Roselle anthocyanin stability profile and its potential role in post-harvest deterioration: A review

Abubakar Abdullahi Lema¹,², Nor Hasima Mahmod¹*, Mohammad Moneruzzaman Khandaker¹ & Mahmoud Dogara Abdulrahman³

¹Department of Plant Science and Biotechnology, Faculty of Bioresources and Food Industry, Universiti Sultan Zainal Abidin (UniszA), Besut Campus, 22200, Terengganu, Malaysia
²Biological Science Department, College of Natural and Applied Sciences Al-Qalam University Kastina, 2137, Katsina state Nigeria
³Department of Biology, Faculty of Education, Tishk International University Erbil, Iraq

*Email: norhasima@uniszA.edu.my

Abstract
The conversion of roselle calyx into a dried extract without decreasing its consistency is a challenge, given the perishability of the calyx and instability of anthocyanin, which can quickly degrade and develop colored or unwanted brown colors because of its high reactivity. The most critical factors influencing anthocyanins’ stability are pH, temperature, light and post-harvest-related enzymes. Besides, the calyx suffered wound injury when removing seed from the calyx, causing stress and eventually, microbial degradation. Nonetheless, mature anthocyanins stimulate plants by responding to stress, especially drought, high salinity, excess light and injury; it is also correlated with improved stress resistance as the genes of individual plants are triggered under these conditions modulate anthocyanin biosynthesis. This work investigates the stability and potential role of roselle anthocyanin in post-harvest deterioration. Anthocyanin stability can, therefore, be achieved by maintaining low pH and temperature, acylation, glycosylation, copigmentation and encapsulation. In the quest for roselle deterioration biomarkers, the detection of critical enzymes, such as Chalcone synthase CHS and FH3 Flavanone 3 hydroxylase, would offer insight into the genetic modification of anthocyanin.

Keywords
Calyx, Deterioration, Encapsulation, Stress, Stability, Malvaceae

Introduction
The roselle (Hibiscus sabdariffa L.) is a member of the Malvaceae family and has been grown in several countries around the globe, including Malaysia (1) (Fig.1). Increasingly, many people believe that medicinal herbs, fruits and vegetables contribute to a broad range of health advantages (2). Phenolic is well-known for its many health advantages, including "regulating..."
glucose levels and increasing antioxidant, anti-inflammatory, anti-mutagenic, anticancer and neuroprotective effects," due to its ability to modulate numerous processes and pathways in the human body (3, 4). Many physicians, nutritionists and other health professionals now believe that a daily regimen of herbal remedies, fruits and vegetables helps protect human health (2). Roselle calyces have abundant flavonoids such as anthocyanins and other phenolic compounds. Naturally, flavonoids are distributed as dietary polyphenol. Roselle dried petals can be used for tea, coffee, jam, pudding, ice cream or the petals that can be boiled and used for syrup (1, 5).

Anthocyanin and their conjugated acyl-glycosylated or glycosylated derivatives, termed anthocyanins, are both flavonoids and a fascinating family of water-soluble vacuolar pigments (4). They are produced via the flavonoid pathway and are thought to be the primary source of the vibrant red, orange, violet and blue colors found in a variety of edible flowers, vegetables, fruits, some cereals, seeds and plant leaves, as well as their derivatives such as juices, tea and red wines (6). Over 4000 flavonoids have been depicted and classified into many major groups, including phenolic flavonols, anthocyanin, Chalcone, catechin, flavones and isoflavones, according to their phenol structures (7). The active roselle extract has shown to be the anthocyanin in several forms and that delphinidin-3-sambubioside leads in folk medicines and activity in the treatment of many diseases (8). Anthocyanin pigments exist in six separate anthocyanin groups, including "delphinidin, cyanidin, malvidin, pelargonidin, petunidin and peonidin," were found in various highly antioxidant-active vegetables and fruits (9, 10).

