

REVIEW PAPER

Extraction of Natural Colourant from Different Fruit Wastes: A Review

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ABSTRACT

The increasing environmental concerns of synthetic dyes and the accumulation of agro-industrial waste have generated interest in sustainable and eco-friendly alternatives, such as natural colorants made from fruit waste. This paper mainly focuses on the extraction of natural colours and pigments from different fruit byproducts such as peels, pomace, seeds, husks, nutshells, and fruit pulp from various fruit crops. Different methods of extraction are discussed. The review highlights the presence of valuable bioactive pigments with improved coloring capacity and potential applications. The use of fruit waste to produce natural dyes contributes to promoting waste valorisation, environmental preservation, and circular economy principles by reducing pollution and producing goods with added value. Although challenges related to stability, standardization, scalability, and commercialization still exist, ongoing research and technological advancements indicate strong future potential for fruit waste-derived natural colorants as sustainable substitutes for synthetic dyes.

Keywords: Fruit Waste, Natural colourant, Ultrasound-assisted extraction, Microwave assisted extraction, Super critical fluid extraction, Enzyme assisted extraction, Solvent extraction, Aqueous extraction

According to the Third Advanced Estimates of Horticulture Crops 2023-24, India's fruit crop covers 71.58 million hectares, with a productivity of 15.75 MT/ha and a production of around 112.73 million tonnes (Dept. of AFW, 2024-25). According to the latest advance estimates for the year 2024-2025, 8.97 lakh hectares in Maharashtra were planted with different fruit crops, and 168.40 million tonnes of fruit were produced throughout (HAPIS, 2025-26).

Baysal and Ülkü, (2022) stated that, based on estimates, approximately one-third of the food generated each year is either discarded or lost. Unlike other food processing sectors, the fruit and vegetable industries generate larger amounts of waste, comprising 25-30% peels, along with seeds, skins, shells, pods, cores, pulp, pomace, and more (Rifna *et al.* 2021).

Fruit waste (byproducts) produced by agro-industries is typically used as residual biomass rich in a range of bioactive functional components. Fruit wastes are naturally rich in phytochemicals, and many aspects of them, including their fibre, phenolic compounds, and other beneficial components, have been thoroughly investigated. The main components of fruit byproducts are peels, seeds, and pomace, which are important sources of bioactive substances with noteworthy functional and nutritional qualities. These consist of a variety of secondary metabolites, proteins, carbohydrates, and polysaccharides (Nirmal *et al.* 2023).

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The valuation of agricultural waste results in cost-effective ways to extract bioactive natural components from food waste and supports waste reduction and circular economic practices (Delgado-Vargas *et al.* 2000).

Fruit processing produces large amounts of peel waste that are frequently thrown away without being used, adding to environmental strain. These peels hold considerable levels of natural pigments such as tannins, flavonoids, anthocyanins, and polyphenols. These substances have chromophoric characteristics and can attach to textile fibres via hydrogen bonding and metal coordination when mordants are present (Bechtold and Mussak, 2009). Transforming fruit peel waste into natural dyes signifies a sustainable method that merges waste management with environmentally friendly textile manufacturing (Vankar, 2000).

Dyeing refers to the method of imparting a relatively lasting colour to a fibre, yarn, thread, or fabric through submersion in a dye solution (Castle, 2007). Colour is the visual reaction to the wavelengths of sunlight identified as red, blue, green, etc.; possessing the physical characteristics of hue, intensity, and value (Bone *et al.* 2002).

At present, there is a considerable worldwide demand for natural colours due to the non-biodegradable and carcinogenic characteristics associated with synthetic dyes (Chungkrang and Bhuyan, 2020). Most dyes are organic substances (i.e., they contain carbon). The textile sector has historically been a significant source of environmental pollution because of the heavy reliance on synthetic dyes and chemical mordants. The wastewater produced by the dyeing industry with excessive water would contaminate the environment. The synthetic dyes generate toxic waste, comprising dangerous effluents that present significant environmental threats, such as water pollution, which introduces harmful chemicals and heavy metals into aquatic ecosystems, impacting both human health and soil quality (Mussak and Bechtold, 2009).

Natural dyes hold significant importance as they

offer numerous advantages over synthetic dyes. Clearly, natural dyes are healthier options since they do not contain harmful chemicals that can negatively affect health (Baliarsingh *et al.* 2013). These dyes are derived from natural sources and can be easily broken down in the environment after their use; thus, they do not contribute to pollution when disposed of (Alam *et al.* 2020). Primarily, natural dyes are utilized for colouring textiles, food, pharmaceuticals, and cosmetic products. Additionally, small amounts of these dyes are employed for colouring various items such as paper, leather, shoe polish, wood, cane, candles, and other products that require colour (Gulrajani, 2001).

For hundreds of years, natural dyes have been utilized to tint materials, like fabrics. Nevertheless, early in the twentieth century, the emergence of synthetic dyes led to a significant reduction in the use of these dyes (Bhuiyan *et al.* 2017). Concerns regarding environmental risks, human health, and sustainability connected to their production, processing, and application have renewed worldwide interest in natural dyes, which could be healthier, more sustainable, and eco-friendlier (Mahdi *et al.* 2020).

The application of these natural dyes on synthetic colour substrates like textiles is restricted, primarily due to their limited availability, elevated processing expenses, inadequate dye adsorption, consistency in shade reproduction, and unsatisfactory fastness properties (Haddar *et al.* 2014).

Extraction Method of natural dye/ colour

1. Ultrasound-assisted extraction (UAE)

The ultrasonic extraction method employs high-frequency sound vibrations to obtain chemicals from various substances, such as plant elements. This method is non-invasive and effective for extracting specific molecules, eliminating the need for aggressive solvents or elevated temperatures. The substance to be extracted is positioned in a container alongside an appropriate extraction solvent (Amir-Al Zumahi *et al.* 2020). The Ultrasound-assisted

Table 1: Extraction method uses to extract natural colorant

Fruit Crop	Part of fruit used	Extraction method	Reference
Mango	Peel	Hot aqueous extraction method	Miraj <i>et al.</i> 2024
	Peel and leaves	Aqueous extraction	Ayele <i>et al.</i> 2020
	Seed Extract	Hot aqueous extraction	Sobandi <i>et al.</i> 2023
Cashew nut	Husk	Microwave assisted	Patil <i>et al.</i> 2015
		Enzyme assisted	
		Aqueous extraction method	
	Cashew apple extract	Solvent extraction method	Abreu <i>et al.</i> 2013
Kokum	Peel	Soxhlet extraction	Prasetyo <i>et al.</i> 2026
Jamun	Pulp	Aqueous extraction	Maran <i>et al.</i> 2014
Coconut	Husk	Solvent extraction method	Braide <i>et al.</i> 2025
Karonda	Pulp	Solvent extraction method	Harshitha <i>et al.</i> 2024
	Cut pieces	Boiling in water	Aliño, 2014
Arecanut	Areca nut powder waste	Ethanol extraction	Wijayarathna <i>et al.</i> 2023
	Areca nut extract	Aqueous extraction	Le and Nguyen, 2021
Pomegranate	Peel	Solvent extraction	Kulkarni <i>et al.</i> 2011
Passion Fruit	Pericarp	Either water, ethanol, or ethanol + ultrasonication	Kawasoe <i>et al.</i> 2021
Mandarin Orange	Peel	Water solvent extraction	Kusumawati <i>et al.</i> 2020
Sweet orange	Peel	Aqueous extraction	Romdhani <i>et al.</i> 2022
Lime	Peel	Ethanol cold extraction method	Kumar and Dhinakaran, 2017
Pineapple	Peel	Alkaline-water extraction	Pramod <i>et al.</i> 2025
Grape	Pomace	Solid-liquid extraction process	Fonseca <i>et al.</i> 2024
Avocado	Seed	Ultrasonic assisted extraction	Arlene <i>et al.</i> 2015
Walnut	Shell	Soxhlet extraction using ethanol as a solvent	Mirjalili <i>et al.</i> 2011
Dragon Fruit	Peel	Maceration method	Dewi <i>et al.</i> 2020

extraction method has been used for the extraction of colour from different fruits, as shown in the Table 1.

