JOURNAL OF NATURAL REMEDIES
DOI: 10.18311/jnr/2025/44998

REVIEW ARTICLE

A Review on Nature Treasured Biochrome: Anthocyanins, with Five Major Maharashtrian Sources

Shweta Kashid*, Jai Karne, Rutuja Athawale and Akshay Kotkar

Department of Biotechnology, Sinhgad College of Engineering (Affiliated to Savitribai Phule Pune University), Pune – 411041, Maharashtra, India; smkashid.scoe@sinhgad.edu

Abstract

Background: Anthocyanins are natural hydrophilic pigments appreciated for their bright red, purple, and blue hues and belong to the group of phenolic compounds. Anthocyanins are found in all plant parts. Tropical fruits and vegetables like grapes, pomegranates, eggplants, red cabbages, *etc*. are sources containing high levels of anthocyanins, which can be easily extracted using various methods. The market size of anthocyanins is growing rapidly due to increasing applications of anthocyanins as natural dyes in the textile and cosmetic industry, food additives in the food and beverage industry, pharmaceutical and nutraceutical industries and is expected to reach a value of nearly 27.8 million USD by 2032. **Aim:** The review focuses on five major Maharashtrian sources of anthocyanins, namely; Eggplant (*Solanum melongena*), Grapes (*Vitis vinifera*), Jamun (*Syzygium cumini*), Kokum (*Garcinia indica*), and Pomegranate (*Punica granatum*) with significant emphasis on their phytochemical aspects and anthocyanin content. **Methods:** The various extraction methods like Solid Liquid Extraction (SLE), High Hydrostatic Pressure (HHP) Extraction, Supercritical Fluid Extraction (SFE), Pulse Electric Field Extraction (PEFE), Ultrasound-Assisted Extraction (UAE) and Agitated Bed Extraction (ABE) and techniques for purification and identification of anthocyanins are highlighted here. Also, the review delves into an extensive range of anthocyanin applications in various industries providing a promising way to develop novel, safer and healthier products with enhanced stability and quality. **Conclusion:** The review concludes that anthocyanins have a very significant role in the physiology of these five major Maharashtrian sources and the Eggplant has high anthocyanin content. Amongst all extraction methods, ultrasound-assisted extraction (UAE) was found to be a highly flexible, affordable, simple and rapid method giving maximum anthocyanin yield. Therefore, anthocyanins are a treasured natural pigment having versatile applications in various industries.

Major Findings: A comparison of five major Maharashtrian sources revealed that Eggplant (*Solanum melongena*) possesses high anthocyanin content. Amongst all extraction methods, ultrasound-assisted extraction (UAE) was found to be a highly flexible, affordable, simple and rapid method giving maximum anthocyanin yield. Application of anthocyanins in various industries will provide a promising way to develop the novel, safer and healthier products with enhanced stability and quality to benefit humans.

Keywords: Anthocyanins, Applications, Extractions, Hydrophilic Pigments, Maharashtrian Sources, Nutraceutical

Abbreviations: ABE-Agitated Bed Extraction; APCI-Atmospheric Pressure Chemical Ionisation; C3G-Cyanidin-3-Glucoside; CAGR-Compound Annual Growth Rate; CF-FAB-Continuous Flow Fast Atom Bombardment; D3G-Delphinidin-3-Glucoside; DF-Dilution Factor; DM-Dry Matter ; ESI- Electrospray Ionisation; GC-Gas Chromatography; GC-MS-Gas Chromatography-Mass Spectrometry; HHP-High Hydrostatic Pressure; HIV-Human Immunodeficiency Virus; HPLC -High-Performance Liquid Chromatography; LC-Liquid Chromatography; LC-MS-Liquid Chromatography-Mass Spectrometry; LC-UV-Liquid Chromatography UV-Vis Spectrophotometry; MALDI - Matrix-Assisted Laser Desorption Ionisation ; MS-Mass Spectrometry; MW-Molecular Weight, NMR-Nuclear Magnetic Resonance Spectroscopy; PC-Paper Chromatography; PEFE-Pulse Electric Field Extraction; ROS - Reactive Oxidative Species ; SC-CO2 Supercritical Carbon Dioxide; SFE -Supercritical Fluid Extraction; TAC - Total Anthocyanin Content; TLC- Thin Layer Chromatography; UAE-Ultrasound Assisted Extraction; USD - United States Dollar; UV – Ultraviolet; UV-Vis - Ultraviolet Visible

*Author for correspondence

Article Received on: 16.07.2024 Revised on: 20.01.2025 Accepted on: 25.01.2025

1. Introduction

Anthocyanins are hydrophilic vacuolar pigments which belong to the Phenolic group and mainly exist in glycosylated forms[1]. Anthocyanins are members of the class of flavonoids, synthesised via a pathway called phenylpropanoid pathway. Anthocyanins are found in tissues of vascular plants in parts such as flowers, stems, leaves, and fruits and are largely responsible for diverse pigmentation varying from red and orange to various shades of purple and blue. Anthocyanins are commonly found in fruits and vegetables such as blackberries, blueberries, cherries, elderberries, grapes, pomegranates, red onion, radish, red cabbage, and eggplant[2].

The market size of anthocyanins is reported to be growing rapidly and is anticipated to achieve a target of nearly 27.8 million USD by the year 2032 with an accelerating Compounded Annual Growth Rate (CAGR) of 5.15% owing to the versatile applications of anthocyanins in food, textile, cosmetics as well as the pharmaceutical industry. Anthocyanins are feasibly utilized as natural colouring agents and food additives in the textile industry, food and beverage industries. They also serve various potential applications in the cosmetic industry, especially in skin care formulations, hair products, nail paints and lipsticks. Being biologically active compounds, anthocyanins are beneficial to human health and protect against some of the prevailing human diseases such as cardiovascular disease, cancer, diabetes, and neurodegenerative disorders, and hence are extensively utilised in the healthcare and pharmaceutical industries as a potent nutraceutical and pharmaceutical ingredient[3-5].

In this review, the main focus is on the five major Maharashtrian sources of anthocyanins, namely; Eggplant (*Solanum melongena*), Grapes (*Vitis vinifera*), Jamun (*Syzygium cumini*), Kokum (*Garcinia indica*), Pomegranate (*Punica granatum* L.). From these five anthocyanin sources; the Eggplant (*S. melongena*) is a popular vegetable rich in anthocyanins and has a variety of potential health benefits[6,7]. The rest of the four sources are the anthocyanin-rich Fruits, out of which Grapes (*V. vinifera*) and Jamun (*S. cumini*) are the berries; while, the Kokum (*G. indica*), known as the 'Cool King' of Indian fruits is a tropical fruit native to Maharashtra and mostly found in Kokan region and the Pomegranate (*P. granatum* L.) known as the 'Superfruit' being rich in the antioxidant phytochemicals[8-10]. All these Maharashtrian sources contain high levels of anthocyanins and have enormous pharmaceutical benefits including the anti-oxidant, anti-irritants, cardioprotective immunomodulatory and neuro-psychopharmacological characteristics caused by the availability of the several bioactive polyphenols which constitutes the flavonoids, carotenoids, anthocyanins, flavones, tannins and gallic acid[11-16]. These five major Maharashtrian sources of anthocyanins will be significantly reviewed emphasising the methods of extraction, identification and purification of anthocyanin pigments from these five anthocyanin sources. Herein, the various extraction and purification techniques of anthocyanins will be discussed with their advantages and disadvantages along with process conditions and corresponding anthocyanins yield. Additionally, a special focus will be on exploring the potential applications of these anthocyanins in various industries like cosmetics, food and packaging, nutraceutical, pharmaceutical and textile industries.

2. Chemistry of Anthocyanins

'Anthocyanins' name has been established from ancient Greek words "*Anthos*" implying flowers, and "*Kyanous*" a deep blue colour[3]. Anthocyanins have a molecular weight ranging from 400 to 1200 Dalton[17]. Anthocyanins share a basic structure with flavonol pigments but lack ketone oxygen at the 4th position of the flavylium ion core. The flavylium ion in anthocyanin has the empirical formula $C_{15}H_{11}O^+$ and weighs about 207.24 g/mol[3]. Figure 1 represents the structure of the anthocyanin generated using the ChemSpider; where the A indicates any functional group.

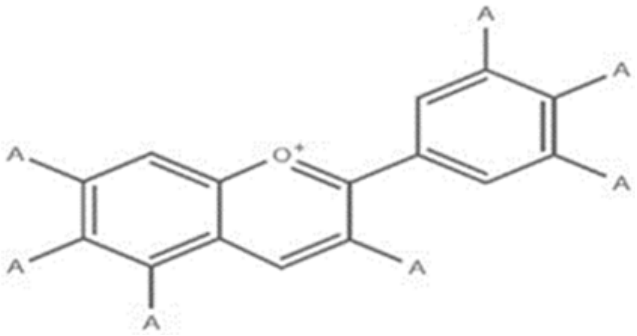


Figure 1. Structure of anthocyanin.

Table 1. Types of anthocyanins and their colours at specific pH[17]

S. No.	Type	Colour	pH
1	Cyanidin	Magenta	pH 7-8
2	Delphinidin	Purple	pH 3-11
3	Pelargonidin	Red	pH < 3
4	Peonidin	Magenta	pH 7-8
5	Petunidin	Purple	pH 3-11
6	Malvidin	Purple	pH 3-11

Anthocyanins can exist in different forms depending on the pH of their environment[18]. The eight conjugated bonds having the positive charge present in the anthocyanins result in a red or orange colour at acidic pH below 2 whereas at alkaline pH their colour changes to blue and purple. The intensity and colour of anthocyanins are also influenced by the total number of hydroxyl (-OH) groups as well as methoxyl ($-OCH_3$) groups in their structure. More hydroxyl groups lead to a bluish colour whereas more methoxyl groups lead to increased redness[2]. The six most common types of anthocyanins are listed in Table 1 along with their colours corresponding to the various pH values.

Anthocyanin's stability is affected by a variety of factors and can be improved by processing and storage at low temperatures, whereas the increase in temperature induces slow degradation of the anthocyanin pigments. Similarly, the exposure to light can be very destructive for the anthocyanins. Also, anthocyanins exhibit high reactivity towards metals, forming stable complexes with metals for instance iron, copper and tin. The presence of oxygen and hydrogen peroxide can lead to the oxidization of anthocyanins, which is accelerated by catalysts like the ascorbic acid[2].

3. Five Major Maharashtrian Sources of Anthocyanins

Anthocyanins have a significant role in the physiology of plants and are majorly stored in flowers and fruits, although they can be also found in other plant parts including the leaves, stem, and roots. These



Figure 2. Taxonomical classification of five major Maharashtrian sources of anthocyanins.

anthocyanins are considerably affected by various factors like light availability, temperature, agronomic factors and also the genetic makeup of the plant. Hence, the Total Anthocyanins Content (TAC) varies between different plants as well as cultivars of the same plants.

Maharashtra is famous for a variety of fruits and vegetables and also includes some important fruit zones like Marathwada, Western Deccan Area, Kokan, *etc*. From the popular fruits and vegetables of Maharashtra, the five major Maharashtrian sources of anthocyanins are Eggplant, Grapes, Jamun, Kokum and Pomegranate. From the studies, it has been observed that the Eggplant is the sole vegetable with high anthocyanin content[2,19]. The taxonomical classification of the five major Maharashtrian anthocyanin sources is represented in Figure 2.

3.1 Eggplant (*S. melongena*)

Eggplant (*S. melongena*) is, a member of the *Solanaceae* family and genus *Solanum* which consists of around 2000 various species. Eggplant is a majorly grown and consumed vegetable native to the Indian subcontinent and Southeast Asia; over time, Eggplant has become globally a common ingredient in Mediterranean, Middle Eastern, Asian, and African food dishes[20,21]. Eggplant is an annual crop produced in warmer countries like India, Italy, China, USA, France, Japan, Spain, and Korea[21,22].

Eggplant is known as the "King of Vegetables" because it is the most significant among all vegetables grown in India and is widely used in daily Indian cuisines. In India, the principal Eggplant producer states are Maharashtra, Bihar, West Bengal, Chhattisgarh, Orissa, Madhya Pradesh, Karnataka, Assam, Andhra Pradesh, Haryana, Uttar Pradesh, Tamil Nadu, and Gujarat; out of all, Maharashtra is the second largest Eggplant producer after West Bengal[21,23].

3.1.1 Morphological Aspects

Morphology of Eggplant varies across different varieties and species. Typically, the plant is characterised by broad, lobed leaves and produces fruit in various shapes, including oval, egg-shaped, elongated, and round. Their colour spectrum includes shades of purple, green, yellow, white, and even striped varieties with bicolour through a range of green and purple pigmentation. The outer skin of Eggplant is glossy and sometimes slightly waxy and the flesh is usually cream to pale green[21,22,24].