Plants activated anthocyanin, due to poor post harvest regulation and in response to stresses like dryness, increased salinity, light and wound degradation, also are associated with increased stress tolerance. Anthocyanins can protect the plant against oxidative stress due to stabilizing unpaired electrons in free radicals. The sensitivity of its antioxidants is higher than that of vitamins C and E (11, 12). Many anthocyanins have demonstrable antiviral, antibacterial and fungicidal activity like other flavonoids (13, 14). Pathogenic microorganism infections can be protected from plants (15, 16). However, the instability of anthocyanin leads to early degradation and develops unwanted brown colors due to its high reactivity. The most critical factors influencing anthocyanins’ stability are pH, temperature, light and post-harvest-related enzymes. Therefore, the present study summarizes and critically reviews recent findings concerning the effect of anthocyanin stability and its potential role in roselle post harvest deterioration. Particular emphasis will be placed on the mechanism and stability of anthocyanins’ degradation, subject to heat, pH, storage, degradation kinetics and the role of anthocyanin in post harvest deterioration.

**Anthocyanin**

Anthocyanins constitute a significant class of flavonoids containing many secondary metabolites and natural pigments present in the roselle calyx, fruits and vegetables (Table 1). Anthocyanins are polyphenol glycosylated compounds ranging from orange, red and purple to blue in flowers, fruits and vegetative tissue (17). In nature, about 600 anthocyanins have been discovered (18). Anthocyanins’ most prominent plants include “pelargonidin, cyanidin, delphinidin, peonidin, petunidin and malvidin” (17). Anthocyanins protect plants against various biotic and abiotic stresses (19, 20). As seen in (Fig. 2), two benzene rings with a three-carbon linear chain are used for anthocyanins (C2, C3, C4); this means they have a single C6-C3-C6 skeleton (21). Chemically, anthocyanins are anthocya-
Economic and Medicinal Benefit of Anthocyanin

(or is especially acidic at pH 1-3, with a high pH of about 4, and the majority of colors are blue and purple with pH levels ranging from 6-7 (22). Anthocyanin’s various functions include its coloring effects in plants and numerous health effects, including antioxidants, anti-diabetic, anti-hypertensive, anticancer, cardioprotective and many other medicinal properties. They’re considered to be very unstable. pH, temperature, light and storage are the most critical factors influencing stability (22, 23).

**Anthocyanin Biosynthesis**

A general flavonoid pathway synthesizes anthocyanins. Three malonyl-CoA is condensed by CHS and 4-coumaroyl-CoA molecules generated from tyrosine phenylalanine (shikimate or phenylpropanoid pathway) into naringenin, which is furthermore converted to naringenin via CHI (chalcone isomerase). F3H and flavonoid 3’5’-hydroxylase (F3’S’H) enzymes modified naringenin, resulting in different DFR (dihydroflavonols (F3’5’H) enzymes modified naringenin, resulting in different DFR (dihydroflavonols-4 reductase). These molecules were reduced to make leucoanthocyanidins (leucocyanidin, leucopelargonidin and leucodelphinidin) via DFR (26). Anthocyanidin synthase (ANS) oxidation of leucoanthocyanidins produces unstable flavylum cation anthocyanidin which is further bound to C3 monosaccharide residue in ring C or other flavonoid glucosyltransferases (UGFT)-catalyzed glycosylation and methyltransferase (TM) positions, resulting in the formation of complicated aglycones and anthocyanin, creating stable anthocyanin molecules (25) Fig. 3. Glucose is the most abundant sugar; natural anthocyanins have galactose and xylose (26). Additional modifications are also possible, including hydroxyl ring B methylation and acylation (24). Such intrinsic improvements are intended to improve the anthocyanin’s stability or diversify anthocyanin colors (19).