The ultrasonic treatment performed at reduced temperatures improves the temperature sensitivity of the extract's bioactive elements, resulting in a high dye extraction yield. Owing to mass transfer kinetics, ultrasonic treatment additionally enhances the separation of functional components (Tissera *et al.* 2016).

The elevated frequency of ultrasound (20–100 kHz) can aid in intensifying and enhancing extraction processes. During ultrasound exposure of liquids, micro-bubbles expand, oscillate rapidly, and can burst forcefully under elevated pressures. These thrilling micro-bubbles have the ability to harm the

solid surface and create micro-channels and pores (Feng *et al.* 2011). Additionally, heat and mass transfer in the liquid phase around the particles and through the channels are enhanced by breaking down the cell walls (Sivakumar *et al.* 2009; Mason *et al.* 1996).

Asma *et al.* (2015) utilized the ultrasound-assisted extraction (UAE) method for dye extraction. The extraction was performed using a sonicator. The sample was ground and combined with ethanol, and then the samples were subjected to sonication in a sonicator bath. Following ultrasound extraction, the samples were filtered with filter paper. The solvent was removed by evaporation with a rotary evaporator at ambient temperature. Subsequently, the samples were centrifuged. The supernatant was kept at 4°C in the dark before analysis.

2. Microwave assisted extraction (MAE)

Microwave-assisted extraction (MAE) utilizes electromagnetic waves to modify biomass composition, enhancing efficiency relative to traditional techniques. MAE directly heats the solid matrix, generating vapor pressure that breaks cell walls and liberates pigments. Microwave power and temperature are intricately connected, as the extraction matrix increases in temperature upon absorbing microwave energy. This boosts the solvent's capacity to dissolve solute compounds, improving solvent infiltration and matrix wetting, resulting in greater pigment yields. Nonetheless, although raising microwave power typically enhances extraction yield, there comes a moment when additional increases yield diminishing returns or may even lower efficiency because of the thermal degradation of compounds. MAE has been shown to be the most efficient technique for extracting anthocyanins, producing markedly higher Total Anthocyanin Content (TAC) and total phenolic content relative to conventional hot-water extraction (Jhanji *et al.* 2024). Different fruits have been utilized for colour extraction using the microwave assisted extraction method, as presented in the Table 1.

3. Super critical fluid extraction

The supercritical state of a pure organic compound occurs when it is subjected to pressure and temperature conditions that exceed its critical point values. When above these values, the fluid is classified as supercritical and exhibits characteristics resembling both a gas and a liquid, which are advantageous for extracting molecules from plants (Kabir *et al.* 2019). The Table 1 shows various fruits used for colour extraction through super critical fluid extraction.

Supercritical fluid extraction utilizes the high solubility of desired dyes in supercritical fluids like carbon dioxide (CO₂), propane, butane, or ethylene. The colorant engages with the supercritical fluid inside an extraction chamber under elevated pressure. Carbon dioxide is the most commonly

utilized supercritical fluid because of its low critical temperature, non-flammable nature, low toxicity, and cost-efficient accessibility in its pure state. Usually, CO₂ is used within a temperature range of 40°C to 80°C and a pressure range of 35- 75 MPa. One of the main benefits of this method is that slight fluctuations in temperature and pressure lead to considerable alterations in the density and solvating capacity of the supercritical fluid, which facilitate effective extraction (Vankaretal, 2001).

Dhouibi *et al.* (2020) employed a supercritical extraction technique to obtain natural dye employing supercritical carbon dioxide (99.9% CO₂) in a pilot-plant-scale supercritical fluid extractor. The extraction unit includes two cylindrical extractors and two separators, all featuring separate controls for pressure and temperature. The SCFE system features a recirculation pump for CO₂ condensation and was filled with dried powder of the sample. The extraction was conducted under particular supercritical extraction conditions tailored to each type of plant material. The supercritical extracts were collected in amber vials, weighed, and stored in refrigeration at +4 °C for future use.

4. Enzyme assisted extraction

Extraction aided by enzymes presents a viable substitute for conventional solvent-based techniques for obtaining bioactive compounds from plant sources. A primary benefit of this technique is its capacity to improve solvent pre-treatment, either by minimizing solvent consumption or boosting the yield of extractable substances. Enzymes such as cellulases, pectinases, and hemicellulases play a crucial role in degrading plant cell walls, enhancing the extraction of bioactive substances. These enzymes break down cell wall components, increasing the permeability of the walls and resulting in greater yields of bioactive compounds. Optimizing enzyme-assisted extraction requires a deep understanding of the catalytic properties of enzymes, their mechanisms of action, the optimal conditions, and the most suitable enzymes or enzyme combinations for the specific plant material (Puri *et al.* 2012). Colour

extraction from different fruits using enzyme assisted extraction is summarized in the Table 1 below.

5. Solvent extraction method

This technique requires minimal equipment investment, facilitating easier purification, solvent elimination, and reuse compared to the aqueous method. Alcohol-based solvent extraction usually demonstrates greater efficiency than aqueous extraction. Due to the characteristics of colorants, water-soluble pigments are typically extracted with water or ethanol, which are hydrophilic organic solvents, whereas fat-soluble pigments are extracted using solvents like hexane. To achieve efficient extraction, the solvent needs to possess high solubility for the target solute along with any other existing substances (Salaududin *et al.* 2021). The main factors that affect extraction are the level of grinding, temperature, extraction duration, equipment type, and solvent selection. The Soxhlet apparatus can efficiently carry out solvent extraction. The procedure involves tightly sealing finely milled plant matter within a permeable pouch crafted from sturdy filter paper or pristine linen. The solvent is added to the bottom flask, and a thimble filled with plant material is positioned in the extraction chamber. When the solvent is heated, it evaporates and moves through the condenser, where it condenses and interacts with the plant material, extracting the needed compounds. When the solvent in the extraction chamber reaches the top of the siphon, it returns to the flask, carrying the extracted compounds with it. The process persists until the extraction is finished (Bhalekar *et al.* 2022). The solvent extraction method has been used for the extraction of colour from different fruits, as shown in the Table 1.

6. Aqueous extraction method

The aqueous extraction technique is traditional, straightforward, and appropriate for extracting plant elements that can be steam-distilled without altering their molecular structure. To enhance the extraction efficiency, the coloured substances are chopped into smaller fragments, then ground into a powder and

kept overnight in a steel container or longer to break down the cell structure (Merdan *et al.* 2017; Selvam *et al.* 2015). These compounds are either incompatible with water or only slightly soluble and exhibit a specific vapor pressure at 100 °C boiling point. The substance can be transported with steam when the water is boiling. Following condensation, it is separated using an oil-water separator to remove the water and acquire the necessary plant components. The process of boiling and separating can be reiterated based on the results of the extraction. A trickling filter can readily separate the dye and small plant remnants. The colour yield of temperature-sensitive dyes can be influenced by boiling; therefore, it is advisable to use low temperatures. Dyes produced through this method can serve textile purposes (Samanta and Agarwal, 2009). The Table 1 shows various fruits used for colour extraction through aqueous extraction method.