3.1.2 Functional and Therapeutic Roles

Eggplant significantly possesses various antioxidants such as α-carotene, lutein, lycopene, kaempferol, and myricetin, which protect human cells from oxidative damage[22,25]. It is beneficial in treating anaemia, lowering cholesterol levels by stimulating the intrahepatic metabolism of blood cholesterol, and high blood pressure[22]. These compounds collectively contribute to better digestion, bone health, and overall well-being of the individuals[26].

3.1.3 Phytochemical Aspects and Anthocyanin Content

The bioactive compounds present in Eggplant include phenolic compounds, flavonoids and alkaloids, contributing to its potential health benefits. Phenolic compounds such as Delphinidin also called Nasunin, which is an anthocyanin and chlorogenic acid found in Eggplant are associated with properties like anti-inflammatory, anti-oxidant and anti-cancer[26,27]. This reduces the effect of free radicals on the cells which prevents the development of cancer. Delphinidin also prevents the damage caused to the membrane of brain cells by free radicals, along with the prevention of neuroinflammation, memory loss and age-related mental retardation[22]. The anthocyanin content in Eggplant varies among different varieties and ranges from 4193-9863 mg/100g[7].

3.2 Grapes (*V. vinifera*)

Grape (*V. vinifera*) is a botanical berry belonging to the genus *Vitis*, native to the Mediterranean region[28]. Globally, India is one of the leading producers of Grapes, with Maharashtra as the highest producer followed by Karnataka, Tamil Nadu and Andhra Pradesh. In Maharashtra, Nashik and Sangli are the major producers of Grapes, and Nashik is called the 'Grape Capital of India[29,30].

3.2.1 Morphological Aspects

Grapes are non-climacteric fruits which occur in a bunch of 15 to 300 on deciduous woody vines of the flowering plant with a flexible stem that grows up to considerable lengths. The leaves are green with serrated edges and are

alternate, palmately lobed with three to seven lobes. The Grape berries have a broad colour spectrum, including green, red, purple and black, depending on the Grape variety and are spherical or slightly ovoid[28].

3.2.2 Functional and Therapeutic Roles

Grapes are important sources of phenolics such as resveratrol, flavonol quercetin, catechins, procyanidins, and anthocyanins with health benefits like reducing the chances of occurrence of cardiovascular diseases, improving cognition and neuronal function along with various properties like antitumor, anti-inflammation, antimicrobial activity, *etc*[31,32].

3.2.3 Phytochemical Aspects and Anthocyanin Content

Grapes contain various significant phytochemical compounds including phenolic compounds, aromatic acids, flavonoids, proanthocyanidins, and stilbenoids[33]. The Red Grapes contain anthocyanins ranging from 30-750 mg/100g[34].

3.3 Jamun (*Syzygium cumini*)

Jamun (*S. cumini*) belongs to the flowering plant family *Myrtaceae* and is commonly known as Indian blackberry. It is native to the Indian mainland and Southeast Asia, while it is also grown as an introduced species in East Africa, the USA and South America[35,36]. Jamun is an important fruit of India produced largely in Maharashtra, Gujrat, Uttar Pradesh as well as tropical and sub-tropical regions. In Maharashtra, the Sindhudurg from Konkan is the major producer of Jamun fruit[36-38].

3.3.1 Morphological Aspects

Jamun is a tropical evergreen tree which grows up to a height of 30 m. The Jamun fruits are single-seeded, elliptically shaped with size around 1-3 cm and grow in clusters of about 10-40 fruits. The fruit's colour ranges from deep-purple to bluish-black whereas the pulp can be purple-pink or greyish-white. Jamun fruits when raw are green in colour, and the colour changes to pink, then shining crimson, and finally to bluish purple as they completely ripen[35,37,39].

3.3.2 Functional and Therapeutic Roles

The presence of bioactive polyphenolic constituents, such as carotenoids, gallic acid, tannins, isoflavones, flavones and anthocyanins contributes to the nutraceutical nature and excellent therapeutic attributes of Jamun fruit like free-radical scavenger, hepatoprotective, anti-cancer, anti-HIV, antiallergic, anti-inflammatory, nephroprotective, anti-ulcer, anti-oxidant, antimicrobial properties along with blood purifying characteristics[35,37,40]. The Jamun fruit largely contains carbohydrates, vitamins, proteins, and minerals which improve the overall immunity and health of an individual and help to reduce stomach pain and flatulence by improving digestion[36,37].

3.3.3 Phytochemical Aspects and Anthocyanin Content

The therapeutic properties of Jamun are due to various phytochemicals including alkaloids, flavonoids, saponins, phenols, cardiac glycosides, *etc*. The Jamun fruit consists of anthocyanins like petunidin, cyanidin, malvidin, peonidin and delphinidin along with the non-anthocyanin phenolic compounds and flavonols[41]. Cyanidin and diglucosides give the purple colour to the Jamun fruit[37]. Anthocyanin content in Jamun fruit is found to be in the range from 115.38-210.76 mg to 803-1808 mg/100g[35,37].

3.4 Kokum (*Garcinia indica*)

Kokum (*G. indica*) often known as the "Cool King" of Indian fruits, is a member of the *Clusiaceae* plant family[42]. It is a tropical indigenous fruit primarily found in the Konkan region of Maharashtra, Goa, Karnataka, and Kerala, as well as the forests of Assam, West Bengal and Meghalaya[43].

3.4.1 Morphological Aspects

A tropical evergreen Kokum tree reaches 15 meters tall. Kokum fruit is a globular berry that measures about 2-4 cm in diameter and has a smooth, thick, leathery rind. The fruit changes colour from green to reddish-purple or dark purple as it ripens completely[44].

3.4.2 Functional and Therapeutic Roles

Kokum rinds include three key bioactive compounds, namely; anthocyanins, hydroxy citric acid, and garcinol, which have anti-cancer and anti-obesity properties[45].

3.4.3 Phytochemical Aspects and Anthocyanin Content

Bioactive substances such as anthocyanins, garcinol, isogarcinol, and hydroxycitric acid are abundant in Kokum fruits[46]. Approximately 2.4% of the total biomass of fruit is made up of anthocyanins[47]. Anthocyanin content reported in the Kokum fruit is in the range of 85 mg/100g[8].

3.5 Pomegranate (*Punica granatum*)

Pomegranate (*P. granatum*) also called "Super Fruit" contains significant amounts of antioxidant phytochemicals and has a variety of health benefits. Pomegranate is native to northern India and Iran, with India being the major Pomegranate producer across the globe. In India, the principal producer states are Maharashtra commonly called as "Pomegranate Basket of India" along with Uttar Pradesh, Gujarat, Karnataka, Tamil Nadu and Andhra Pradesh[48,49].

3.5.1 Morphological Aspects

Pomegranates are typically round fruits with a diameter of about 5-12 cm, although their size can vary. The outer skin or peel is thick and leathery, ranging in colour from yellow-orange to deep red or purple, depending on the variety and may also have a glossy appearance. The fruit is divided into several compartments, each containing juicy, jewel-like edible seeds known as arils which vary in colour from translucent to deep red.

3.5.2 Functional and Therapeutic Roles

Pomegranate arils are rich in polysaccharides, vitamins, fatty acids, and diverse biological compounds which play a preventive role against ailments such as hypertension, prostate cancer, cardiovascular issues and other infectious diseases. Pomegranate possesses various beneficial therapeutic properties such as antimicrobial, anti-hepatotoxic, antiviral, anti-inflammatory, anticancer, antioxidant, and anti-diabetic effects, contributing to skin health, cardiovascular well-being, enhanced sperm quality, and Alzheimer's prevention; hence named as a "Healing Food"[49].

3.5.3 Phytochemical Aspects and Anthocyanins Content

Pomegranate peel possesses a very high concentration of polyphenolic compounds including tannins, flavonoids and anthocyanins[50]. The Pomegranate arils have high anthocyanin concentrations of about 29.9%-73.2% of the total phenolics varying with cultivars[51]. The anthocyanin content present in the Pomegranate is 1.5-25.5 mg/100g[52].

Table 2 depicts the TAC in all five Maharashtrian anthocyanin sources.

4. Extraction Methods for Anthocyanins from Fruit Sources

A combination of plant metabolites including flavonoids, glycosides, alkaloids, phenolics and terpenoids are present in the initial crude extract[53]. Several methods can be utilised for anthocyanin extraction from the five Maharashtrian anthocyanin sources. These methods are unique and have profound results on the concentration, yield, stability and purity of extracted anthocyanins[54,55]. Anthocyanins can be extracted using various methods such as Solid Liquid Extraction (SLE), High Hydrostatic Pressure (HHP) Extraction, Supercritical Fluid Extraction (SFE), Pulsed Electric Field Extraction (PEFE), Ultrasound-Assisted Extraction (UAE), Agitated Bed Extraction (ABE); are summarised below along with their advantages and disadvantages as well as the extraction process conditions and corresponding anthocyanins

Table 2. Anthocyanin content (mg/100g) of five Maharashtrian anthocyanin sources

S. No.	Source of anthocyanin	Scientific name	Anthocyanin content (mg/100g)	References
1	Eggplant	*Solanum melongena*	4193 - 9863	7
2	Grapes	*Vitis vinifera*	30 - 750	34
3	Jamun	*Syzygium cumini*	803.04 -1808.08	35
4	Kokum	*Garcinia indica*	85.03	8
5	Pomegranate	*Punica granatum*	1.5-25.5	52

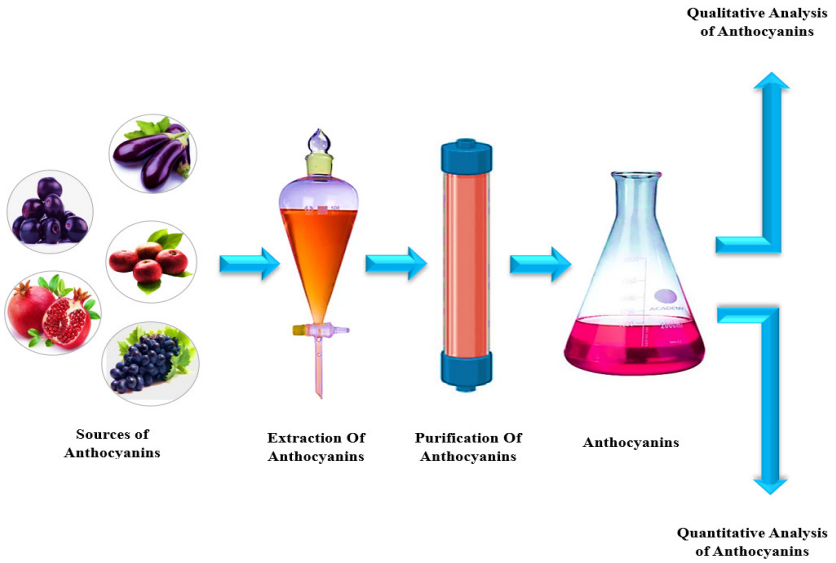


Figure 3. Extraction methods, identification, qualitative analysis, purification and quantitative analysis of anthocyanins.

yield obtained. The complete scheme of the process of extraction of anthocyanins from the five Maharashtrian anthocyanin sources namely; the Eggplant, Grapes, Jamun, Kokum and Pomegranate along with the identification and purification to obtain the high quality and stable anthocyanins is represented in Figure 3.

4.1 Solid-Liquid Extraction (Solvent Extraction)

Anthocyanins due to their polar characteristics can be extracted from the five Maharashtrian sources of anthocyanins by applying the Solid Liquid Extraction (SLE) method using various polar solvents such as ethanol, methanol, acetone as well as water. The frequently used extraction solvents for anthocyanins from the various Maharashtrian sources are represented in Table 3.

For Eggplant, the solid-liquid extraction was performed for 30 min at 50°C using 96% ethanol and resulted in the maximum concentration of anthocyanin, Delphinidin 3-O-rutinoside around 1.11±0.08 mg D3G/g DM from the Eggplant peels[56,61]. While, during the extraction of anthocyanins from Grapes, 20 % methanol was found to be more effective than 73% ethanol and water[57,62]. The extraction process for the Jamun was carried out for 8 h by boiling the solution of fruit sample and ethanol or acidified ethanol with the sample: solvent ratio of 1:25 at around 78°C, yielding the anthocyanins about 5.3±0.1 mg C3G/g DM[58]. Anthocyanins from Kokum were extracted using the aqueous two-phase system method with solvents acidified water and ethanol-propanol mixture and about 5.53 mg/g anthocyanin yield was obtained[8,46]. For Pomegranate the extraction of anthocyanins was carried out using methanol as a solvent which resulted in a high concentration of anthocyanins up to 102.2 ± 16.4 mg C3G/g DM[59,60,63].

Table 3. Solvents utilized in the extraction of anthocyanins

S. No.	Sources	Solvents utilized	References
1	Eggplant	70% and 96% Ethanol and HCL	56
2	Grapes	Methanol, Ethanol, and Water	57
3	Jamun	Ethanol and HCL	58
4	Kokum	Acidified water and Ethanol + Propanol	46
5	Pomegranate	Water and Methanol or Ethanol	59,60

The solid liquid extraction method is advantageous for the extraction of anthocyanins as it is easy technique and requires simple instrumentation. But this method has some limitations like it is a slow process, requiring higher temperature and large volumes of solvents.