**Economic and Medicinal Benefit of Anthocyanin**

Anthocyanins are generally used in the medical, food manufacturing and cosmetics industries (26). Anthocyanins are more prominent than the food industry dyes and can provide alternatives to synthetic dyes. The return of red or blue colorants to anthocyanin sources dramatically increases anthocyanin intake (27). The demand for food color has risen steadily in recent years and is expected to rise from 10% to 15% per annum. The market for natural food coloring is expected to expand at a reasonably fast pace to over $7.7 billion in 2019 compared to synthetic hue (28). Similarly, it was argued that the overall production of food colors keeps on expanding globally (29). Global markets are expected to expand by sales at an average growth rate of 6.22% in 2015-2019. Anthocyanins, carotenoids and chlorophyll are also used for coloring food. Roselle is a unique food in terms of nutritional properties because of its high concentration of vitamin C and anthocyanins. Roselle calyces, according to nutritionists are a good source of calcium, potassium, magnesium, sodium, niacin, riboflavin and iron (29).

Consumers are becoming more mindful of what they are consuming owing to the variety of illnesses currently impacting the globe (30). The production of healthcare in human life has proved to be facilitated by anthocyanins and other nutritious bioactive. Daily colorful fruit and vegetable consumption is essential for a balanced way of life to protect against chronic diseases (31). Low fruit and vegetable intake are estimated to be one of the causes of 1.7 million deaths worldwide (32). Recent experimental studies have shown that colored food, fruit and vegetable compounds may inhibit baked-food mutation. In preventing diseases linked to lifestyle, the use of roselle anthocyanins may have an essential role including, hyperglycemia, neurological and cancer disorders, antioxidant, anti-hypertension among others (33).

**Anticancer**

Anthocyanins from H. sabdariffa induce apoptosis in HL-60 cancer cells by activating p38 MAP kinase, which phosphorylates the target protein C-Jun, initiating apoptotic protein cascades that include Fas-mediated signaling and culminate in the release of cytochrome C from mitochondria and caspase-3 cleavage (34). Delphinidin 3-sambubioside from H. sabdariffa causes dose-dependent apoptosis in human promyelocytic leukemia (HL-60) cells via a mitochondrial malfunction pathway mediated by reactive oxygen species (ROS) (35). It was shown for the first time that anthocyanins from H. sabdariffa changed mitochondrial activity and accelerated cell death in MCF-7 cells via autophagy and necrosis rather than programmed cell death (36). The previous research establishes that anthocyanins produced from roselle have anticancer activity.

**Antioxidant Activity**

Although free radicals are produced naturally during metabolism, their accumulation can be harmful to cells, causing oxidation of cellular components (such as nucleic acids, proteins and fatty acids) and lipid peroxidation, which accelerates aging and contributes to the development of a variety of chronic diseases such as cancer, atherosclerosis and ulcerative colitis (37). Antioxidants made from synthetic materials have been linked to various health problems,
which is why more and more people are turning to natural sources. The antioxidant properties of anthocyanins are widely documented. Antioxidant activity of roselle extracts has been shown; in actuality, this plant has only recently emerged due to the growing interest in natural antioxidants. According to Hai-Yao Wu, the roselle extract is rich in anthocyanins and has significant antioxidative properties (38). Researchers used \textit{H. sabdariffa} extract to reduce the severity of the drug-induced sperm abnormalities and enhance sperm motility by increasing antioxidant capacity and the activity of testicular antioxidant enzymes.

\textbf{Antihypertensive}

According to the studies, \textit{H. sabdariffa} is a safe and effective therapy for mild to moderate essential hypertension and that it is on par with current pharmaceutical antihypertensive medicines. Roselle may be the first line of defense against increasing blood pressure (39). For the first time in humans, it was showed the antihypertensive effects of \textit{Hibiscus sabdariffa} extracts on angiotensin-converting enzyme (ACE), giving scientific legitimacy to the use of roselle extract in traditional medicine to regulate blood pressure (40). As the anthocyanin content increases, enzyme activity decreases because the anthocyanins compete with the active site for electron flow. The enzyme ACE turns angiotensin I into angiotensin II.