Extraction of Natural Colourant from Different Fruit Waste

1. Cashew Nut

Anacardium occidentale, popularly referred to as the cashew tree, is a tropical evergreen plant that is part of the Anacardiaceae family. Originally from South America, it is now widely grown in numerous tropical areas for its valuable nut and cashew apple (Hirpara *et al.* 2025). Fig. 1 shows the cashew fruit and its various parts. As per CMIE, (2024) for the year 2023-24, India's cashew nut production area spans 1,199.10 thousand hectares, yielding 794.90 thousand million tonnes, with a productivity rate of 674 kg/ha. Fig. 1 shows the parts of cashew fruit and Fig. 1(a) shows the cashew fruit which is commonly used for consumption and processing.

Cashew is primarily recognized for its nuts. The tiny nut, shaped like a kidney and connected to it, is commonly utilized, while the cashew nut shell and cashew apple are deemed waste. The overall waste from cashew nut shell is approximately 60% per kg of cashew nut, while the waste from cashew apple is 40% (Akinwale, 2000). Fig. 1(b) illustrates the cashew



Fig. 1: Parts of Cashew fruit (a) Cashew nut with apple (b) Cashew Apple (c) Cashew Shell

apple, which is generally considered a waste by-product.

The waste from cashew is nutshells which is promising due to its abundance, the presence of intriguing dye molecules like quinones, and its ease of handling attributed to a low moisture content (Dulo *et al.* 2022). Fig. 1(c) shows the cashew nutshell, the waste material generated during cashew processing. Table 1 shows the part of the mango fruit used, colour range, pigment, colour yield and processing conditions.

Dulo *et al.* (2022) Assess the possibilities of using natural dyes derived from cashew nutshell waste. The dye compound was obtained through a reflux extraction technique utilizing a 50 v/v% ethanol/water solution at 90 °C for 60 minutes. The results show that all the extracts had polyphenolic compounds, including tanning and potentially a minor quantity of quinone compounds, which can provide colour to a wool substrate. All extracts were determined to colour wool most effectively under acidic conditions (pH 3 for cashew nutshell), resulting in yellowish hues with satisfactory K/S (colour strength) (0.6–14.9), washing (4–5), and light fastness (3–8) characteristics, even in the absence of mordants. Consequently, this indicates that the obtained dye is suitable for colouring textiles, with or without metal mordant, while still providing

fastness characteristics applicable in industrial settings. In the absence of the metal mordant, the dyes from nutshells exhibited satisfactory results, likely due to the existence of natural mordants like tanning found in the nutshell structure. Furthermore, the LCA determined that employing these bio-dyes results in a reduced environmental impact (for example, regarding climate change, human toxicity, and water depletion, it is approximately 60% lower) in comparison to synthetic dyes, suggesting that the extracted dye is less detrimental to the environment.

De Abreu *et al.* (2013) study a method for acquiring a cashew apple extract (referred to as CAE) utilizing cashew apple fibres as the primary material and water as the solvent. The water could extract the carotenoids (which exhibit lipophilic properties) since these elements, in this particular product/process, exist in an emulsified form. The end product features a vibrant yellow hue, indicating its possible application as a food dye. The refined procedure includes enzymatic processing of the cashew apple fibres, then sequential pressing and crossflow microfiltration. CAE has a bright yellow hue due to its high carotenoid content, with auroxanthin and b-cryptoxanthin making up approximately 50% of the total carotenoids.

2. Mango

Mango (*Mangifera indica*), referred to as the supreme fruit, possesses a delightful flavour and aroma along with significant nutritional benefits. Mango holds significant commercial value in India, which produces about 55% of the worldwide crop. The fruit comprises three primary components: pulp, skin, and seed. Fig.2 shows the mango fruit and its various parts. The mango fruit shown in Fig. 2(a) is commonly used for processing and consumption. Fig. 2(b) and Fig.2(c) shows mango peel and mango seed, which is commonly discarded as waste during processing. The pulp is the most-eaten portion, whereas the peel and kernel are often thrown away (Lebaka *et al.* 2021). Mango holds significant economic value as the third-largest agricultural product in India. In India, mango farming spans approximately 2.26 million acres, accounting for 40% of the overall area dedicated to fruit production in the country (APEDA, 2020). India ranks as the top producer of mangoes globally, generating 20,772 thousand metric tons in 2021-22, accounting for over 40 percent of total mango production (Indiastat, 2023). The Konkan region of Maharashtra has around 100,000 hectares dedicated to mango farming, yielding 50 thousand metric tons with a productivity of 3.12 tonnes per hectare (Ganeshamurthy *et al.* 2019). Table 2 and 3 shows the part of the mango fruit used for colour extraction, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

According to Pradeep *et al.* (2014) the proportions of various elements collected during mango pulp extraction are mango pulp (45 – 65%), peel (15 – 20%), pulpier waste (15 – 20%), and stone (10 - 20%), which vary based on the variety. The handling of mangoes results in significant waste, primarily consisting of peels and seeds, which account for 35-60% of the fruit's weight, depending on the variety and techniques employed (García-Mahecha *et al.* 2023).

Carotenoids, polyphenols, and other bioactive substances are among the beneficial phytochemicals found in mango peels that have been shown to improve human health (Beerh *et al.* 1976; Larrauri, 1999).

Miraj *et al.* (2024), investigated mango peel with the aim of extracting natural dyes from it and applying these dyes to three types of fabrics (cotton, chief value cotton, and viscose) to determine which fabric is most appropriate. Tannin obtained from tea leaves served as a natural mordanting agent. The dye and mordant were obtained through a hot water extraction technique. Findings indicate that mango peel dye can serve as an efficient and eco-friendly substitute for synthetic dyes, demonstrating significant potential for use in textile processing. Additionally, the tannin obtained from tea leaves improved the dye's binding to all three fabric varieties, demonstrating excellent colour fastness and longevity.

3. Coconut

The coconut palm (*Cocos nucifera*) is often called

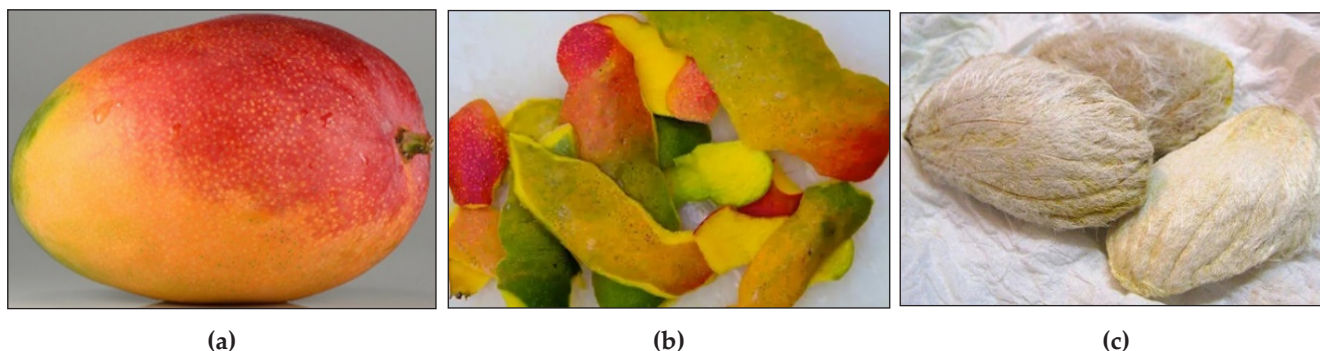


Fig. 2: Mango fruit and its various parts (a) Mango (b) Mango Peel (c) Mango Seed

the “wish-fulfilling tree of heaven” or “ tree of life ” because of its significant contribution to the global agricultural scene, enhancing the livelihood, social, nutritional, health, and wellness security of millions worldwide. This sector is said to supply nutrition to around 60 million households and offer jobs to roughly 30 million farmers (Zainol *et al.* 2023).