4.2 Supercritical Fluid Extraction (SFE)

Supercritical fluid extraction with Supercritical carbon dioxide (SC-CO_2) as supercritical fluid is mainly used for anthocyanin extraction from Eggplant, Grapes, Jamun and Pomegranate; which is more efficient and provides maximum yields[64-67]. SFE is carried out using a supercritical fluid extractor with ethanol as a co-solvent which enhances the polarity of the solvent and improves the efficiency of SC-CO_2 extraction as compared to solvent extraction[64]. Chatterjee *et al.,*[65] reported the highest concentration of anthocyanin (17.04 mgD3G/g DM), with two major forms Delphinidin-3-rutinoside and Delphinidin-3-glucoside. These were obtained from Eggplant extracts by using SFE and it was observed that the concentration of Delphinidin-3-rutinoside was higher than Delphinidin-3-glucoside[56,65]. Pazir *et al.*[66] reported that SFE for Grape juice performed at 95°C for 180 min gave the highest concentration of anthocyanin (1.9321 mgC3G/g DM). The Supercritical Fluid extraction of anthocyanin from Grape juice resulted in 63% more anthocyanin yield than other conventional methods[66,68]. As per the findings of Maran *et al.*[64] the anthocyanin was obtained in greater concentration (2.312 mgC3G/g DM) from Jamun extract by using SFE[54]. anthocyanins extraction from Pomegranate by SFE the maximum yield was obtained at 40 MPa and 40°C[67].

The SFE is an advantageous technique for the extraction of anthocyanins as it requires less extraction time and is carried out at lower pressure using a small amount of solvent and the SC-CO_2 can be easily separated from the anthocyanins[68,69]. Whereas, the need for co-solvent and higher temperatures for anthocyanin extraction from different sources of plants are some disadvantages of this method[68].

4.3 Ultrasound-Assisted Extraction (UAE)

Ultrasound-assisted extraction method employs ultrasound energy and an appropriate solvent to extract anthocyanins from the Eggplant, Grapes, Jamun and Pomegranate. UAE is advantageous as it accelerates the destruction of cell walls thereby enhancing the extraction rate as well as retaining the functionality of bioactive compounds extracted[70,71]. UAE yielded highest concentration of anthocyanin compound Delphinidin 3-O-rutinoside (1.04 ± 0.10 mg D3G/g DM) from Eggplant extracts using 96% ethanol and extraction performed for 30 min at 25°C at an ultrasound frequency of 20 kHz[56]. Eggplant yielded the highest amount of anthocyanins (2.410 mg C3G/g DM) using a specific extraction process: 54.4% methanol solvent, 37 kHz frequency, 55.1°C temperature, and 44.85 minutes of extraction time[72]. It was observed that the UAE method gave better yields than solvent extraction[56,65]. Anthocyanins were extracted from Grapes skin cells at a high-pressure range of 200 MPa and high-power ultrasound frequencies between 20-25 kHz[73]. The UAE was performed at 63.8 °C for 48 min time with the sample-to-liquid ratio of 1:15, using the 78.9% ethanol solvent and resulted in the maximum anthocyanin yield (1.93 mg/g DM) from the Grapes[34]. Extraction of anthocyanins from Jamun was performed in the ultrasonicator bath at a frequency of 40 kHz, which resulted in a higher concentration of Delphinidin-5-glucoside (54.2 mg C3G/g DM) from Jamun extracts[59,68,74]. An ultrasonic processor with 400W and frequency at 20 kHz was used for the extraction of anthocyanin from Pomegranate which resulted in a greater anthocyanin yield[75].

The UAE is advantageous as it is a highly flexible, affordable, simple and rapid method that allows selective extraction and gives the maximum concentration of anthocyanins in smaller duration of time, but this method is highly expensive limits its utilization for the large-scale applications[68,76].

4.4 High Hydrostatic Pressure (HHP)

High hydrostatic pressure extraction utilizes higher pressure condition for extraction of the anthocyanins from sources like Grapes and Pomegranate. HHP yields a high concentration of anthocyanins in the range of 20-80 % from the Grape juice at a pressure of 550 MPa for 10 min with pressure transmitting medium as water and glycol (20:80)[77,78]. Liu *et al.,*[79] reported in their study that HHP resulted in a lower degradation of anthocyanin compounds after treatment on Grape juice than other conventional methods. For Pomegranate, the maximum operating pressure was 900 MPa at 45°C for 10 min with pressurized fluid as ethanol and water while the castor oil as lubricant. Ferrari *et al.,*[80] reported that the process variables were temperature and pressure which significantly resulted in selective anthocyanin extraction[80]. The HHP method for extraction of

anthocyanins is beneficial due to the smaller time of extraction and lesser quantity of solvents required. But has disadvantages such as requiring higher pressure that can affect the activity and stability of extracted anthocyanins and is an expensive method[68,78].

4.5 Pulsed Electric Field Extraction (PEFE)

PEFE is an advanced non-thermal technology, which assists in easier and more efficient extraction, identification and analysis of anthocyanins than other thermal techniques[81,82]. This method involves the application of a high voltage electric pulse for a short duration to the plant source sample which disrupts the cell membranes and releases anthocyanins. The PEFE is utilized for extraction of anthocyanins from Eggplant, Grapes, and Pomegranate. For Grape pulp, the voltage electric pulse of about 20 kV/cm applied for a short time resulted in considerable anthocyanin yield (0.84 mgC3G/g DM)[83,84]. In another study by Barba *et al.*,[85], it was found that PEFE enhanced the extraction yield by 22-55% when performed at 13.3 kV/cm, and it was also observed that PEFE resulted in a higher rate of recovery of anthocyanin than UAE and other conventional methods. Optimizing extraction parameters such as pulse width, frequency, and voltage; is crucial for anthocyanins from grapes extraction from grapes. These parameters rely on equipment and grape variety[86]. PEFE is used to extract anthocyanin from Eggplant which gives a high concentration of anthocyanins including Cyanidin, Delphinidin, Malvidin, Petunidin and Peonidin[82]. During PEF treatment on Pomegranate the electric field strength was set at 10 kV/cm at 50°C which facilitated the extraction of selective anthocyanin compounds[87,88].

The PEFE is a highly advantageous method as it is an affordable technique which requires less time, and lower energy and can be carried out at room temperature, hence is easier to implement on a larger scale for the extraction of anthocyanins. However, the fluctuations in the high electric field applied during the extraction process can cause damage to the anthocyanins[68,82,88].

4.6 Agitated Bed Extraction (ABE)

Agitated Bed extraction is performed in a rotary shaker with a suitable solvent like ethanol[58]. The ABE is used to extract anthocyanins from the Grapes and Jamun. The agitation speed was kept at 460 rpm at 45°C with a solid/solvent ratio of 1:40 to extract anthocyanins from Grapes. The ABE led to an increase in the anthocyanin yield from Grapes by 0.7-1% as compared to the UAE[89]. For extraction of the anthocyanins from Jamun, agitation was carried out at 150 rpm for 2 h at 30°C with a solid/solvent ratio of 1:10 which yielded the TAC of about 8.0±0.2 mgC3G/g DM[58].

From the results of these extraction methods, it can be observed that Supercritical Fluid Extraction and Ultrasound-Assisted Extraction methods are highly effective and allow for selective extraction of anthocyanins[68,69].

The comparison of anthocyanin yield (mg/g DM) obtained from the five Maharashtrian sources by using the various extraction techniques is represented in the Table 4.

5. Identification and Qualitative Analysis of Anthocyanins

The qualitative analysis is performed to determine the presence of anthocyanins in fruit extract samples of the five Maharashtrian sources of anthocyanins namely; Eggplant, Grapes, Jamun, Kokum and Pomegranate. The qualitative analysis of anthocyanins is a very complex process due to their property to undergo configurational modifications along with the presence of other compounds like flavonoids having similar structures and reactivity characteristics like anthocyanins[92].

The most prevalent methods utilized for structural characterizations and identification of anthocyanins include; firstly, the chromatographic techniques like conventional separation technique of Thin-Layer Chromatography (TLC), Paper Chromatography (PC), and High-Performance Liquid Chromatography (HPLC) applied in combination with two major detection methods, namely the Ultraviolet-Visible spectroscopy (LC-UV) and Mass spectrometry (LC-MS) while secondly, the Spectroscopic techniques like Ultraviolet-Visible Spectroscopy and Nuclear Magnetic Resonance (NMR)[92-94].

Table 4. Comparison of anthocyanin yield (mg/g DM) obtained from five major Maharashtrian sources by using various extraction techniques

S. No.	Major Maharashtrian source	Anthocyanin yield obtained by extraction technique (mg/g DM)					
		SLE	SFE	UAE	HHP	PEFE	ABE
1	Eggplant	1.11± 0.08[56,61]	17.04 ± 0.10[55]	1.04± 0.10[56]	-	-	-
2	Grapes	-	1.9321 ± 0.10[66]	1.93± 0.2[34]	11.58± 0.05[78]	0.84± 0.1[83,84]	-
3	Jamun	5.3 ± 0.10[58]	2.312 ± 0.76[54,64]	54.2± 0.5[59,68,74]	-	-	8.07±0.2[58]
4	Kokum	5.53 ± 0.07[8,46]	-	21.0± 0.10[90]	-	-	-
5	Pomegranate	102.2±16.4[59,60,63]	-	-	-	-	20.6±0.15[91]

Note: Solid Liquid Extraction (SLE), Supercritical Fluid Extraction (SFE), Ultrasound-Assisted Extraction (UAE), High Hydrostatic Pressure (HHP) Extraction, Pulsed Electric Field Extraction (PEFE) and Agitated Bed Extraction (ABE)

5.1 Chromatographic Techniques

5.1.1 *Paper Chromatography (PC) and Thin-Layer Chromatography (TLC)*

Paper Chromatography (PC) and Thin Layer Chromatography (TLC) are two chromatographic techniques conventionally utilized for identification and qualitative analysis of anthocyanins from fruit sources like Eggplant, Grapes, and Pomegranate[92,95].

Paper chromatography is a traditional analytical technique, first introduced and used in 1948 for the identification of anthocyanins by Bate-Smith. Later, this technique was significantly utilized by Harborne and coworkers for the separation and structural identification of anthocyanins by developing suitable solvents for separating them in the years 1958 to 1967, which made it possible to separate the hydrophilic mixtures of plant anthocyanins which was not possible earlier[95].

Earlier the PC was used largely in laboratories due to its simplicity, cost-effectiveness and constant development. But, due to its disadvantages like low product quantity of pure anthocyanins and long development times, nowadays paper chromatography is not widely used for the identification of anthocyanins[92].

Among analytical techniques, TLC stands out for its speed, affordability, and sensitivity in the qualitative analysis of anthocyanins. This advantage stems from its ability to achieve faster elution times compared to other methods[92,96,97]. The TLC analysis can be performed using various stationary and mobile phases to evaluate the presence of anthocyanins in extracted solutions.

Bahreini *et al.,*[98] performed TLC using the silica gel F 254 and the solvent mixture of ethyl acetate, water, formic acid, formic acid and glacial acetic acid in the ratio of 100:26:11:11 (v/v) as mobile phase for confirming the anthocyanins in Eggplant peel extracts and observed that anthocyanins were present in Eggplant and verified by the presence of red spots on the TLC plate after visualisation under visible light. While Filip *et al.,*[99] performed TLC using the Macherey-Nagel cellulose CEL 300-25 glass plates and mobile phase consisting of the hydrochloric acid, glacial acetic acid and water in a ratio of 40:4:12 (v/v) for the Berry fruit sample. After completion of TLC, in reflectance-absorbance mode, the densitometric scanning is performed at 520 nm wavelength.

5.1.2 *High-Performance Liquid Chromatography (HPLC)*

The identification of anthocyanins using High-Performance Liquid Chromatography (HPLC) is carried out using reverse-phase columns for example polystyrene, octadecyl silane or phenyl-bonded columns and utilises the mobile phase containing solvent mixture of acetonitrile-water or methanol-water. The acidic mobile phase having a pH less than 2 is utilised to obtain optimal and reproducible results. It is crucial to control the mobile phase pH to maintain the stability of anthocyanin compounds to decrease the tailing of peaks in the chromatogram. Reverse-phase chromatography exploits the relationship between polarity and retention time for anthocyanin separation. As the number of hydroxyl groups on the flavylium ion increases, so does polarity, leading to a decrease in retention time. Consequently, anthocyanins elute in a specific order based on their hydroxylation pattern:

Delphinidin (most hydroxyl groups, shortest retention time) followed by Cyanidin, Petunidin, Pelargonidin, Peonidin, and finally Malvidin (least hydroxyl groups, longest retention time)[92,100,101].

HPLC is a significant technique used in the identification and qualitative analysis of anthocyanins due to its advantages like high sensitivity and resolution, less analysis time and lower quantity of sample required for analysis[102]. Mostly, for the identification of anthocyanins in fruit extracts, HPLC is integrated with detection techniques like Ultraviolet-Visible spectrophotometry detection (LC-UV) and Mass Spectrometry detection (LC-MS)[92,103,104].