\textbf{Antimicrobial Activity}

To combat the emergence of antimicrobial resistance in bacteria over time, natural products have received considerable attention due to their abundance of metabolites with antimicrobial, antifungal and antiparasitic properties. Indeed, these processes serve as a defensive mechanism for plants against diseases and illnesses throughout their development and growth. Among these phytochemicals, anthocyanins have previously been shown to be capable of inhibiting the replication and development of a variety of Gram-negative and Gram-positive bacteria and parasites (4, 41). According to the studies, flavonoids in roselle extract have antibacterial properties because they form complexes with bacterial cell walls and enhance the extract’s permeability to the surface of the cells. Increasing the permeability of the plasma membrane, which in turn inhibits electron transport protein translocation and other enzyme-dependent functions, may result in an ion leakage from bacterial cells as one potential mode of action (42, 43). Pro-
anthocyanidins found in Roselle combine or disrupt the structural entity of bacterial cells’ P-fimbriae, limiting their ability to adhere and produce biofilms in vitro.

**Anti-inflammatory**

There were investigations on the effect of roselle extract on streptozotocin-induced diabetic rats (44). TNF- was found to be reduced at doses of 72 mg/day/200 g body weight and 288 mg/day/200 g body weight, indicating that Roselle possesses anti-inflammatory properties.

Government policy recommendations like the US dietary guidelines and bodies as the National Fruit and Vegetable Alliance Guidelines note that the contribution made by bioactive nutritional compounds such as anthocyanin should be taken into account (27). Today China has established a specific proposed anthocyanin daily intake level of 50 mg/day (31). Similarly, "NHANES recorded anthocyanin's dietary intake in 2007-2008 at; 11.6 ± 1.1 mg / d per person aged ≥ 20y. Females had more anthocyanin consumption a day (12.6 6.5 mg / d) than males (10.5 6.8 mg / d). The median ingestion of anthocyanins in different racial/ethnic groups has also been shown to differ considerably, with whites having more mean daily intakes (12.5, 6.3 mg / d) than Hispanics (10.1, 6.2 mg / d and non-Hispanic black) in the United States (45). Since anthocyanin is poorly bio-available, the risk of food supply toxicity is low. The Joint FAO/WHO Committee on Food Additives has concluded that anthocyanins have an unquestionable daily intake of 2.5 mg/kg (46). Anthocyanin protection and toxicology tests suggest that animal acute toxicity is extremely poor, and there are no findings that anthocyanin usage in humans is adverse with a regular dietary intake (47). Similarly, it was reported that anthocyanins are considered safe and are recommended, along with physical activity, to reduce stress-related diseases and no adverse effects of anthocyanin consumption have been documented (27).

**Mechanism of anthocyanin degradation**

The anthocyanin color change was described (48). Anthocyanins are commonly used in aqueous solutions as four pH species: QB (quinoid base), FC (flavylium cation), carbinol, or PB (pseudo base) and Chalcone. Anthocyanins are used in acidic conditions (pH<2) in deep-red cation (FC). Increased pH values cause a rapid loss of proton blue or violet quinoid (QB) form. "Flavylium cation (FC) hydration occurs at the same time as carbinol, or pseudo base (PB) is produced, eventually entering the colorless Chalcone (CH) balance. The pH of FC, QB, PB and CH relatively varied (48); this means that ionic anthocyanins modify the molecular structure according to the prevailing pH, leading to varying colors and shades at respective pH values". The pH modification can achieve the average stabilization period of anthocyanine; experience can greatly aid food producers. The degradation index (DI) comprises three degradation components: first, the increase in absorption due to browning; the other is absorbance from colorless carbinol bases and the impact of bathochromic changes due to less stable anthocyanin structures (49). At high temperatures, anthocyanin degrades more quickly than at low temperatures (50). During two stages, heating damage can occur. First and foremost, hydrolysis takes place in glycosidic anthocyanin bonds so that aglycons are unstable and therefore released into carbinol and Chalcone (Fig. 4) (51).