Indonesia, Philippines, India, Brazil, Sri Lanka, Thailand, Vietnam, Malaysia, Papua New Guinea, and Tanzania are the leading ten coconut-producing nations, together making up 91% of worldwide output (FAOSTAT, 2022). The global coconut market is anticipated to hit \$30 billion by 2026, spurred by a compound annual growth rate (CAGR) of 13.6%, indicating an estimated revenue rise of \$19.7 billion from 2018 to 2026 (Prithviraj *et al.* 2024). Table 2 and Table 3 shows the part of the coconut fruit used for colour extraction, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications. The monospermic drupe fruit of the coconut palm tree is made up of 25% water, 12% endocarp (copra), 35% mesocarp (fibre), 28% endosperm (meat), and exocarp (coconut skin) (Sánchez and Maya, 2013; Lu *et al.* 2020). Fig. 3 shows the coconut fruit and their parts. The coconut fruit shown in Fig. 3(a) is commonly used for processing and consumption and Fig. 3(b) illustrates the coconut husk utilized for colour extraction.

The yearly demand for coconut is rising, leading to a buildup of coconut waste such as husks. Coconut husk consists of 30% fibre and 70% pith. It is also rich in cellulose (41%), lignin (40%), and phenolic compounds (Israel *et al.* 2011). The coconut husk is made up of the exocarp, mesocarp, and endocarp, which account for approximately 30-35% of the entire coconut (Tan *et al.* 2008). It is estimated that 5,280 kilograms of dry coconut husk are generated per hectare annually (Rodiah *et al.* 2018).

There is an urgent necessity to discover a method to handle the coconut waste. One method involves enhancing the waste by using the coconut husk as a colouring agent for dyeing cotton fabric. Coconut husk waste is inexpensive, harmless, effective, and easily obtainable. Consequently, utilizing coconut waste as a natural dye can lower waste management expenses and aid in minimizing environmental pollution (Braide *et al.* 2025).

Braide *et al.* (2025) obtained dye from coconut husk utilizing a Soxhlet extractor, employing solvents like acetone, ethanol, and methanol. The ethanol fraction of “dye sourced from coconut husk exhibited the highest dye pigment yield of 40.3%, 24.3%, and 12.2%, demonstrating that the dye from coconut husk possesses a strong affinity for binding with cotton fabric, resulting in an attractive colour.



(a)



(b)

Fig. 3: Coconut and their part (a) Coconut (b) Coconut Husk

Table 2: Fruit Crops Used as Sources of Natural Dyes and Pigments

Sl. No.	Fruit Crop	Part of fruit used	Colour/Dye	Pigment	Colour Yield	Processing Conditions	Reference
1	Mango	Leaves and peel	Orange-brown to light yellowish green shades and orange-red to darker scarlet shades.	Flavonoids	—	100 °C for 40–60 min using distilled water	Ayele <i>et al.</i> 2020
2	Kokum	Rind	Red, Purple, Blue, Yellow	Anthocyanin, Tanin	—	Aqueous extraction at 100°C	Kusumawati <i>et al.</i> 2017
3	Cashew Nut	Cashew apple juice	Red, orange, yellow	Anthocyanins	—	Used ethanol as solvent	Dass <i>et al.</i> 2018
4	Coconut	Husk	Brown	Polyphenols	33%	Material to liquor Ratio 1:150, 75°C, 255 min, pH 7.	Samant and Gaikwad, 2020
5	Areca nut	Areca nut powder	Reddish-brown	Polyphenols	—	Areca nut concentration- 10 g / 100 mL water, 90°C, 120 min	Le and Nguyen, 2021
6	Jamun	Pomace	—	Anthocyanin	Aqueous Extract 152.6±0.9mg/100g, Ethanol Extract 290.01±0.2	Solid to solution ratio of 1:15, 45°C, 90 min aqueous and ethanol (%).	Panda <i>et al.</i> 2022
7	Karonda	Pulp	Red	Anthocyanins	—	Cold extraction with ethanol	Hare Krishna <i>et al.</i> 2017
		Karonda extract	Red, purple, or blue	Anthocyanin	—	Extract heated in water for 20 min	Aliño, 2014
8	Pomegranate	Peel	Reddish-Brown	Tannins and Flavonoids	18.33%	Material to liquor Ratio 3 g/100 mL, pH 3, for 15 min	Bhatt <i>et al.</i> 2025
9	Passion fruit	Pericarp	Red to purple, depending on the pH.	Anthocyanins	—	Water or ethanol as a solvent, Solvent volume: 2 mL, Extraction methods: either water, ethanol, or ethanol + ultrasonication	Kawasoe <i>et al.</i> 2021
10	Mandarin Orange	Peel	Yellow	Hesperidin	—	Water used as solvent	Kusumawati <i>et al.</i> 2020
11	Sweet orange	Peel	—	Carotenoid	—	60 °C, 120 min, material-to-liquor ratio of 1:20 (wt/ vol) for both 100 % and 0 % ethanol.	Che <i>et al.</i> 2024

12	Pineapple	Peel	—	Tannin	35-40%	Mass-to-liquid ratio 1:10, 12% NaOH, 80 °C and 2 h extraction time	Pramod <i>et al.</i> 2025
13	Grape	Pomace	Purple and brown	Anthocyanin	Varies from 100 mg to 3200 mg/kg of grape pomace variety	Water: ethanol ratio 90:10 (v/v) at 40°C	Rym <i>et al.</i> 2012
14	Avocado	Seed	Orange	—	22.56%	Temp. 70 °C, feed to solvent ratio 1:12	Arlene <i>et al.</i> 2015
15	Walnut	Shell	—	Flavonoids	—	Soxhlet extraction using ethanol as a solvent	Mirjalili <i>et al.</i> 2011
16	Apple	Peel	Yellowish red	—	—	pH 1–9 temperatures 50–100°C (10–60 min).	El-sayed and El-Shemy, 2022
17	Dragon Fruit	Peel	Red	Betacyanin	—	Ethanol used as a solvent	Rahayu and Christiani, 2023
		Peel	Red	Anthocyanin	52.27 mg/L	10% citric acid solvent (1: 3) and 4-days of maceration	Dewi <i>et al.</i> 2020

Sharan *et al.* (2018), researched the creation of a colour palette utilizing coconut waste (husk) on cotton. This research concentrated on the utilization of agricultural byproducts, specifically coconut calyx (husk), as natural colouring agents. The study conducted on cotton fabric involved using coconut calyx, the leftover parts of the coconut after the edible portion was consumed, to extract dye from it. The fabric was dyed using two natural mordants, pomegranate rind and lemon rind, along with one metallic mordant, alum, at 2%, 4%, 6%, and 8% shades respectively, by altering the pH values to create a colour palette. Results indicated that coconut husk could serve as an effective dyeing agent, yielding reasonably good outcomes. Coloured cotton fabrics displayed various tones of brown, yellow, and pink. Optimal outcomes were achieved at 8% shade in acidic conditions using alum. Cotton infused with lemon peel showed optimal outcomes at 4% in the self-pH (6 pH). Cotton treated with pomegranate exhibited the highest values in alkaline concentration

with 8% dye. In general, the value achieved on cotton with pomegranate rind exhibited greater colour depth, followed by lemon rind and alum.

4. Jamun

Java plum (*Syzygium cumini*), part of the Myrtaceae family, is often called Jamun or Indian blackberry (Adithya *et al.* 2025a). The worldwide output of Jamun is estimated at 13.5 million tons, with India ranking second by contributing 15.4% of the total (Sane & Tripathi, 2025). Fig. 4(a) shows the jamun fruit which is generally used for consumption and processing while Fig. 4(b) shows the jamun pulp used for colour extraction.