5.1.2.1 HPLC with UV-Vis Spectrophotometry Detection

In an acidic medium, the distinctive absorption maximum at 520 nm allows the anthocyanins to be accurately identified and distinguished from the other flavonoids present in fruit extracts. The absorption maxima of anthocyanins vary based on their molecular structure. Pelargonidin exhibits a peak at 520 nm, while Peonidin and Cyanidin share a maximum absorption at 535 nm. Petunidin, Delphinidin, and Malvidin, on the other hand, demonstrate a higher degree of conjugation within their structures, leading to a red-shifted maximum absorption at 544 nm[92,104,105].

5.1.2.2 HPLC with Mass Spectrometry Detection (LC-MS)

Liquid chromatography-mass spectrometry (LC-MS) has emerged as a powerful analytical tool for anthocyanin identification. Its capabilities extend beyond simple identification, allowing for the determination of molecular weight, characterization of complex anthocyanin mixtures, and elucidation of their structural features[92,102]. LC-MS integrates the separation of anthocyanins by utilizing liquid chromatography by sensitively detecting the compound-specific precursor *m/z* and characteristic fragment *m/z* which results in selective, accurate and effective identification of the extracted anthocyanins[106].

The various ionisation methods used in LC-MS which are appropriate for the identification of anthocyanin include Matrix-Assisted Laser Desorption Ionisation (MALDI), Atmospheric Pressure Chemical Ionisation (APCI), Continuous-Flow Fast-Atom Bombardment (CF-FAB), and Electrospray Ionisation (ESI).

Earlier, CF-FAB was the commonly used technique in LC-MS. However, due to its disadvantage of the need to perform sample purification and dissolution in a polar matrix before injection for analysis. To avoid this problem ESI method is used for the effective identification of anthocyanins, which is a soft ionization technique that provides information regarding the molecular weight and structural configuration of anthocyanins[92,93,106].

For anthocyanin detection by LC-MS, a typical method utilizes a C18 column and injects 10 µl sample volume. The mobile phase consists of a 5% (v/v) formic acid in acetonitrile mixture maintained at a flow rate of 1 mL/min and a temperature of 30°C. Detection is achieved by monitoring the wavelength of 520 nm[93]. Mass spectrometric detection employed positive ion mode with an ionization voltage of 3.5 kV. The source temperature was set to 200°C, utilizing nitrogen (N_2) as the nebulizer gas at a flow rate of 1.5 L/min. Additionally, drying gas (air) was applied at a pressure of 0.1 MPa. The experiment employed a segmented MS scan, acquiring data in three distinct mass ranges: m/z 200-1500 (primary), m/z 100-1500 (secondary), and m/z 50-1500 (tertiary). Data collection was automated, utilizing argon (Ar) as the collision gas with a collision energy setting of 50%[93].

Using primary mass spectra, the relative molecular masses obtained for the fragment (m/z) of anthocyanins are shown in Table 5.

5.2 Spectroscopic Techniques

5.2.1 Nuclear Magnetic Resonance (NMR) Spectroscopy

Nuclear Magnetic Resonance (NMR) Spectroscopy is another significant method applied for the qualitative analysis of anthocyanins[102]. NMR spectroscopy determines the accurate anthocyanin structures based on differences in chemical shifts and proton signals. The anthocyanins are analysed by detecting changes in the NMR parameters like self-diffusion coefficient, chemical shift, relaxation rate, and linewidth. Due to this NMR spectroscopy is considered advantageous over the chromatographic technique, LC-MS for the identification and qualitative analysis of anthocyanins[93].

For the analysis of anthocyanins by NMR method, high-purity anthocyanins are required. The 0.1mg/ml anthocyanin sample solution was prepared by dissolving 1mg anthocyanin powder in tritiated methanol and passing it through the 0.22-micron filter membrane[102]. Then the monomer is dissolved in CF_3COOD-CD_3OD solvent in a ratio of 5:95 (v/v) to obtain a 10 mg/ml sample concentration. Anthocyanin structural characterization was performed using a Bruker AVANCE III 600 MHz spectrometer equipped with a CPQCI probe. This probe facilitates both Hydrogen-1 (^1H) NMR spectroscopy at 600 MHz and Carbon-13 (^{13}C) NMR spectroscopy at 150 MHz. The analysis was conducted at a controlled temperature of 25°C [93,107].

5.2.2 UV-Visible Spectroscopy

Ultraviolet-visible spectroscopy is extensively utilized for the identification and characterization of anthocyanins extracted from all five Maharashtrian sources of anthocyanins[106,108]. Anthocyanins exhibit characteristic absorption spectra with two distinct bands. The first band, located in the Ultraviolet (UV) region, has a wavelength range of 260-280 nm. The second, more prominent band, appears in the visible region between 490-550 nm. Notably, the absorption maxima within this visible range for various anthocyanins fall between 520 and 546 nm, as documented in previous studies[99,106]. Table 6 depicts the absorption maxima in the visible range for different types of anthocyanins present in five major Maharashtrian sources.

The factors like pH of anthocyanins and the nature of the solvent affect the position and intensity of absorption bands in the visible region. At pH equal to 1, there is a coloured oxonium form of anthocyanin as the predominant form, whereas at pH 4.5 the predominant form is the colourless semi-ketone form. At alkaline pH, anthocyanins appear blue, which results in the shift of wavelength to higher wavelengths[99,111].

Table 5. Fragment *(m/z)* of types of anthocyanins[93].

S. No.	Type of anthocyanins	*m/z*
1	Cyanidin	287
2	Delphinidin	303, 262, 172
3	Pelargonidin	271
4	Peonidin	301, 286, 258
5	Petunidin	316, 302, 274
6	Malvidin	311, 299, 287

6. Purification and Quantitative Analysis of Anthocyanins

During the process of extraction of anthocyanins from different Maharashtrian sources namely, Eggplant, Grapes, Jamun, Kokum and Pomegranate; a large number of impurities like sugars, proteins, organic acids, *etc*. are also extracted along with anthocyanins. The presence of impurities significantly hinders the final quality and stability of anthocyanin extracts. Consequently, the purification of extracted anthocyanins becomes a critical step in obtaining high-purity and stable anthocyanins from diverse Maharashtrian sources. The methods used for the purification of anthocyanins include HPLC and column chromatography[112].

Additionally, the concentration of the anthocyanins obtained from these Maharashtrian sources can be determined by performing quantitative analysis after the extraction and purification of anthocyanins. The five major methods used for quantitative analysis include Gas

Table 6. Absorption maxima in the visible range of different types of anthocyanins[17,92,95,99]

S. No.	Type of anthocyanins	Absorption maxima (in nm)	Colours produced	Sources	References
1	Cyanidin	535	Magenta	Grapes, Kokum, Pomegranate	47,109,110
2	Delphinidin	544-546	Purple, Blue	Eggplant, Grapes, Jamun, Pomegranate	35,95,98,109,110
3	Pelargonidin	520	Orange, Red	Pomegranate	110
4	Peonidin	532-535	Magenta	Grapes	109
5	Petunidin	543-544	Purple	Grapes, Jamun	35,109
6	Malvidin	542-544	Purple	Grapes, Jamun	35,109

Chromatography-Mass Spectrometry (GC-MS), Liquid Chromatography-Mass Spectrometry (LC-MS), pH Differential Method, Subtraction Method and Single pH Method. The GC-MS and LC-MS results in the mass-to-charge (m/z) peaks on a chromatogram, which is used to quantify the anthocyanins present in the sample. The information regarding the different anthocyanin species present in the sample can be determined using a single pH method. Whereas, the anthocyanin quantification using the subtraction method is based on the comparison between absorbance change in samples prior and later to chemical reaction between sulphur dioxide and anthocyanins and the pH difference method analyses only monomeric anthocyanins[102].

6.1 Purification of Anthocyanins

6.1.1 High-Performance Liquid Chromatography (HPLC)

High-Performance Liquid Chromatography (HPLC) serves as a versatile tool for anthocyanin research. It facilitates the purification, separation, identification, and quantification of anthocyanins extracted from various plant sources, including Eggplant, Grapes, Jamun, Kokum, and Pomegranate[113].

The analysis of anthocyanins in Eggplant peel extract was performed using the typical HPLC-DAD K2600 with the formic acid (5%) and acetonitrile (100%) as the solvents and the chromatogram was monitored at 520 nm. Four glycosylated anthocyanin structures were detected in Eggplant, namely the Delphinidin-3-rutinoside-5-glucoside (5.68%,1), Delphinidin-derivative isobaric (1.63%,2), Delphinidin-3-glucoside (1.25%,3), and Delphinidin-3-rutinoside (91.43%,4)[98].

HPLC analysis successfully separated five anthocyanin 3-monoglucosides from Grapes: Malvidin-3-glucoside, Delphinidin-3-glucoside, Cyanidin-3-glucoside, Peonidin-3-glucoside, and Petunidin-3-glucoside. The separation was carried out in a 250mm long C12 Max-RP column with a 4 µm stationary phase while the mobile phase consisting of water: acetonitrile mixture in ratio of 97:3 in solvent A and ratio of 40:60 in solvent B (pH adjusted to 1.8 by adding formic acid)[64,109].

The Zorbax SB-C18 column with UV-Vis detector was used to identify the extracted anthocyanins from Jamun fruit using HPLC with the mobile phase consisting the mixture of water and methanol with 5% formic acid for purification. Three diglucosides anthocyanins, namely; Delphinidin-3,5-O-diglucoside, Malvidin-3,5-O-diglucoside, Petunidin-3,5-O-diglu coside were found in Jamun[35].

HPLC was also adopted for the identification of anthocyanins in Kokum fruit. The 1% acidified solution was used to extract the anthocyanins which were then subjected to an ultrafiltration unit using 10 kDa membrane. A gradient mobile phase system, employing solvent A (acetonitrile) and solvent B (aqueous mixture of 1.0% phosphoric acid, 5.0% acetonitrile, and 3.0% acetic acid), successfully separated anthocyanins in the sample using HPLC. This resulted in the detection of two major peaks corresponding to Cyanidin-3-glucoside and Cyanidin-3-sambubioside[47].

An HPLC system equipped with a UV-Vis Beckman detector and a LiChrocart 100 RP-18 column was employed for the identification of anthocyanins extracted from Pomegranate. The mobile phase consisted of 5% formic acid in methanol. Analysis revealed the presence of several anthocyanin species, including Cyanidin 3,5-diglucoside, Delphinidin 3,5-diglucoside, Pelargonidin 3,5-diglucoside, Cyanidin 3-glucoside, Delphinidin 3-glucoside, and Pelargonidin 3-glucoside[110]. Various anthocyanin pigments found in the five Maharashtrian sources of anthocyanin are listed in Table 7.

6.1.2 Column Chromatography

Column chromatography is a popular method for separating and purifying anthocyanins. The principle behind the purification and separation by using column chromatography is that the distribution coefficients of anthocyanins in solid and mobile phases are different, which leads to the separation of anthocyanins and the removal of impurities. The anthocyanins extracted from different sources were purified using column chromatography having a column packed with Sephadex 100, microporous resins (XDA-7HP Resins), and polyamide resins and utilised 40% ethanol for elution to obtain high-quality anthocyanins[88].

6.2 Quantitative Analysis of Anthocyanins

6.2.1 Liquid Chromatography and Mass Spectrometry (LC-MS)

Liquid chromatography-mass spectrometry (LC-MS) represents a powerful analytical technique that

combines the separation capabilities of LC with the high specificity and sensitivity of MS. This synergy allows for the robust quantitative analysis of anthocyanins, including the determination of their molecular weight and structural elucidation.

LC-MS analysis employing an Agilent 1100 LC/MSD Trap-SL system with Electrospray Ionization (ESI) facilitated the purification and identification of anthocyanins extracted from Pomegranate. Nitrogen gas served as the nebulizer (pressure: 40.0 psi, flow rate: 9.0 L/min) and drying gas (temperature: 350°C) during the analysis. Mass spectra were acquired in positive ionization mode with a capillary voltage of 3.5 kV, covering a mass range of 100 to 1,200 m/z[115,116].

6.2.2 Gas Chromatography and Mass Spectrophotometry (GC-MS)

The GC-MS is the most powerful analytical technique used for determination of the molecular structure of anthocyanins, which is performed by using fused silica HP-5MS capillary column of dimension 30m, 0.25mm, film thickness 0.25m along with Hewlett Packard 6890 gas chromatograph and oven temperature ranged between 60-280°C. Helium served as the carrier gas in the GC-MS analysis, maintaining a flow rate of 2 mL/min. The ionization source operated at 70 eV with a temperature of 200°C during the mass spectrometry (MS) phase[97,117].

6.2.3 Single pH Method

The initial step in this method involves determining the Specific Extinction coefficient (ε), also known as the Molar Extinction coefficient, of the anthocyanin. Then TAC is calculated at the specific wavelength of absorbance according to the Beer-Lambert law[102].