![Figure 4. Degradation mechanism of anthocyanin compounds (130)](image-url)
Anthocyanin decoloration may be caused by active enzyme-driven breakdown processes (52, 53, 52), suggesting that three families are involved in the degradation of anthocyanin: Peroxidase, polyphenol oxidase and β-glucosidase. There are two known mechanisms for anthocyanin degradation. Another method is to oxidize Peroxidase directly. The second step involves deglycosylation of glucosides and oxidation of polyphenol or Peroxidase. There are non-enzymatic factors that affect the color and stability of anthocyanin, which may improve its tolerance to anthocyanin degradation enzymes (53, 54). “Degradation of anthocyanins through isothermal heating is expressed in obeying first-order kinetics for juice and concentrate of sour cherry” (48), strawberries (55) and blackberries (56). Kinetic models are also used to test food health scientifically, quickly and economically. The critical quality parameters can also be predicted using kinetic modeling such as constant rate, reaction order and energy activation to predict food losses during storage and thermal processing. Nutrient deficiency is a significant factor in food production.

**Anthocyanin stability**

Anthocyanins are natural food coloring agents, but consistency issues limit their use (57). Anthocyanin is relatively unstable and can rapidly degrade and form colorless or undesired brown compounds during extraction and storage due to its high reactivity (58). The most significant factors affecting stability are pH, temperature, light, storage, oxygen, enzymes and metal ions (22). Besides affecting food products directly, the deterioration of anthocyanin can result in benzene ring aldehydes production that affects human health (38).

**pH stability**

Shivon Sipahli reported that anthocyanin HCl-acidified ethanol extracts provide excellent stability when exposed to low pH, low heat and dark light. Anthocyanins' kinetic degradation has indicated that it could be heated to up to 70 °C at gradually decreasing antioxidant content (57). It was also clearly shown (59) that increasing pH causes more destruction of anthocyanin. It also indicates at lower pH (< 5.0), anthocyanin is stable while unstable at alkaline (29), decreased pH to 2.8 in anthocyanin solutions, flavylum cation structure changes provide more extended stability (38). It was also reported that rosette anthocyanin is stable at an acidic pH (1-4) (60).

**Temperature and light stability**

The stability of anthocyanins was greater at the lowest storage temperature (4 °C) (61, 62), which indicated that acylated anthocyanins were much more stable than nonacylated anthocyanins at all storage temperatures. Both extracts, however, were stable when stored at 0 °C. Therefore, the consequence of low temperature (≤50 °C) on the stability of anthocyanin is imperative. Because the heat treatment at 55 °C had no discernible effect on the color, it may be assumed that the rosette extract’s red hue stabilized at that temperature. Anthocyanins’ thermal degradation temperature of 80 °C (63, 64) also reported a decrease in the absorbance of anthocyanins in higher temperatures (100 °C). At marginally increased pH 5.0 were discovered New anthocyanin and gum arabic acid solutions (65). A solution of 0.51 mg/ml was heated to 80 °C and 126 °C for 80 min (66). A similar report indicated that adding coumaric, cinnamic and ferulic acids as co-pigments to rosette anthocyanin extracts resulted in significant anthocyanin concentration and color stability over 60 days storage at 10 °C (67).

Investigation was on the effect of temperature on anthocyanin at different temperatures (37, 50 and 100 °C) (under light) (7). Higher temperatures (50 to 100 °C) destroy anthocyanin faster, implying that it should be avoided for anthocyanin processing, storage and usage. On the other hand, the anthocyanin is stable between 4 °C and 37 °C and may therefore be utilized for storage (68).

Investigated anthocyanin degradation under light and discovered that it is temperature-dependent and that exposure to light may destroy anthocyanin molecules (48). According to anthocyanin studies, the chalcone type of anthocyanin has little effect in the visual range but loses substantially in absorbance as temperature increases. Cooling the copigments solution produces changes in the copigments complex, responsible for quantitative color recovery (48). Encapsulation was used to obtain light stability of anthocyanin (69).