Jamun berries with an average weight of 6.4g consist of approximately 35% seed and 65% pulp (Joshi *et al.* 2012). Eating the Jamun fruit directly results in the seed kernel being discarded as waste. The commercial application of Jamun, renowned for its strong antioxidant and therapeutic benefits, is primarily limited



Fig. 4. (a) Jamun fruit (b) Jamun Pulp

to juice extraction, with merely 54% of the fruit being used. The procedure consequently produces 46% of by-products, which consist of pomace (17%) including leftover pulp, discarded skins, and hard seeds from kernels (Kaur *et al.* 2023; Suradkar *et al.* 2017). Table 2 shows the part of the mango fruit used, colour range, pigment, colour yield and processing conditions.

Jamun fruits are utilized in creating a range of culinary dishes. In the process of making jamun juice, a large quantity of pomace is produced, which is considered a low-value byproduct and is mainly utilized for livestock feed or disposed of in landfills. Most food industry by-products are discarded in open spaces (Singh *et al.* 2006).

Maran *et al.* (2014) obtained natural pigments and colours from jamun fruit pulps through an aqueous extraction technique, and the extraction was conducted at various temperatures, times, and solid-liquid ratios.

5. Karonda

Karonda, also known as Christ's thorn (*Carissa carandas*), is a resilient evergreen spiny shrub that originates from India and belongs to the Apocynaceae family. Fig. 5 illustrates the karonda fruit. It is a

bushy tree with multiple branches, often used as a hedge, capable of withstanding hot, dry conditions and strong sunlight in arid and plateau areas (Ghosh, 2014).



Fig. 5: Karonda

Karonda plants grow naturally across various areas in India, such as the Siwalik Hills, Bihar, West Bengal, the Western Ghats, Karnataka, and the Nilgiri Hills. The majority of karonda bushes serve an ornamental purpose, although the tribal regions of Madhya Pradesh, Chhattisgarh, Rajasthan, Gujarat, and

Jharkhand are recognized for cultivating the fruit in a limited capacity. In the Varanasi district of Uttar Pradesh and the South 24-Parganas district of West Bengal, it is cultivated on a commercial basis (Panda *et al.* 2014).

The fruit's high moisture content renders it highly perishable, typically stored at 13° C with 95% relative humidity (Tuladhar, 2020). In spite of its various benefits, it continues to be an underutilized fruit, likely due to its small berry size and tart flavour. One potential application may involve the extraction of natural pigments from mature fruits since certain genotypes of Karonda produce dark red pulp when they ripen (Hare Krishna *et al.* 2017). Table 2 shows the part of the karonda fruit used, colour range, pigment, colour yield and processing conditions.

Harshitha *et al.* (2024) obtain natural dye from Karonda utilizing methanol and ethanol as solvents. Investigations using UV-Vis and FTIR spectroscopy demonstrate that the primary dye components of karonda fruits are anthocyanin derivatives and phenols.

6. Kokum / Mangosteen

Mangosteen (*Garcinia indica*), often referred to as Kokum, is an underappreciated fruit tree species indigenous to India that has recently attracted interest for its potential as a functional food. This enduring evergreen tree flourishes mainly in the Western Ghats, with its natural range primarily found in the South Konkan area of Maharashtra, along with Goa, northern coastal Karnataka, Kerala, and sections of Assam and West Bengal. Marked by a monopodial growth form and great height, Mangosteen continues to be mostly overlooked regarding systematic farming and commercial use. Its presence is primarily limited to household gardens, where it is frequently grown as a rainfed intercrop alongside Coconut and Areca nut in the Konkan area (Rane *et al.* 2025).

Mangosteen is recognized for its sweet-tart white flesh, which makes up approximately 15% of the entire fruit's weight. The leftover parts include 2% seed and 83% inedible pericarp (Chairat *et al.* 2007).

The edible portion of the mangosteen is limited, as over 60% of the entire fruit consists of an inedible, thick dark purple or reddish skin, resulting in a significant amount of residue generated after eating or processing the fruit. Approximately 30.8 million tons of mangosteen pericarp waste are estimated to be generated annually worldwide (Cho *et al.* 2020; Zhang *et al.* 2020). Table 2 and 3 shows the part of the kokum fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

After consumption, the pericarp is typically thrown away as agricultural or domestic waste. Due to its large quantity, unsuitable disposal of mangosteen pericarp may lead to environmental issues. Conversely, recent research has shown its possible uses owing to its abundant polyphenolic compounds and xanthenes, such as α -mangosteen, γ -mangosteen, and various derivatives (Gutierrez-Orozco and Failla, 2013).

The pericarp's rich pigment content-consisting of anthocyanins, tannins, and various natural colorants-renders it a promising raw material for applications in natural dyeing (Prasetyo *et al.* 2025). Mangosteen extract, recognized as a natural dye, has been extensively utilized for various purposes, including dye-sensitized solar cells (Tontapha *et al.* 2017), cotton dyeing (Wang, 2013), silk (Chairat *et al.* 2007), and leather (Kurinjimalar *et al.* 2022), in addition to serving as a food colorant (Manurakchinakorn *et al.* 2016). Fig. 6 shows the kokum and its waste part. Fig 6(a) shows the kokum fruit and Fig. 6(b) shows the kokum peel used as a raw material for colour extraction.

Mar *et al.* (2016) obtained a natural dye from mangosteen peel, stating that by merely boiling mangosteen peels in water, the water-soluble dye could be extracted and subsequently applied to dye cotton fabrics. The findings from this study indicate a promising ability of the natural dye to be practically utilized in the textile sector, where the distinctiveness of the products is leveraged.

Prasetyo *et al.* (2026) obtained hair dyeing pigment from the pericarp of mangosteen specifically to attain



Fig. 6: Kokum and its waste part (a) Kokum (b) Kokum Peel

appealing reddish shades. The ideal reddish hue, marked by high intensity, was attained with FeSO_4 (2% w/v) as a mordant in acidic conditions (pH 1–3). These results underscore the potential use of mangosteen pericarp as an effective, environmentally friendly option for reddish hair colouring, responding to the growing need for sustainable cosmetic components.

7. Areca nut

Areca nut (*Areca catechu*) is a significant cash crop in the Western Ghats and the eastern and northeastern parts of India. Fig. 7 shows the areca nut. Areca nut is a tall, narrow plant growing to a height of 15–20m. The current global production of areca nut is approximately 1.937 million tons from an area of 1.422 million hectares. Areca nut is mainly cultivated in India, Bangladesh, China, Indonesia, Sri Lanka, and Myanmar. India holds the top position in both area (49%) and production (50%) of areca nut. In India, areca nut is grown over an area of 396.8 thousand hectares, yielding 559 thousand tonnes annually, primarily in the states of Karnataka, Kerala, Tamil Nadu, Maharashtra, Assam, West Bengal, and Meghalaya (Nair, 2021).

Le and Nguyen, (2021) obtained dye from areca nut extract through the Aqueous extraction technique. They examined the effects of elements like the mass/

volume ratio of areca nut to water solvent, duration of extraction, extraction temperature, and pH level of the extraction medium on the colorant extraction process from areca nut. Table 2 and 3 shows the part of the areca-nut used for colour extraction, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.



Fig. 7: Areca nut

Wijayarathna *et al.* (2023) studied on extraction and dyeing behaviour of natural dye obtained from areca catechu powder waste for cotton fabric using ethanol extraction method. Two different mordants (Alum and Ferrous sulfate) and two mordanting techniques (pre-mordanting and post-mordanting) at 3% and

5% concentrations were used to set the extracted dye on the cotton fabrics. They were combining Areca nut powder ethanol in a soxhlet apparatus. The solution obtained through extraction was then concentrated to enhance the concentration of the extracted compounds. Subsequently, the solution was poured into Petri dishes and oven-dried. Then, the dye was scratched out of the petri dishes and collected in powder form. The obtained dye extract was then characterized and used for further dyeing studies.