The anthocyanin concentration is determined by using equation 1:

$$\text{Anthocyanin content (mg/L)} = (1000*MW*DF*A)/(\varepsilon*1) \quad \text{Eq. 1}$$

where, MW-molecular weight of anthocyanin, DF-dilution factor, ε-specific extinction coefficient, and 1 is the constant path length which is 1cm [102].

6.2.4 Subtraction Method

Anthocyanins have spectral characteristics which disappear in the visible region on bleaching the anthocyanins using sulphur or sulphite while the bleaching using sulphur dioxide could not affect the absorbance of anthocyanins. The absorbance at a specific wavelength is the comparison between the two measurements of absorbance taken before and after a chemical reaction due to bleaching. Using the working curve of standard anthocyanin as a reference, absorbance is used to determine anthocyanin concentration.

The anthocyanin concentration is obtained using equation 2:

$$\text{Anthocyanin content (mg/L)} = (A1-A2)/k \quad \text{Eq. 2}$$

where, absorbances A_1 and A_2 denote the pre- and post-bleaching measurements, respectively; k is the slope of the standard working curve of standard anthocyanin[102,118].

If there is the presence of a phenyl or methoxy group at the C4 position of Anthocyanin, then the quantitative analysis using the subtraction method is not suitable[102].

6.2.5 pH Differential Method

The pH differential method stands out as a rapid and straightforward spectrophotometric technique for

Table 7. Different anthocyanin pigments found in five Maharashtrian sources

Sr. No.	Sources	Anthocyanin pigments	References
1	Eggplant	Delphinidin-3-rutinoside, Delphinidin-3-glucoside, Delphinidin-derivative isobaric, Delphinidin-3-rutinoside-5-glucoside	98
2	Grapes	Peonidin-3-glucoside, Malvidin3-glucoside, Cyanidin3-glucoside, Delphidin-3-glucoside, Petunidin-3-glucoside	64,109
3	Jamun	Malvidin-3,5-O-diglucoside, Petunidin-3,5-O-diglucoside, Delphinidin-3,5-O-diglucoside	35
4	Kokum	Cyanidin-3-sambubioside, Cyanidin-3-glucoside	47,114
5	Pomegranate	Cyanidin 3,5-diglucoside, Delphinidin 3,5-diglucoside, Pelargonidin 3,5-diglucoside, Cyanidin 3-glucoside, Delphinidin 3-glucoside, Pelargonidin 3-glucoside	110

anthocyanin analysis. An irreversible colour change in the monomeric anthocyanin occurs due to a change in pH. The coloured flavylium cation is obtained at 1 pH, whereas the uncoloured semi-ketone exists at 4.5 pH. The anthocyanin concentration is directly proportional to the absorbance difference of anthocyanin at wavelength 520 nm and 700 nm at different pH[118-123].

Equation 3 was employed to calculate the effect of pH on the absorbance of the sample at various wavelengths:

Absorbance (A) = (A520nm – A700nm)
pH 1.0 - (A520nm – A700nm) pH 4.5 Eq. 3

The concentration of monomeric anthocyanin pigment can be obtained from equation 1. However, polymeric forms of anthocyanin are resistant to colour change due to the change in pH. Hence, this method is not suitable for measuring the concentration of the polymeric anthocyanin pigments[102,118].

7. Applications of Anthocyanins

Anthocyanins have a broad range of applications across various industries. In the textile industry, they serve as natural dyes. In the food and beverage industry, they find use as colourants and additives. Additionally, the cosmetic industry utilizes them in skin care products, sunscreens, lipsticks, eyeshadows, and blushes for their vibrant colours[8,114].

Anthocyanins also serve as a potent nutraceutical and pharmaceutical ingredient in healthcare and pharmaceutical industries and are beneficial to human health by protecting them against prevalent diseases like cardiovascular disease, cancer, diabetes, and neurodegenerative diseases[3-5]. Anthocyanins have versatile applications in these various industries which are summarized in Figure 4.

7.1 Cosmetic Industry

In the cosmetic industry, anthocyanins have extensive applications as natural colourants to produce bright hues ranging from red to blue. Anthocyanins are mainly used in skincare products, sunscreens, nail polishes, lipsticks, perfumes, deodorants, hair care products, hair dyes, styling products, *etc*. The anthocyanins associated with cosmetic products provide a healthy aging outcome due to their excellent bioactive properties like antioxidant characteristics which protect skin from oxidative stress, UV-absorbing capacities serve as strong UV protectors for skin and reduces photoaging, which enhances the application of anthocyanins as Biocosmetics[4,124].

7.2 Food and Packaging Industry

The global market for natural food pigments is experiencing stable growth with a Compound Annual Growth Rate (CAGR) of about 6.22%, which reflects the increasing recognition of benefits and applications of natural pigments including anthocyanins which are significantly used in food industries[125].

The bioavailability and stability of anthocyanins in food products can be enhanced through their interaction with dietary proteins, which influences the functions, structure and nutritional value of proteins, and provides an effective strategy for maintaining the colour quality of food products[126,127].

The development of eco-friendly packaging films is a novel packaging approach driven by environmental concerns and presents a sustainable solution for reducing non-renewable resource usage. These packaging films serve as carriers for anthocyanins, contributing to their potential applications in the food industry[128].

Anthocyanins obtained using plant extracts can be absorbed in carrier filter paper which will act as a colorimetric sensor in intelligent packaging whose colour transitions from red to green with variations in pH of food products, that offers a convenient, non-destructive, and visual method for monitoring food spoilage during storage and predicting the shelf life of the food products. This smart packaging allows consumers to easily determine the quality of food products by visualizing the package colour, which can reduce food waste and improve the overall food supply chain[129-131].

7.3 Nutraceutical Industry

Nutraceuticals are nutrients that modulate physiological and pathophysiological molecular mechanisms and have beneficial health outcomes[16]. Nutraceuticals serve the purpose of delivering bioactive compounds to the body in higher quantities than those of normal food materials[132]. Anthocyanins are gaining popularity

in the Nutraceutical industry due to their bioactive properties and diverse health benefits.

Anthocyanins have a significant role in plants as antioxidants, phytoalexins, and in plants' chemical defence mechanisms against different infections[132]. Similarly, anthocyanins offer a range of health benefits to our body and possess anti-inflammatory, antimicrobial, anti-carcinogenic, anti-fibrotic, and antioxidant properties which have significant health benefits like vision enhancement, induction of apoptosis, and neuroprotective effects, due to this anthocyanins can be favourably used in the treatment of cancer, neurological diseases, inflammation, ageing, and diabetes[3-5,96,133].

The functional foods prepared by incorporation of anthocyanins are red rice used for the treatment of cardiovascular diseases and abdominal pain. Canadian purple wheat contains 13 major anthocyanins of which Cyanidin 3-glucoside is the major one. This purple wheat can prevent obesity and related metabolic complications and is used to produce purple bread, and noodles pasta[134-138].

7.4 Pharmaceutical Industry

Pharmaceuticals are a group of organic compounds used to treat various diseases and improve the quality of human life[139]. Anthocyanins are very potent pharmaceutical ingredients due to their various health-beneficial properties like anti-oxidative, anti-angiogenesis, anti-cancer, anti-diabetes, anti-obesity, and anti-microbial. Anthocyanins are water-soluble pigments which can be rapidly absorbed in the bloodstream and manifest a very powerful biological activity which makes them very advantageous in the treatment and prevention of several diseases namely, diabetes, neurodegenerative disorders, cancers, cardiovascular diseases, metabolic diseases, microbial infections, *etc.*[3-5,133]. In the prevention of these diseases, anthocyanins follow different mechanisms of action like inflammatory cytokines signalling, free-radical scavenging, and variations in blood biomarkers[5]. Table 8 describes the different mechanisms of action of anthocyanins to prevent various diseases.

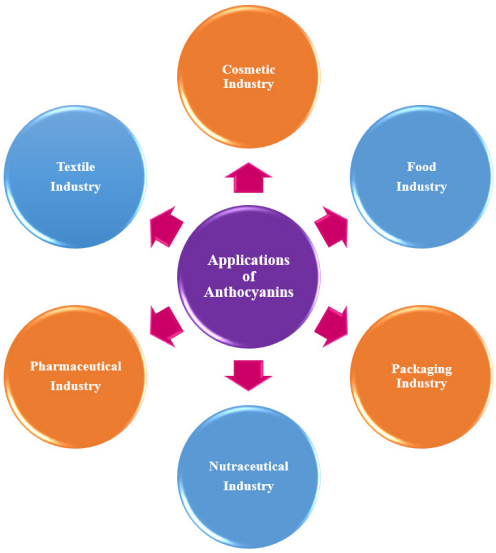


Figure 4. Applications of anthocyanins in different industries.

7.5 Textile Industry

Anthocyanins are natural-coloured pigments rich in vibrant colours ranging from red, orange, and yellow to intense purple and blue which are significantly used as textile colourants in the Textile industry. The combination of the mordant with anthocyanins provides a red-violet colour with fast washing properties to cotton and silk fabrics[140]. Due to the antibacterial properties of anthocyanins fabrics such as cotton, wool and silk dyed using anthocyanin show very good antimicrobial activity[141]. Fabrics made from natural fibres are treated with anthocyanins to make them environment-friendly and to increase sustainability[142].

8. Conclusion

Anthocyanins are vacuolar pigments found in different fruits, flowers and vegetables which are soluble in water. This anthocyanin can be extracted from a number of natural plant sources including fruits such as cherries, currants, oranges, grapes, pomegranates, bilberries, blackberry, blueberries, black and red raspberries, and vegetables like eggplant, red cabbage, red onion, radish, and red-skinned potato. From these popular fruit and vegetable sources, the five major Maharashtrian sources of anthocyanins, the Eggplant, Grapes, Jamun, Kokum and Pomegranate contain high levels of anthocyanins, which can be easily extracted by different methods of extraction like solid-liquid extraction, ultra-sound assisted extraction, agitated bed extraction, *etc.* The anthocyanins have gained increased recognition in a

Table 8. Action mechanism of anthocyanins in preventing diseases[1,3-5]

Neuroprotective	Cardio-protective	Anti-diabetic	Anti-obesity	Anti-oxidant	Anti-cancer
Decreases ischemia	Decreases glutathione	Decreases glucose production	Decreases plasma lipids	Decreases mitochondria damage	Increases apoptosis
Decreases neuro-inflammation	Increases mitochondria and respiratory chain enzyme activity	Increases pancreatic response	Decrease fatty acid	Decreases Reactive Oxygen Species	Increases autophagy in malignant cells
Decrease Reactive Oxidative Species (ROS)	Decreases Reactive Oxidative Species	Decreases insulin response	Decrease β oxidation of fatty acids	Decreases lipids peroxidation	Decreases angiogenesis
Decreases apoptosis	Decreases lysosomal enzyme activity	Decreases absorption	Decreases obesity risk		Decreases metastatic migration of tumour cells
	Decreases myocardial damages	Decreases glucose release from the liver			

variety of industrial sectors due to their natural bright colours, astonishing bioactive properties and numerous health benefits. There is a rapid increase in the market size of anthocyanins due to their increasing applications in various industries such as the cosmetics, food and packaging, nutraceutical, pharmaceuticals and textile industries. Moreover, the identification of the potential of anthocyanins in other industries would allow for enhanced and innovative applications of anthocyanins in these industries to develop novel, environment-friendly and sustainable products. However, more knowledge is required about the different extraction and purification techniques in order to reduce solvent usage, and environmental repercussions and shorten the extraction and purification times which shall maximize the yield of anthocyanins from the various plant sources.

9. Acknowledgements

The authors would like to express their sincere gratitude to the Department of Biotechnology, Sinhgad College of Engineering, Pune.

10. Author Contribution

All authors have contributed in Material preparation and data collection. The design and conceptual flow of manuscript was decided by Dr. Shweta Kashid. The writing and compilation of manuscript was performed by all authors while Ms. Jai Karne has designed the figures. Crosschecking of manuscript was performed by Ms. Jai Karne and Ms. Rutuja Athawale. Formatting and compilation of bibliography was done by Mr. Akshay Kotkar. The final manuscript composition was done and finalised by Dr. Shweta Kashid. All authors have read and agreed to the published version of the manuscript.

