for value addition. Presently, jackfruit is predominantly grown as a scattered homestead crop in the country. The integration of jackfruit trees in rubber plantations will improve the orderliness of jackfruit cultivation. It will result in easy collection and processing of jackfruit, leading to accelerated development of the jackfruit industry. jackfruit has enormous potential for value addition and is healthy food. It will also provide financial security to the rubber growers who are otherwise at the mercy of fluctuating global rubber prices.

Comparison of *Artocarpus heterophyllus* and *Hevea brasilensis* latex bore important observations. The low molecular weight, polydispersity and mechanical properties like tensile and shear strengths make it an inadequate substitute for natural rubber in many applications. However, specific properties like high work of adhesion, high surface energy, low contact angle and its hydrophilic nature provide jackfruit latex with desired properties like high stickiness, flexibility and good contact area of bonding. These make it a good candidate for adhesives. Several studies support jackfruit latex as a bio-adhesive. In addition to being eco-friendly, it is also cheaper than commercial adhesives.

Also, natural rubber has a broad particle distribution, and the predominant particle size is small. It reinforces the idea that particles of different sizes and similar chemical compositions may be combined to obtain better adhesive. So, there is the possibility of blending jackfruit latex with rubber latex to improve certain properties of existing natural rubber-based adhesives.

Superiority of jackfruit tree over rubberwood in most properties. It is naturally durable, has medicinal properties, and unlike rubber trees, does not require any significant chemical treatment. It will be a viable alternative to conventional timber as it is already respected as timber in India and is not considered inferior like rubber-wood even after chemical treatment.

Latex extraction from *Hevea brasilensis* is from the bark of the tree. However, the same extraction methodology might be insufficient for the jackfruit tree as the latex in the jackfruit tree is found in every part of the tree in varying proportions. For example, latex content from fruit is higher than from the bark. Therefore, studies on an efficient extraction methodology integrated with jackfruit processing for value addition might be more suitable for jackfruit.

Future studies can also help identify the share of rubber plantation areas that can be substituted with jackfruit trees. It is based on the use of jackfruit tree latex as an alternative to natural rubber adhesives. The properties of jackfruit latex in adhesive applications can be further improved by adding suitable additives. Optimal blending ratios of jackfruit and rubber latex in adhesive applications must also be studied in greater detail.

Conclusion

The increasing demand for natural rubber and rubberwood has led to rubber monocropping. The present study seeks to mitigate the negative impacts of this practice by reviewing existing literature to understand the feasibility of introducing another native tree species as a multi-crop in rubber plantations. The jackfruit tree is considered as it is a local crop in all the major rubber-producing states of the country. While it was found that jackfruit tree latex cannot replace *Hevea brasiliensis* latex in most commercial applications, it shows promise in adhesive-based applications.

The present study explores the potential of jackfruit latex in bio-adhesive applications. It will help convert a particular share of rubber plantations to grow jackfruit trees. The multiple benefits and concerns of integrating jackfruit as a multi-crop are also discussed.

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