8. Pomegranate

When compared to other fruits examined, pomegranates (*Punica granatum* L.), one of the oldest known edible fruits, have the greatest concentration of total polyphenols (Fazaeli, Yousefi, & Emam-Djomeh, 2013). Pomegranates are mostly used in the culinary industry for their fresh juice and pomegranate-based beverages. Every year, enormous amounts of by-product trash, including peels, are produced because the juice yield of pomegranates is less than half of the fruit weight. Waste from pomegranate byproducts has historically been used as animal feed. Some fruit or vegetable by-products may be a natural source of antioxidants, according to several recent studies (Llorach *et al.* 2003; Wolfe, Wu, & Liu, 2003). Pomegranate peels are a strong source of phenolic compounds and antioxidants, according to Kim *et al.* (2002). Table 2 and 3 shows the part of the pomegranate fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

The fruit peels of the wild pomegranate variety Daru were used by Bhatt *et al.* (2025) to optimize a natural colorant. Fig. 8(a) shows the pomegranate fruit which is commonly used for consumption and processing while Fig. 8(b) shows the pomegranate peel, a waste part remaining after consumption of the fruit, used for colour extraction. Fruit peel samples weighing 1, 2, 3, 4, 5, and 6 grams were boiled with 100 grams of distilled water for a duration ranging from 15 to 90 minutes at intervals of 15 minutes under various pH conditions. The pH was adjusted using sodium carbonate (Na_2CO_3 , 0.01%) and citric acid (0.01%). To prevent total evaporation, the boiling temperature was kept at 90°C. A reddish-brown dye with a high optical density (1.41) and a notable yield (18.33%) was produced under the ideal circumstances, which were pH 3 and a 15-minute extraction period. Significant amounts of total tannin content (0.28%) and total flavonoid content (0.14%), which are important components of the dye's colouring qualities and antioxidant potential, were validated by phytochemical analysis. Alum was used as a mordant while applying the natural dye extract (0.5%) to silk, cotton, and wool textiles. Although cotton, a cellulose fabric, has relatively milder hues, colour adhesion was greatly enhanced by mordanting. The cloth developed deep brownish tones as a result of the mordant's efficient chelation with the dye molecules. The dye's viability for textile applications was further supported by the enhanced colour strength and uniformity that came from post-mordanting with alum.



Fig. 8. (a) Pomegranate fruit (b) Pomegranate peel

9. Sweet Orange

One of the primary obstacles to orange juicing applications is still orange pomace. Fig. 9(a) shows the sweet orange fruit. Peel, pith, pulp, core, and seeds make up these juice processing wastes, which can account for as much as 45% to 60% of the fruit (O'Shea *et al.* 2012). According to Sawalha *et al.* (2009), orange peel alone makes up between 20% and 35% of the entire orange. Orange peel is a possible source of natural food colouring, and phenolic and carotenoid chemicals are primarily responsible for orange peel colours (Vasso Oreopoulou and Constantina Tzia, 2006). As the concentration of phenolic chemicals becomes more prevalent, orange peel becomes less red and more yellow. Orange peel turned more yellowish due to ionizing irradiation and storage, which raised the concentration of total phenols (Moussaid, 2004). Table 2 and 3 shows the part of the sweet orange fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

Orange peel colorants were isolated by Che *et al.* (2024) as plant dyes, and their potential for dyeing silk materials was examined. Fig. 9(b) illustrates the sweet orange peel discarded after consumption of the fruit and utilized for colour extraction. In order to get the greatest absorbance for the extracted solution,

they compared 100% ethanol, 70% ethanol, and water to identify the ideal extraction conditions. For both 100% and 0% ethanol, the optimal performance was achieved with an extraction temperature of 60°C, an extraction duration of 120 minutes, and a material-to-liquor ratio of 1:20 (wt/vol). The total findings offer strong support for the ideas of using agricultural waste as natural colorants for the fashion sector instead of synthetic ones.

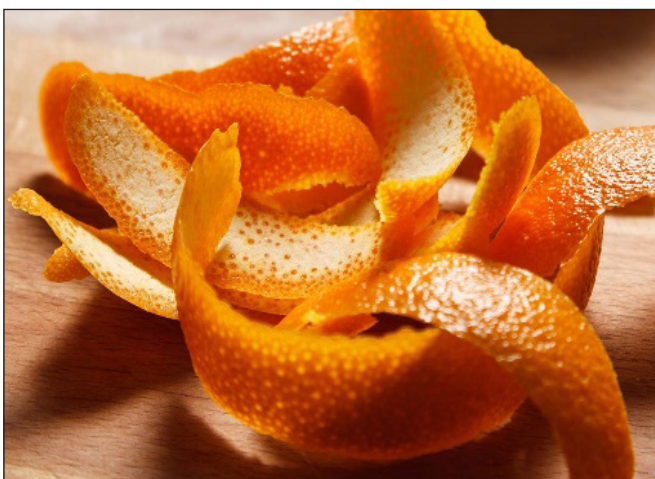
10. Mandarin Orange

Approximately 50–70% of the weight of processed fruit is made up of citrus peel waste. Depending on the particular fruit variety and the method employed, the precise percentages may differ (Grover *et al.* 2025). Fig. 10(a) shows the mandarin orange fruit.

Citrus peels are the main sources of polyphenols in these fruits, according to a study by Castro-Vazquez *et al.* (2016). Significant amounts of phenolic acids and flavonoids, specifically flavanones, glycosylated flavanones, and polymethoxyflavones, have been found in the peels of bitter and sweet oranges, mandarins, and lemons Castro-Vazquez *et al.* (2016). Table 2 shows the part of the mango fruit used, colour range, pigment, colour yield and processing conditions.



(a)



(b)