11. References

1. Salehi B, Sharifi-Rad J, Cappellini F, Reiner Ž, Zorzan D, Imran M, *et al.* The therapeutic potential of anthocyanins: current approaches based on their molecular mechanism of action. Front Pharmacol. 2020; 11. https://doi.org/10.3389/fphar.2020.01300 PMid:32982731 PMCid:PMC7479177
2. Horbowicz M, Kosson R, Grzesiuk A, Dębski H. Anthocyanins of fruits and vegetables - Their occurrence, analysis and role in human nutrition. J Fruit Ornam Plant Res. 2008; 68(1):5-22. https://doi.org/10.2478/v10032-008-0001-8
3. Ahmed M, Bose I, Goksen G, Roy S. Himalayan Sources of anthocyanins and its multifunctional applications: A review. Foods. 2023; 12(11). https://doi.org/10.3390/foods12112203 PMid:37297448 PMCid:PMC10252932
4. Câmara JS, Locatelli M, Pereira JA, Oliveira H, Arlorio M, Fernandes I, *et al.* Behind the scenes of anthocyanins—From the health benefits to potential applications in food, pharmaceutical and cosmetic fields. Nutrients. 2022; 14(23):5133. https://doi.org/10.3390/nu14235133 PMid:36501163 PMCid:PMC9738495
5. Khoo HE, Azlan A, Tang ST, Lim SM. Anthocyanidins and anthocyanins: Colored pigments as fo od, pharmaceutical

ingredients, and the potential health benefits. Food Nutr Res. 2017; 61(1):1361779. https://doi.org/10.1080/16546628.2017.1361779 PMid:28970777 PMCid:PMC5613902
6. Karimi A, Kazemi M, Samani SA, Simal-Gandara J. Bioactive compounds from by-products of eggplant: Functional properties, potential applications and advances in valorization methods. Trends Food Sci Technol. 2021; 112:518-531. https://doi.org/10.1016/j.tifs.2021.04.027
7. Nayanathara AR, Mathews AP, Aalolam KP, Reshma JK. Evaluation of total Phenol, flavonoid and anthocyanin content in different varieties of eggplant. 2016. https://api.semanticscholar.org/CorpusID:56124162
8. Vasundhara M, Radhika BJ, Thara BS, Priyanka R, Jayaram A. Organic colours for Ayurvastra from kokum fruits and rinds. J Med Plants Stud. 2016; 4:104-107. https://api.semanticscholar.org/CorpusID:55112103
9. Taghavi T, Patel H, Rafie R. Anthocyanin extraction method and sample preparation affect anthocyanin yield of strawberries. Nat Prod Commun. 2022; 17(5). https://doi.org/10.1177/1934578X221099970.
10. Fellah B, Scharinger M, Rocchetti G, Lucini L, Ferchichi A. Phenolic profiling and antioxidant capacity in flowers, leaves and peels of Tunisian cultivars of *Punica granatum* L. J Food Sci Technol. 2018; 55. https://doi.org/10.1007/s13197-018-3286-8 PMid:30150819 PMCid:PMC6098781
11. Ananga A, Georgiev V, Ochieng JW, Phills BR, Tsolova V. Production of anthocyanins in grape cell cultures: A potential source of raw material for pharmaceutical, food, and cosmetic industries. The Mediterranean Genetic Code - Grapevine and Olive; 2013. https://doi.org/10.5772/54592 PMid:23448438
12. Chitnis KS, Palekar SB, Koppar DR, Mestry DY. Evaluation of *Syzygium cumini* Linn. seed formulations available in the market using spectrophotometric and chromatographic techniques. Int J Pharm Sci Res. 2012; 3(2):556. https://api.semanticscholar.org/CorpusID:9680170
13. Sah AK, Verma VK. *Syzygium cumini*: An overview. J Chem Pharm Res. 2011; 3(3):108-113. https://api.semanticscholar.org/CorpusID:7951267
14. Mastan SK, Latha TB, Latha TS, Srikanth A, Chaitanya G, Kumar KE. Influence of methanolic extract of *Syzygium cumini* seeds on the activity of gliclazide in normal and alloxan-induced diabetic rats. Pharmacol. 2009; 3:845-850. https://api.semanticscholar.org/CorpusID:74732910
15. Mastan SK, Saraseeruha A, Gourishankar V, Chaitanya G, Raghunandan N, Reddy GA, *et al*. Immunomodulatory activity of methanolic extract of *Syzygium cumini* seeds. Pharmacologyonline. 2008; 3:895-903.
16. Kumar A, Ilavarasan R, Jayachandran T, Deecaraman M, Aravindan P, Padmanabhan N, *et al*. Anti-diabetic activity of *Syzygium cumini* and its isolated compound against streptozotocin-induced diabetic rats. J Med Plants Res. 2008; 2(9):246-249. https://api.semanticscholar.org/CorpusID:100253864
17. L. S, Shetty N. Biosynthesis and regulation of anthocyanin pathway genes. Appl Microbiol Biotechnol. 2022; 106:1783-1798. https://doi.org/10.1007/s00253-022-11835-z PMid:35171341
18. He F, Mu L, Yan G, Liang NN, Pan QH, Wang J, *et al*. Biosynthesis of anthocyanins and their regulation in colored grapes. Mol Basel Switz. 2010; 15:9057-9091. https://doi.org/10.3390/molecules15129057 PMid:21150825 PMCid:PMC6259108
19. Wu X, Beecher GR, Holden JM, Haytowitz DB, Gebhardt SE, Prior RL. Concentrations of anthocyanins in common foods in the United States and estimation of normal consumption. J Agric Food Chem. 2006; 54(11):4069-4075. https://doi.org/10.1021/jf060300l PMid:16719536
20. Sadilova E, Stintzing FC, Carle R. Anthocyanins, colour and antioxidant properties of eggplant (*Solanum melongena* L.) and violet pepper (*Capsicum annuum* L.) peel extracts. Z Für Naturforschung C. 2006; 61(7-8):527-535. https://doi.org/10.1515/znc-2006-7-810 PMid:16989312
21. Swamy K. Origin, distribution, taxonomy, botanical description, cytogenetics, genetic diversity and breeding of okra (*Abelmoschus esculentus* (L.) Moench.). Int J Dev Res. 2023; 13(3):62026-62046.
22. Sahu P, Mandloi M, Jaiswal R. Evaluation of different varieties of brinjal (*Solanum melongena* L.) for growth, yield and economics attributing characters. Pharma Innov J. 2022; 11(1):107-111. https://api.semanticscholar.org/CorpusID:264434945
23. Kumar S, Misra A, Verma AK, Roy R, Tripathi A, Ansari KM, *et al*. Bt Brinjal in India: A long way to go. GM Crops. 2011; 2(2):92-98. https://doi.org/10.4161/gmcr.2.2.16335 PMid:21865863
24. Niño-Medina G, Urías-Orona V, Muy-Rangel MD, Heredia JB. Structure and content of phenolics in eggplant (*Solanum melongena*) - A review. South Afr J Bot. 2017; 111:161-169. https://doi.org/10.1016/j.sajb.2017.03.016
25. Shaikh A, Iqbal M, Qadeer A. A rev iew on therapeutic potential and nutritional composition of eggplant. Eur Acad Res. 2022; X:545-557.
26. Ockermann P, Headley L, Lizio R, Hansmann J. A Review of the properties of anthocyanins and their influence on factors affecting cardiometabolic and cognitive health. Nutrients. 2021; 13(8):2831. https://doi.org/10.3390/nu13082831 PMid:34444991 PMCid:PMC8399873
27. Kandoliya U, Bajaniya V, Bhadja N, Bodar P, Golakiya B. Antioxidant and nutritional components of egg plant (*Solanum melongena* L) fruit grown in Saurastra region. Int J Curr Microbiol App Sci. 2015; 42:806-813.
28. Fahad S, Faisal S, Naushad M. Grape production critical review in the world. SSRN Electron J. 2020. http://dx.doi.org/10.2139/ssrn.3595842

29. Patil DR, Chavan AM. Economic analysis of grape production: A case study of Zavala and Manerajuri villages of Tasgoan block in Sangli district. Inter J Agr Rural Eco Res. 2023; 11(1):l. http://dx.doi.org/10.36713/epra12221
30. Nithin K. Production and export performance of grapes from India: An econometric analysis. Res J Agric Sci. 2016; 7:143-146.
31. Xia E, He X, Li H, Wu S, Li S, Deng G. Chapter 5 - Biological activities of polyphenols from grapes. In: Watson RR, Preedy VR, Zibadi S, editors. Polyphenols in human health and disease. San Diego: Academic Press; 2014. p. 47-58. https://doi.org/10.1016/B978-0-12-398456-2.00005-0 PMCid:PMC3932731
32. Yang J, Xiao YY. Grape phytochemicals and associated health benefits. Crit Rev Food Sci Nutr. 2013; 53(11):1202-1225. https://doi.org/10.1080/10408398.2012.692408 PMid:24007424
33. Insanu M, Karimah H, Pramastya H, Fidrianny I. Phytochemical compounds and pharmacological activities of *Vitis vinifera* L.: An updated review. Biointerface Res Appl Chem. 2021; 11:13829-13849. http://dx.doi.org/10.33263/BRIAC115.1382913849
34. Zhou Z, Yang D. Economical and eco-friendly isolation of anthocyanins from grape pomace with higher efficiency. Food Chem X. 2022; 15:100419. https://doi.org/10.1016/j.fochx.2022.100419 PMid:36211793 PMCid:PMC9532796
35. Saeed A, Kauser S, Iqbal M. Nutrient, mineral, antioxidant, and anthocyanin profiles of different cultivars of *Syzygium cumini* (Jamun) at different stages of fruit maturation. Pak J Bot. 2018; 50:1791-1804.
36. Tomar R, Pal R, Singh P, Tiwari S, Solanke AU, Tasleem M, *et al*. Jamun an under-exploited indigenous fruit tree of India: A review. Int J Agric Sci. 2020; 11(1). https://doi.org/10.53390/ijas.v11i1.8
37. Porika H, Suchithra M. Jamun: An underutilized fruit loaded with nutraceuticals: A review. J Pharmacogn Phytochem. 2022; 11(4):326-330.
38. Rokade NP, Naik DV, Jachak RS, Malave DD, Sawant MS. Marketing of Jamun in Sindhudurg district of Maharashtra. Pharma Innov J. 2023; 12(12S):1875-1881.
39. Veigas JM, Narayan MS, Laxman PM, Neelwarne B. Chemical nature, stability and bioefficacies of anthocyanins from fruit peel of *Syzygium cumini* Skeels. Food Chem. 2007; 105(2):619-627. https://doi.org/10.1016/j.foodchem.2007.04.022
40. Swami SB, Thakor NSJ, Patil M, Haldankar PM. Jamun (*Syzygium cumini* (L.)): A review of its food and medicinal uses. Food Nutr Sci. 2012;0 3:1100-1117. https://doi.org/10.4236/fns.2012.38146
41. Jagetia G. Phytochemical composition and pleotropic pharmacological properties of jamun, *Syzygium Cumini* Skeels. J Explor Res Pharmacol. 2017; 2:54-66. https://dx.doi.org/10.14218/JERP.2016.00038
42. Dembitsky VM, Poovarodom S, Leontowicz H, Leontowicz M, Vearasilp S, Trakhtenberg S, *et al*. The multiple nutrition properties of some exotic fruits: Biological activity and active metabolites. Food Res Int. 2011; 44(7):1671-1701. https://doi.org/10.1016/j.foodres.2011.03.003
43. Padhye S, Ahmad A, Oswal N, Sarkar FH. Emerging role of Garcinol, the antioxidant chalcone from *Garcinia indica* Choisy and its synthetic analogs. J Hematol Oncol. 2009; 2(1):1-13. https://doi.org/10.1186/1756-8722-2-38 PMid:19725977 PMCid:PMC2743703
44. Kumari S, Hegde L, Athani SI, Hegde NK, Manju MJ, Fakrudin B, *et al*. Comparative studies on red and yellow kokum (*Garcinia indica* Choisy) types under hill zone of Karnataka for morphological characters. Int J Chem Stud. 2021; 9(2):41-45; http://dx.doi.org/10.22271/chemi.2021.v9.i2a.11908
45. Ranveer R, Sahoo A. Bioactive constituents of kokum and its potential health benefits. Nutr Food Toxicol. 2017; 1:236-244.
46. Nainegali BS, Iyyaswami R, Belur PD. Simultaneous extraction of four different bioactive compounds from *Garcinia indica* and their enrichment using aqueous two-phase systems. Food Bioprod Process. 2019; 114:185-195. https://doi.org/10.1016/j.fbp.2019.01.002
47. Chetan A. Nayak NKR, Raghavarao KSMS. Bioactive constituents present in *Garcinia Indica* Choisy and its potential food applications: A review. Int J Food Prop. 2010; 13(3):441-453. https://doi.org/10.1080/10942910802626754.
48. Farag M, El-Shamy S, Fahmy H. Pomegranate juice as a functional food; A comprehensive review of its polyphenols, therapeutic merits, and recent patents. Food Funct. 2020; 11(7):5768-5781. https://doi.org/10.1039/d0fo01251c PMid:32608443
49. Kumar N, Neeraj, Kumar S. Functional properties of Pomegranate (*Punica granatum* L.). Pharm Innov J. 2018; 7(10):71-81.
50. Fawole OA, Makunga NP, Opara UL. Antibacterial, antioxidant and tyrosinase-inhibition activities of pomegranate fruit peel methanolic extract. BMC Complement Altern Med. 2012; 12(1):200. https://doi.org/10.1186/1472-6882-12-200 PMid:23110485 PMCid:PMC3527236
51. Russo M, Fanali C, Tripodo G, Dugo P, Muleo R, Dugo L, *et al*. Analysis of phenolic compounds in different parts of pomegranate (*Punica granatum*) fruit by HPLC-PDA-ESI/MS and evaluation of their antioxidant activity: Application to different Italian varieties. Anal Bioanal Chem. 2018; 410(15):3507-3520. https://doi.org/10.1007/s00216-018-0854-8 PMid:29350256