Fig. 9: (a) Sweet Orange (b) Sweet Orange Peel

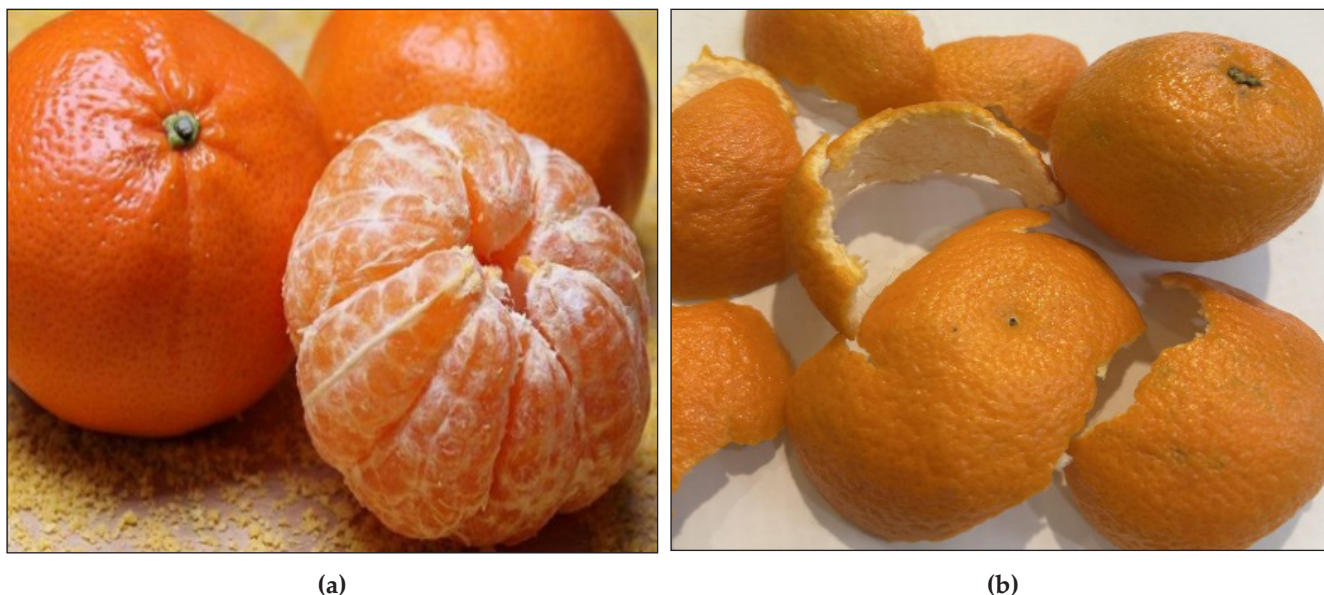


Fig. 10: (a) Mandarin Orange (b) Mandarin Orange Peel

Mandarin orange peel was used by Taura *et al.* (2024) to extract a natural colour for use in textiles. Fig. 10(b) shows the mandarin orange peel, a waste by-product, used for colour extraction. A 400 mL beaker filled with around 200 mL of distilled water, and 12 g of dried and ground citrus peels were soaked in the water for 48 hours. The dye extract was then allowed to sit at room temperature for 30 minutes before being filtered. The coloured crude dye solution (150 cm³) was used for dyeing right away after being diluted with 50 cm³ of distilled water. They came to the conclusion that this investigation was successful in extracting a natural dye from orange peel that was proven to be somewhat useful for clothing colouring. Following dye application, fabric weights grew in response to temperature and NaOH concentration, suggesting improved dye uptake and binding to the fabric. Only washing has an impact on the dyed cloth; sunlight and rubbing effects have no effect. NaOH, a modifier-like mordant, worked well to stop the dyed fabric from fading too quickly.

11. Lemon

Beyond the valuable pectin (Ciriminna *et al.* 2016; Nuzzo *et al.* 2020) and lemon oil, the waste lemon

peel, which accounts for approximately 50% of the weight from lemon juice processing, serves as an appealing raw material for the production of a water-soluble and highly stable yellow natural colorant. The lemon fruit shown in Fig. 11(a) is commonly used for processing and consumption.

Kumar and Dhinakaran, (2017) utilized the aqueous extraction method to obtain natural colour from lemon peels. Fig. 11(b) shows the lemon peel, a waste by-product, used for colour extraction. They employed ethanol as the organic solvent. The solvent was combined with the dry ground materials in ratios of 1:1, 1:2, and 1:3. The mixture was shaken at room temperature for an entire day. The ethanol evaporated within this time frame. Afterward, the dye was collected by filtering the residue through filter paper. They concluded that a dye uptake was enhanced with 30% mordanting. Lemon peel was shown to have greater dye production when 50 milliliters of ethanol were extracted. Cotton fabric dyed with lemon peel extracts has demonstrated improved resistance to rubbing in both dry and wet conditions when a 1:1 material-to-liquor ratio and 30% pre-mordanting are used. Fastness to washing exhibits a similar pattern. This study makes it



Fig. 11: (a) Lemon (b) Lemon Peel

abundantly evident that lemon peel extracts can be utilized as a source of natural cotton fabric colours, which will improve the value addition of leftover lemon waste from the food processing industry.

12. Dragon Fruit

Dragon fruit has 35% to 37% peel, which is typically thrown away during processing and causes environmental issues (Jamilah *et al.* 2011). Fig 12(a) shows the dragon fruit is commonly used for processing and consumption. The colour of the dragon fruit is derived from the betalain pigments' betacyanins and betaxanthins. Betacyanins include phyllocactins, betanidins, and betanins (Wybraniec *et al.* 2007; Kim *et al.* 2011).

Dragon fruit peel colour extract was used by Pavithra (2021) as a functional component in a dragon fruit RTS beverage. Fig. 12(b) shows the dragon fruit peel, a waste by-product, used for colour extraction. The colour that was obtained by hydro-extracting the peel at room temperature was added to the drink to create a visually appealing and nutritious beverage. The water content was substituted with varying quantities of colour extract (20%, 30%, 40%, and 50%) to create coloured drinks. The coloured beverage

was shown to have higher levels of betalain and antioxidant activity than the colourless one. Table 2 and 3 shows the part of the dragon fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

Dragon fruit was used by Athira (2021) as a natural colorant. Five distinct extraction techniques were used to create peel colour extracts from the peels of both white and purple dragon fruit varieties: hydro maceration, ethyl alcohol maceration, hydro maceration of freeze-dried peel, low-temperature hydro maceration, and low-temperature ethyl alcohol maceration for 24 hours using a 1:2 peel to solvent ratio. Extracts made from purple dragon fruit peels contained more betalain than those made from the other fruit peels. Hydro maceration of the peels yielded extracts with the greatest betalain content among the maceration techniques.

The purple dragon fruit peel that was extracted using the hydro maceration process had the highest betalain content (67.14 mg/L) and overall antioxidant activity (62.49%). The purple dragon fruit peel colour extract, obtained through low-temperature hydro maceration, demonstrated the highest antioxidant

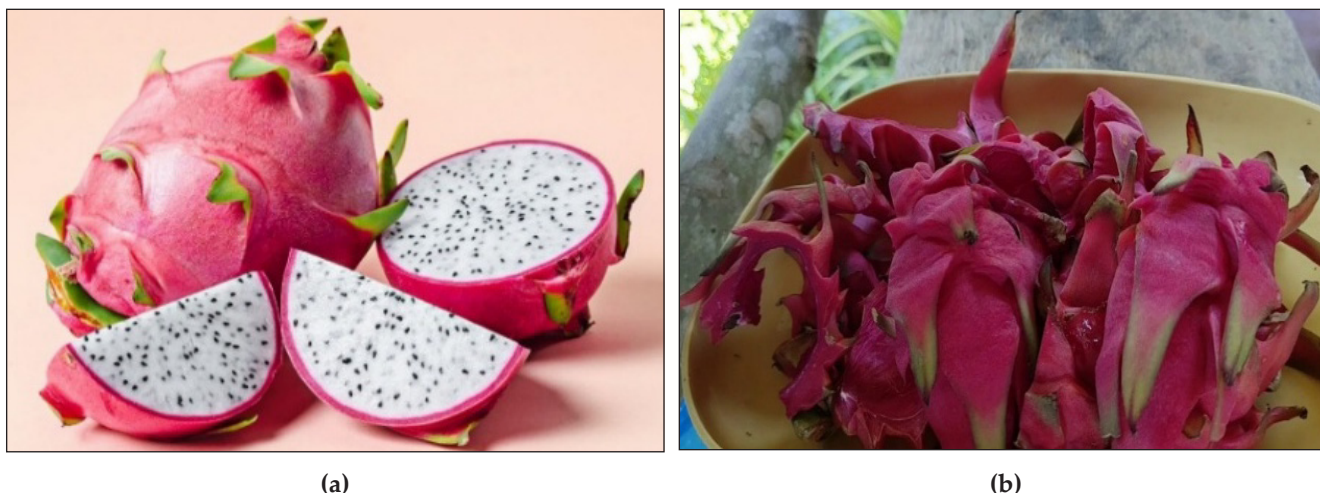


Fig. 12: (a) Dragon Fruit (b) Dragon Fruit Peel

activity at 83.61% and the second-highest betalain concentration at 53.8 mg/L. The extracts made by hydro macerating the freeze-dried peels of white dragon fruit had the lowest betalain concentration, while the extract made by hydro macerating the peels at a low temperature had the lowest antioxidant activity. Therefore, it was determined that, out of all the maceration methods, hydro maceration of purple fruit peel and storage at a low temperature of 4-7 °C maintains a relatively better stability throughout a three-month storage period. However, storage of betalain extract cannot be advised for colour preservation because the betalain content is significantly decreased.

13. Avocado

Rich in phenolic chemicals, catechins, and tannins, avocado peels oxidize and combine with textile fibers to generate a brown to reddish hue. According to Rodriguez-Carpena *et al.* (2011) these substances have a strong metal-chelating capacity that improves colour persistence and dye fixing. Fig. 13 shows the avocado fruit is commonly used for consumption and processing.

Nazlı Üren (2022) focused on using extracts from avocado seeds and peels to dye cotton and wool fabrics in an environmentally friendly manner. They used avocado peels and seeds to make two different

dye extracts. After being peeled, fresh avocado seeds were sliced into $3.0 \text{ g} \pm 0.5 \text{ g}$ slices. After being separated from the pulp, avocado peels were allowed to dry for 24 hours at room temperature.



Fig. 13: Avocado

The prepared seeds (or peels) were heated to boiling for four hours after being combined with a 0.01 M NaHCO_3 solution in a 1:20 material-to-liquor ratio (M:L). The findings show that avocado seed and peel extracts can be used to colour cotton and wool textiles with excellent washing and rubbing fastness ratings without the need for mordants. Except for the iron-mordanted samples, the colours of the cotton and wool samples were mild to moderate shades of grayish red and moderate to dark shades of reddish orange, respectively. Olive brown and grayish

yellowish brown were the colours of the samples that were pre-mordanted with ferrous sulfate and dyed with seed and peel extracts, respectively. Table 2 and 3 shows the part of the avocado fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

14. Apple

About 10% of an apple's mass is made up of its peel, which is typically thrown away as garbage. Anthocyanins and quercetins, two water-soluble flavonoids found in this colourful waste, would be good choices for wool fabric dyeing. Polyphenols, such as flavan-3-ols, flavonols, dihydrochalcones, anthocyanidins, and a smaller proportion of phenolic acids, are the primary phytochemicals found in apple skin (Mendoza-Wilson *et al.* 2016). Fig. 14 shows the apple fruit.



Fig. 14: Apple

Red apple peel dye was extracted by El-Sayed and El-Shemy, (2021) they used varying concentrations of red apple peel (RAP) extract (20–60 g/100 mL) at varying pH levels (1–9) and dyeing temperatures (50–100°C) for varying dyeing times (10–60 min). The necessary temperature was reached in ten minutes during the dyeing process using infrared dyeing equipment. The ratio of material to liquor (MLR) was consistently 1:20. Wool fabric was successfully dyed using a natural colorant that was derived from red apple peel in an aqueous medium. When

the ideal dyeing circumstances were followed, the color strength of the wool fabric colored with red apple peel (RAP) extract was effective whether or not four mordants- Fe^{+2} , Cu^{+2} , Al^{+3} , and Sn^{+2} —were used utilizing the pre-, meta-, and post-mordanting methods. It was discovered that the best dyeing conditions for wool fibers using RAP extract without a mordant were pH 5, 90 minutes, 90°C, and L.R. 1:20. When it comes to washing, light, rubbing, and sweating, the dyed textiles offer adequate to excellent fastness qualities. Table 2 and 3 shows the part of the apple fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

15. Grape

Various by-products are produced throughout the winemaking process and make up about 30% of the total grape use. These byproducts include lees, pomace, grape stalks, and vine pruning. A combination of the skins, seeds, and stem that remain after grape pressing, grape pomace can make up 25% to 45% of the entire weight of the grape (Genisheva *et al.* 2024). Grape pomace has been investigated for a number of uses, including as a source of natural colours or bioactive compounds. Because GP has a large number of chemicals with strong antioxidant properties, its chemical makeup is encouraging. Anthocyanins, flavonols, flavan-3-ols, procyanidins, phenolic acids, and resveratrol are examples of polyphenols. Grape pomace is widely used to make distillates, extracts, and colouring agents like enocyanin and tartaric acid. (Caponio *et al.* 2023; Baaka *et al.* 2015; Baaka, *et al.* 2019). Table 2 and 3 shows the part of the grapes used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

Fonseca *et al.* (2024) investigated grape pomace as a possible source of natural dye. To extract the biocolours present, the grape pomace was subjected to a solid-liquid extraction procedure. 30 g of pomace and 500 mL of solvent were employed in the extraction process in a flask submerged in a thermoregulated bath ($\pm 1^\circ\text{C}$). Water was selected as the solvent and

used for three hours at a temperature of 80 °C with varying pH values (pH = 2.4, pH = 8.0, and pH = 12.2). Apart from water extraction, dye was also extracted using a 50% v/v water/ethanol solution at the same temperature and duration. Small amounts of the solution were taken out of the extraction flasks on a regular basis. Filtration was used to separate the solid residue that remained in the flask following extraction. After centrifuging the filtered solution for ten minutes at 4000 rpm, it was vacuum-filtered via a filtration system that had a membrane with a diameter of 47 mm and a porosity of 0.2 µm. Lastly, a rotary evaporator was used to concentrate the extract solution. When about 40 mL of extract was left, it was transferred to vials that had been previously weighed, labeled, and frozen in preparation for lyophilization. This procedure made it possible to calculate the extraction yield. Before being employed as a dyeing solution, a part of the lyophilized extract was diluted ten times after being dissolved in 25ml of distilled water. 11–19% yield is obtained after this process is finished.

16. Pineapple

The peel of pineapples is frequently thrown away as garbage after processing. Fig. 15(a) shows the pineapple fruit. Due to its vulnerability to microbial deterioration, which can have detrimental effects on the environment, the disposal of pineapple peel waste has grown in importance (Sarangi *et al.* 2023). An important agricultural waste, pineapple peel provides a wealth of bioactive substances like polyphenols and flavonoids that can be used to create environmentally friendly textile and other dyes (Mala *et al.* 2024; Li *et al.* 2014). Table 2 and 3 shows the part of the pineapple fruit used, colour range, pigment, colour yield, processing conditions, solubility, colour strength, colour stability and applications.

Pineapple peel waste was utilized by Pramod *et al.* (2025) to create a natural dye. Fig. 15(b) shows the pineapple fruit peel, a waste by-product, used for colour extraction. In order to facilitate the release of colorants, finely crushed pineapple peel chips were suspended in distilled water, heated to 60 °C, and stirred magnetically for one hour. To guarantee



(a)



(b)

Fig. 15: (a) Pineapple (b) Pineapple Peel

clarity, the resultant solution was filtered twice. As a comparative solvent screening across a polarity range, they repeat the extraction process using a variety of extraction media, including water-based systems like alkaline solutions (water/NaOH), acidic solutions (water and acetic acid), and water with added inorganic salts, as well as organic solvents (hexane, ethanol, and methanol). The same heating, stirring, and filtering conditions were used for every extraction. In comparison to the other extraction media, the water/NaOH solvent system showed the highest performance among the studied systems, producing 35-40% pigment extraction, or roughly 35-40 g of dry dye powder from 100 g of dried pineapple peel chips.

CONCLUSION

The extraction of natural pigments from fruit waste represents a sustainable and environmentally responsible approach for the utilization of agro-industrial byproducts. Fruit wastes such as peels, pomace, seeds, husks, and nutshells are rich sources of valuable pigments, including anthocyanins, flavonoids, tannins, carotenoids, and polyphenols that can effectively replace synthetic dyes in various applications. Different extraction methods such as aqueous, solvent, microwave-assisted, ultrasound-assisted, enzyme-assisted, and supercritical fluid extraction have demonstrated significant potential in improving pigment recovery and extraction efficiency. The reviewed studies confirm that colorants obtained from fruit waste exhibit promising applications in textile dyeing, food colouring, cosmetics, pharmaceuticals, and other eco-friendly products because of their biodegradability, non-toxic nature, and functional properties. Additionally, waste reduction, resource recovery, and the advancement of circular economy concepts are all aided by the conversion of fruit processing waste into natural dyes. The future scope and industrial adoption of fruit waste-derived natural colorants are anticipated to be improved by ongoing advancements in extraction technologies and growing consumer preference for sustainable products, despite current limitations

related to color stability, fastness properties, large-scale processing, and commercialization.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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