52. Pascual-Teresa D, Moreno DA, García-Viguera C. Flavanols and anthocyanins in cardiovascular health: a review of current evidence. Int J Mol Sci. 2010; 11(4):1679-1703. https://doi.org/10.3390/ijms11041679 PMid:20480037 PMCid:PMC2871133
53. Soumya, Swami SB, Sawant A, Khandetod YP, Mohod AG, Dhekale JS. Extraction methods used for extraction of anthocyanin: A review. Pharma Innov J. 2019; 8:280-285. https://api.semanticscholar.org/CorpusID:210893580
54. Farooq S, Shah MA, Siddiqui MW, Dar B, Mir SA, Ali A. Recent trends in extraction techniques of anthocyanins from plant materials. J Food Meas Charact. 2020; 14:3508-3519. https://doi.org/10.1007/s11694-020-00598-8
55. Ongkowijoyo P, Luna DA, Mejia E. Extraction techniques and analysis of anthocyanins from food sources by mass spectrometry: An update. Food Chem. 2018; 250:113-126. https://doi.org/10.1016/j.foodchem.2018.01.055 PMid:29412900
56. Condurache (Lazăr) NN, Croitoru C, Enachi E, Bahrim GE, Stănciuc N, Râpeanu G. Eggplant peels as a valuable source of anthocyanins: Extraction, thermal stability and biological activities. Plants. 2021; 10(3):577. https://doi.org/10.3390/plants10030577 PMid:33803722 PMCid:PMC8003047
57. Metivier R, Francis F, Clydesdale F. Solvent extraction of anthocyanins from wine pomace. J Food Sci. 2006; 45(4):1099-1100. https://doi.org/10.1111/j.1365-2621.1980.tb07534.x
58. Santos DT, Cavalcanti RN, Rostagno MA, Queiroga CL, Eberlin MN, Meireles MAA. Extraction of polyphenols and anthocyanins from the jambul (*Syzygium cumini*) fruit peels. Food Pub Health. 2013; 3(1):12-20. https://doi.org/10.5923/j.fph.20130301.02
59. Davies KM, Gould KS, Winefield C. Anthocyanins: Biosynthesis, functions, and applications. Springer; 2009. http://dx.doi.org/10.1007/978-0-387-77335-3
60. Elfalleh W, Hannachi H, Tlili N, Yahia Y, Nasri N, Ferchichi A. Total phenolic contents and antioxidant activities of pomegranate peel, seed, leaf and flower. J Med Plants Res. 2012; 6(32):4724-4730. http://dx.doi.org/10.5897/JMPR11.995
61. Horincar G, Enachi E, Stănciuc N, Râpeanu G. Extraction and characterization of bioactive compounds from eggplant peel using ultrasound-assisted extraction. Ann Univ Dunarea Jos Galati Fascicle VI-Food Technol. 2019; 43(1):40-53. http://dx.doi.org/10.35219/foodtechnology.2019.1.03
62. Amr A, Jaradat S, AlKhatib H, Hamadneh I, Hamadneh L, Hodali H, *et al*. Extraction of anthocyanins from black grape by-products and improving their stability using Cobalt (II) complexation. Prev Nutr Food Sci. 2022; 27(4):457. https://doi.org/10.3746/pnf.2022.27.4.457 PMid:36721754 PMCid:PMC9843720
63. Masci A, Coccia A, Lendaro E, Mosca L, Paolicelli P, Cesa S. Evaluation of different extraction methods from pomegranate whole fruit or peels and the antioxidant and antiproliferative activity of the polyphenolic fraction. Food Chem. 2016; 202:59-69. https://doi.org/10.1016/j.foodchem.2016.01.106 PMid:26920266
64. Maran JP, Priya B, Manikandan S. Modeling and optimization of supercritical fluid extraction of anthocyanin and phenolic compounds from *Syzygium cumini* fruit pulp. J Food Sci Technol. 2014; 51:1938-1946. https://doi.org/10.1007/s13197-013-1237-y PMid:25190849 PMCid:PMC4152520
65. Chatterjee D, Jadhav NT, Bhattacharjee P. Solvent and supercritical carbon dioxide extraction of color from eggplants: Characterization and food applications. LWT-Food Sci Technol. 2013; 51(1):319-324. http://dx.doi.org/10.1016/j.lwt.2012.09.012
66. Pazir F, Koçak E, Turan F, Ova G. Extraction of anthocyanins from grape pomace by using supercritical carbon dioxide. J Food Process Preserv. 2021; 45(8):e14950. https://doi.org/10.1111/jfpp.14950
67. Tan WK, Lee SY, Lee WJ, Hee YY, Abedin NHZ, Abas F, *et al*. Supercritical carbon dioxide extraction of pomegranate peel-seed mixture: Yield and modelling. J Food Eng. 2021; 301:110550. http://dx.doi.org/10.1016/j.jfoodeng.2021.110550
68. Tena N, Asuero AG. Up-to-date analysis of the extraction methods for anthocyanins: Principles of the techniques, optimization, technical progress, and industrial application. Antioxidants. 2022; 11(2):286. https://doi.org/10.3390/antiox11020286 PMid:35204169 PMCid:PMC8868086
69. Xu DP, Li Y, Meng X, Zhou T, Zhou Y, Zheng J, *et al*. Natural antioxidants in foods and medicinal plants: Extraction, assessment and resources. Int J Mol Sci. 2017; 18(1):96. https://doi.org/10.3390/ijms18010096 PMid:28067795 PMCid:PMC5297730
70. Kumar K, Srivastav S, Sharanagat VS. Ultrasound assisted extraction (UAE) of bioactive compounds from fruit and vegetable processing by-products: A review. Ultrason Sonochem. 2021; 70:105325. https://doi.org/10.1016/j.ultsonch.2020.105325 PMid:32920300 PMCid:PMC7786612
71. Fu X, Zhu C, Shen A, Fan W, Shan C. Extraction of anthocyanin from eggplant peel by ultrasonic assisted method and application in cosmetics. Tahir MS, Xing L, editors. E3S Web Conf, Vol 267; 2021. https://doi.org/10.1051/e3sconf/202126702002
72. Dranca F, Oroian M. Optimization of ultrasound-assisted extraction of Total Monomeric Anthocyanin (TMA) and Total Phenolic Content (TPC) from eggplant (*Solanum melongena* L.) peel. Ultrason Sonochem. 2016;

31:637-646. https://doi.org/10.1016/j.ultsonch.2015.11.008 PMid:26701808
73. Morata A, Escott C, Loira I, López C, Palomero F, González C. Emerging non-thermal technologies for the extraction of grape anthocyanins. Antioxidants. 2021; 10(12). https://doi.org/10.3390/antiox10121863 PMid:34942965 PMCid:PMC8698441
74. de Sousa Sabino LB, Alves Filho EG, Fernandes FAN, de Brito ES, da Silva Júnior IJ. Optimization of pressurized liquid extraction and ultrasound methods for recovery of anthocyanins present in jambolan fruit (*Syzygium cumini* L.). Food Bioprod Process. 2021; 127:77-89. http://dx.doi.org/10.1016/j.fbp.2021.02.012
75. Sharayei P, Azarpazhooh E, Zomorodi S, Ramaswamy HS. Ultrasound assisted extraction of bioactive compounds from pomegranate (*Punica granatum* L.) peel. Lwt. 2019; 101:342-350. http://dx.doi.org/10.1016/j.lwt.2018.11.031
76. Carrera C, Ruiz-Rodríguez A, Palma M, Barroso CG. Ultrasound assisted extraction of phenolic compounds from grapes. Anal Chim Acta. 2012; 732:100-104. https://doi.org/10.1016/j.aca.2011.11.032 PMid:22688040
77. Morata A, Del Fresno JM, Gavahian M, Guamis B, Palomero F, López C. Effect of HHP and UHPH high-pressure techniques on the extraction and stability of grape and other fruit anthocyanins. Antioxidants. 2023; 12(9):1746. https://doi.org/10.3390/antiox12091746 PMid:37760049
78. Corrales M, García AF, Butz P, Tauscher B. Extraction of anthocyanins from grape skins assisted by high hydrostatic pressure. J Food Eng. 2009; 90(4):415-421. https://doi.org/10.1016/j.jfoodeng.2008.07.003
79. Liu S, Xu Q, Li X, Wang Y, Zhu J, Ning C, *et al*. Effects of high hydrostatic pressure on physicochemical properties, enzymes activity, and antioxidant capacities of anthocyanins extracts of wild Lonicera caerulea berry. Innov Food Sci Emerg Technol. 2016; 36:48-58. http://dx.doi.org/10.1016/j.ifset.2016.06.001
80. Ferrari G, Maresca P, Ciccarone R. The application of high hydrostatic pressure for the stabilization of functional foods: Pomegranate juice. J Food Eng. 2010; 100(2):245-253. http://dx.doi.org/10.1016/j.jfoodeng.2010.04.006
81. Ranjha MMA, Kanwal R, Shafique B, Arshad RN, Irfan S, Kieliszek M, *et al*. A critical review on pulsed electric field: A novel technology for the extraction of phytoconstituents. Molecules. 2021; 26(16):4893. https://doi.org/10.3390/molecules26164893 PMid:34443475
82. Bocker R, Silva EK. Pulsed electric field assisted extraction of natural food pigments and colorings from plant matrices. Food Chem X. 2022; 15:100398. https://doi.org/10.1016/j.fochx.2022.100398 PMid:36211728
83. López N, Puértolas E, Condón S, Álvarez I, Raso J. Effects of pulsed electric fields on the extraction of phenolic compounds during the fermentation of must of Tempranillo grapes. Innov Food Sci Emerg Technol. 2008; 9(4):477-482. https://doi.org/10.1016/j.ifset.2007.11.001
84. Carpentieri S, Ferrari G, Pataro G. Pulsed electric fields-assisted extraction of valuable compounds from red grape pomace: Process optimization using response surface methodology. Front Nutr. 2023; 10:1158019. https://doi.org/10.3389/fnut.2023.1158019 PMid:37006934
85. Barba FJ, Brianceau S, Turk M, Boussetta N, Vorobiev E. Effect of alternative physical treatments (ultrasounds, pulsed electric fields, and high-voltage electrical discharges) on selective recovery of bio-compounds from fermented grape pomace. Food Bioprocess Technol. 2015; 8:1139-1148. https://doi.org/10.1007/s11947-015-1482-3
86. Jacobo-Velázquez DA, Cuéllar-Villarreal M del R, Welti-Chanes J, Cisneros-Zevallos L, Ramos-Parra PA, Hernández-Brenes C. Nonthermal processing technologies as elicitors to induce the biosynthesis and accumulation of nutraceuticals in plant foods. Trends Food Sci Technol. 2017; 60:80-87. https://doi.org/10.1016/j.tifs.2016.10.021
87. Chatzimitakos T, Athanasiadis V, Kalompatsios D, Mantiniotou M, Bozinou E, Lalas SI. Pulsed electric field applications for the extraction of bioactive compounds from food waste and by-products: A critical review. Biomass. 2023; 3(4):367-401. https://doi.org/10.3390/biomass3040022
88. Rajha HN, Abi-Khattar AM, El Kantar S, Boussetta N, Lebovka N, Maroun RG, *et al*. Comparison of aqueous extraction efficiency and biological activities of polyphenols from pomegranate peels assisted by infrared, ultrasound, pulsed electric fields and high-voltage electrical discharges. Innov Food Sci Emerg Technol. 2019; 58:102212. http://dx.doi.org/10.1016/j.ifset.2019.102212
89. Bonfigli M, Godoy E, Reinheimer MA, Scenna NJ. Comparison between conventional and ultrasound-assisted techniques for extraction of anthocyanins from grape pomace. Experimental results and mathematical modeling. J Food Eng. 2017; 207:56-72. https://doi.org/10.1016/j.jfoodeng.2017.03.011
90. Shastry RP, Sriramareddy SB. Application of Microwave and Ultrasonication for anthocyanin extraction process from *Garcinia indica* Choisy fruit waste and assessment of antioxidant activity using *Caenorhabditis elegans* model. Curr Bioact Compd. 2023; 19(7):39-50. http://dx.doi.org/10.2174/1573407219666230113162742
91. Blando F, Calabriso N, Berland H, Maiorano G, Gerardi C, Carluccio MA, *et al*. Radical scavenging and anti-inflammatory activities of representative anthocyanin groupings from pigment-rich fruits and vegetables. Int J Mol Sci. 2018; 19(1):169. https://doi.org/10.3390/ijms19010169 PMid:29316619
92. Welch CR, Wu Q, Simon JE. Recent advances in anthocyanin analysis and characterization. Curr Anal Chem. 2008;

4(2):75-101. https://doi.org/10.2174/157341108784587795 PMid:19946465
93. Yan S, Li Y, Liu J, Si D, Zhang X. Guideline for extraction, qualitative, quantitative, and stability analysis of anthocyanins. eFood. 2023; 4(1):e59. http://dx.doi.org/10.1002/efd2.59
94. Escribano-Bailón MT, Santos-Buelga C, Rivas-Gonzalo JC. Anthocyanins in cereals. J Chromatogr A. 2004; 1054(1-2):129-141. https://doi.org/10.1016/j.chroma.2004.08.152 PMid:15553138
95. Bueno JM, Sáez-Plaza P, Ramos-Escudero F, Jiménez AM, Fett R, Asuero AG. Analysis and antioxidant capacity of anthocyanin pigments. Part II: Chemical structure, color, and intake of anthocyanins. Crit Rev Anal Chem. 2012; 42(2):126-151. http://dx.doi.org/10.1080/10408347.2011.632314
96. Cai L. Thin layer chromatography. Curr Protoc Essent Lab Tech. 2014; 8(1):6.3.1-6.3.18. http://dx.doi.org/10.1002/9780470089941.et0603s08
97. Kashid S, Joshi K, More S, Shinde A, Nene S. Enhanced productivity of fragrance compounds: Biotransformation of d-limonene using whole cell immobilization of pseudomonas putida and rhodococcus erythropolis. J Inst Eng India Ser E. 2023; 104(1):83-93. https://doi.org/10.1007/s40034-022-00252-6
98. Bahreini Z, Heydari V, Vahid B, Asadi M. Extraction, identification and thermal stability of anthocyanins from eggplant peel as a natural colorant. Prog Color Color Coat. 2014; 8(1):59-67. https://doi.org/10.30509/pccc.2014.75845
99. Filip M, Vlassa M, Copaciu F, Coman V. Identification of anthocyanins and anthocyanidins from berry fruits by chromatographic and spectroscopic techniques to establish the juice authenticity from market. J Planar Chromatogr-Mod TLC. 2012; 25(6):534-541. http://dx.doi.org/10.1556/JPC.25.2012.6.8
100. Mazza G, Cacace J, Kay C. Methods of analysis for anthocyanins in plants and biological fluids. J AOAC Int. 2004; 87:129-145. http://dx.doi.org/10.1093/jaoac/87.1.129 PMid:15084096
101. da Costa CT, Horton D, Margolis SA. Analysis of anthocyanins in foods by liquid chromatography, liquid chromatography-mass spectrometry and capillary electrophoresis. J Chromatogr A. 2000; 881(1-2):403-410. https://doi.org/10.1016/s0021-9673(00)00328-9 PMid:10905723
102. Teng Z, Jiang X, He F, Bai W. Qualitative and quantitative methods to evaluate anthocyanins. EFood. 2020; 1(5):339-46. http://dx.doi.org/10.2991/efood.k.200909.001
103. Andersen OM, Markham KR. Flavonoids: Chemistry, biochemistry and applications. CRC Press; 2005. https://doi.org/10.1201/9781420039443
104. Kong JM, Chia LS, Goh NK, Chia TF, Brouillard R. Analysis and biological activities of anthocyanins. Phytochemistry. 2003; 64(5):923-933. https://doi.org/10.1016/s0031-9422(03)00438-2 PMid:14561507
105. Hong V, Wrolstad RE. Use of HPLC separation/photodiode array detection for characterization of anthocyanins. J Agric Food Chem. 1990; 38(3):708-715. https://doi.org/10.1021/jf00093a026
106. Saha S, Singh J, Paul A, Sarkar R, Khan Z, Banerjee K. Anthocyanin profiling using UV-vis spectroscopy and liquid chromatography mass spectrometry. J AOAC Int. 2020; 103(1):23-39. http://dx.doi.org/10.5740/jaoacint.19-0201 PMid:31462350
107. CAO S qian, PAN S yi, YAO X lin, FU H fei. Isolation and purification of anthocyanins from blood oranges by column chromatography. Agric Sci China. 2010; 9(2):207-215. http://dx.doi.org/10.1016/S1671-2927(09)60085-7
108. Patel S, Raulji A, Patel D, Panchal D, Dalwadi M, Upadhyay DU. A review on UV visible spectroscopy. Int J Creative Res Thoughts. 2022; 10(10):b399-b411.
109. García-Beneytez E, Cabello F, Revilla E. Analysis of grape and wine anthocyans by HPLC-MS. J Agric Food Chem. 2003; 51:5622-5629. https://doi.org/10.1021/jf0302207 PMid:12952411
110. Miguel G, Fontes C, Antunes M, Neves A, Martins D. Anthocyanin concentration of "assaria" Pomegranate fruits during different cold storage conditions. J Biomed Biotechnol. 2004; 2004:338-342. https://doi.org/10.1155/S1110724304403076 PMid:15577199 PMCid:PMC1082890
111. Andersen ØM, Francis GW. Simultaneous analysis of anthocyanins and anthocyanidins on cellulose thin layers. J Chromatogr A. 1985; 318:450-454. https://doi.org/10.1016/S0021-9673(01)90714-9
112. Tan J, Han Y, Han B, Qi X, Cai X, Ge S, *et al*. Extraction and purification of anthocyanins: A review. J Agric Food Res. 2022; 8:100306. https://doi.org/10.1016/j.jafr.2022.100306
113. Malviya R, Bansal V, Pal OP, Sharma PK. High performance liquid chromatography: A short review. J Glob Pharma Technol. 2010; 2(5):22-26.
114. Nayak CA, Srinivas P, Rastogi NK. Characterisation of anthocyanins from *Garcinia indica* Choisy. Food Chem. 2010; 118(3):719-724. https://doi.org/10.1016/j.foodchem.2009.05.052
115. Pratima NA, Gadikar R. Liquid chromatography-mass spectrometry and its applications: A brief review. Arc Org Inorg Chem Sci. 2018; 1(1):26-34. http://dx.doi.org/10.32474/AOICS.2018.01.000103
116. Caridi A, Nicolò A, Modafferi A, De Bruno A. Effect of pomegranate supplementation on the wine yeast response to acidic and osmotic stresses. Eur Food Res Technol. 2022; 248(8):2003-2007. http://dx.doi.org/10.1007/s00217-022-04024-9

117. Sarpate RV, Deore TK, Patil MV, Tupkari SV. Characterization of anthocyanins by GCMS. Int J Chem Sci. 2010; 8(1):415-423.
118. Jian Y, Han S, Zhang B, Zhu X, Wang J, Cui R. Comparison of single pH method, pH-differential method and substraction method for determining content of anthocyanins from red wine. Sci Technol Food Ind. 2012; 33(23):323-325. https://dx.doi.org/10.13386/j.issn1002-0306.2012.23.057
119. Brooks LM, Kuhlman BJK, McKesson DW, McCloskey L. Poor interoperability of the Adams-Harbertson method for analysis of anthocyanins: Comparison with AOAC pH differential method. J AOAC Int. 2013; 96(1):86-90. http://dx.doi.org/10.5740/jaoacint.12-216 PMid:23513962
120. Lee J, Durst RW, Wrolstad RE, Collaborators. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: Collaborative study. J AOAC Int. 2005; 88(5):1269-1278. https://doi.org/10.1093/jaoac/88.5.1269 PMid:16385975
121. Sawai Y, Sugawara T, Oki T, Nishiba Y, Ujihara K, Suda I. Comparison of high-performance liquid chromatography and pH differential method: Correlations for quantitation of anthocyanins in black pearl rice and soybean. J Jpn Soc Food Sci Tech. 2012; 59(2):104-108. https://doi.org/10.3136/nskkk.59.104
122. DeQun S, XianJun M, ChenYang W, GuanQun W, LüChunMao. Determination of blueberry anthocyanins through pH differential method; 2013.
123. Tonutare T, Moor U, Szajdak L. Strawberry anthocyanin determination by pH differential spectroscopic method-how to get true results? Acta Sci Pol Hortorum Cultus. 2014; 13(3).
124. Kashid S, Joshi K, Nene S. Comparison of hydrodynamic characteristics of Tulsion and Siran immobilised beads in a fluidised bed bioreactor. Biocatal Agric Biotechnol. 2022; 43:102428. https://doi.org/10.1016/j.bcab.2022.102428
125. Cortez R, Luna-Vital DA, Margulis D, Gonzalez de Mejia E. Natural pigments: Stabilization methods of anthocyanins for food applications. Compr Rev Food Sci Food Saf. 2017; 16(1):180-198. http://dx.doi.org/10.1111/1541-4337.12244 PMid:33371542
126. Mateus N, de Freitas V. Anthocyanins as food colorants. Anthocyanins: Biosynthesis, functions, and applications. Springer; 2008. p. 284-304. https://doi.org/10.1007/978-0-387-77335-3_9
127. Wang JZY, Zhang L. Anthocyanin-dietary proteins interaction and its current applications in food industry. Food Rev Int. 2023; 39(6):3301-3313. https://doi.org/10.1080/87559129.2021.2012189
128. Filho JG de O, Braga ARC, Oliveira BR de, Gomes FP, Moreira VL, Pereira VAC, *et al*. The potential of anthocyanins in smart, active, and bioactive eco-friendly polymer-based films: A review. Food Res Int. 2021; 142:110202. https://doi.org/10.1016/j.foodres.2021.110202 PMid:33773677
129. Weston M, Phan MAT, Arcot J, Chandrawati R. Anthocyanin-based sensors derived from food waste as an active use-by date indicator for milk. Food Chem. 2020; 326:127017. https://doi.org/10.1016/j.foodchem.2020.127017 PMid:32434111
130. Becerril R, Nerín C, Silva F. Bring some colour to your package: Freshness indicators based on anthocyanin extracts. Trends Food Sci Technol. 2021; 111:495-505. https://doi.org/10.1016/j.tifs.2021.02.042
131. Shukla V, Kandeepan G, Vishnuraj MR, Soni A. Anthocyanins based indicator sensor for intelligent packaging application. Agric Res. 2016; 5:205-209. http://dx.doi.org/10.1007/s40003-016-0211-0
132. Ghafoor K, Al Juhaimi FY. Effects of anthocyanins as nutraceuticals. Agro Food Ind Hi-Tech. 2014; 25(4):9-13.
133. Salehi B, Sharifi-Rad J, Cappellini F, Reiner Ž, Zorzan D, Imran M, *et al*. The therapeutic potential of anthocyanins: Current approaches based on their molecular mechanism of action. Front Pharmacol. 2020; 11:1300. https://doi.org/10.3389/fphar.2020.01300 PMid:32982731 PMCid:PMC7479177
134. Francavilla A, Joye IJ. Anthocyanins in whole grain cereals and their potential effect on health. Nutrients. 2020; 12(10):2922. https://doi.org/10.3390/nu12102922 PMid:32987758 PMCid:PMC7598678
135. Deng GF, Xu XR, Zhang Y, Li D, Gan RY, Li HB. Phenolic compounds and bioactivities of pigmented rice. Crit Rev Food Sci Nutr. 2013; 53(3):296-306. https://doi.org/10.1080/10408398.2010.529624 PMid:23216001
136. Ficco DBM, Borrelli GM, Giovanniello V, Platani C, De Vita P. Production of anthocyanin-enriched flours of durum and soft pigmented wheats by air-classification, as a potential ingredient for functional bread. J Cereal Sci. 2018; 79:118-126. http://dx.doi.org/10.1016/j.jcs.2017.09.007
137. Hosseinian FS, Li W, Beta T. Measurement of anthocyanins and other phytochemicals in purple wheat. Food Chem. 2008; 109(4):916-924. https://doi.org/10.1016/j.foodchem.2007.12.083 PMid:26050008
138. Sharma S, Khare P, Kumar A, Chunduri V, Kumar A, Kapoor P, *et al*. Anthocyanin-biofortified colored wheat prevents high fat diet-induced alterations in mice: nutrigenomics studies. Mol Nutr Food Res. 2020; 64(13):1900999. https://doi.org/10.1002/mnfr.201900999 PMid:32383217 PMCid:PMC7507204
139. Peña OIG, Zavala MÁL, Ruelas HC. Pharmaceuticals market, consumption trends and disease incidence are not driving the pharmaceutical research on water and wastewater. Int J Environ Res Public Health. 2021; 18(5):2532. https://doi.org/10.3390/ijerph18052532 PMid:33806343 PMCid:PMC7967517

140. Mansour R, Yusuf M. Natural dyes and pigments: Extraction and applications. H and B Renew Mater Color Finish. 2018; 75-102. http://dx.doi.org/10.1002/9781119407850.ch5
141. Brudzyńska P, Sionkowska A, Grisel M. Plant-derived colorants for food, cosmetic and textile industries: A review. Mater Basel Switz. 2021; 14(13):3484. https://doi.org/10.3390/ma14133484 PMid:34201459 PMCid:PMC8269454
142. El Harfi S, El Harfi A. Classifications, properties and applications of textile dyes: A review. Appl J Environ Eng Sci. 2017; 3(3):311. https://doi.org/10.48422/IMIST.PRSM/ajees-v3i3.9681