**Color stability**

As consumers increasingly reject synthetic pigments, there has been increasing interest in food colorants from natural or naturally derived sources (70). The worry is increasing since it has been revealed that synthetic pigments or antioxidants may affect cardiovascular disease (70). Anthocyanin is a natural colorant that is extensively utilized in the food industry. Spray-dried encapsulated anthocyanins Color stability, encapsulated with polysaccharides accompanied by sufficient processing to improve anthocyanin stability for practical usage in food systems, noticed that malto-dextrin and Arabic gum combinations had the highest encapsulation performance. C3 is more efficient in stabilizing diglycosides as compared to mono glycosides. Glycosylation of C5 reduces the pigment density. Acylation improves anthocyanin stability, and the increase in acyl moieties tends to alter the colors from red to blue (71). For instance, metal ions such as iron and magnesium enhance the stability of anthocyanins by creating complexes (29).

**Storage stability**

In a research, there examined the durability of pigment-copigments complexes generated during a 6 month storage period (72). Throughout the storage period, the addition of ferulic and caffeic acids significantly increased the color intensity of pelargonidin 3-glucoside. According to a study, no deterioration was seen during the refrigerated storage of anthocyanin at (4 °C) (73). It was indicated that anthocyanin stability and color concentration was achieved for over 60 days storage at 10 °C through addition of coumaric, cinnamic and ferulic acids as co-pigments (67).

**Enzymatic stability**

The stability of anthocyanins is due to their modification. Following the production of anthocyanidin aglycones, cyto-
solic modification processes include glycosylation, methylation and acylation (Fig. 6). Knowledge of these modification processes' biochemistry and molecular biology, as well as the enzymes involved, has exploded in the past decade attributable to the molecular cloning of the enzyme genes from various plant species (74). Reports are on anthocyanins' decolorization to the activity of a β-glycosidase (75). Several additional researchers, notably (76) shown that crude vegetable extracts may substantially degrade anthocyanins only when phenols are present. Polyphenol oxidase, they claim, is the enzyme responsible for this activity. In this case, the anthocyanin would be destroyed as a consequence of its interaction with the quinone generated by the oxidation of an appropriate phenol substrate. According to research, acylation increases the stability of anthocyanins, whereas structural changes increase their bioactivity (77).

**Anthocyanin encapsulation**

Different delivery methods have been developed to address the fact that the integration of phenolic compounds into foods and pharmaceutical products is a challenge because of their instability and degradation during processing and storage. Encapsulation is one of the best approaches among them all (4). Encapsulation is an effective method for avoiding colorant degradation and premature color development. When anthocyanins are encapsulated, their stability improves because of an effective barrier between them and external environmental variables like light and temperature. They are also protected against enzymes and reactive substances by encapsulation. Spray drying (78), freeze-drying (79, 80), emulsification (36, 81, 82), liposomal encapsulation (83), gelation (84, 85) and complexation have all been described (86). Due to the anthocyanin instability and sensitivity to deterioration, during processing and storage, different delivery methods have been devised to protect these phenolic compounds and ensure their use in foods and pharmaceuticals (87).

Natural colors that have been encapsulated are more resistant to changes in temperature, light and pH. Products with color encapsulation have a longer shelf life, are more stable over a broader pH range and do not develop color during storage. As a consequence, the chosen hue

---

**Figure 6.** Anthocyanidins modulated via acylation, glycosylation and, methylation (80)
is instantly accessible following manufacturing. At the moment, food researchers are very interested in microwave encapsulation owing to its many potential benefits, including reduced drying time, cheap cost, better product quality, and the ability to produce a range of dried products (88). For example, (88) reported that Margarine with roselle encapsulated anthocyanin was more stable than non-encapsulated anthocyanin. Also, previously published reviews addressed encapsulating agents and methods for stabilizing and delivering anthocyanins (82, 89, 90).

**Anthocyanin copigmentation**

Copigmentation is a "process through which anthocyanins form complexes with copigments such as phenolic, metal ions and biopolymer (48). In addition to increasing color intensity, this process also protects colored flavylium cations from water molecules' nucleophilic assault and improves antioxidant capabilities. Copigmentation ideas from theory and experiment have recently been presented in a complete description of modulating anthocyanin stability and color via copigmentation (91). The kind of copigments used is critical for successful copigmentation. For instance, phenolic substances such as hydrolyzable tannins (92), flavonoids (93) and phenolic acids (94, 95) all copigments with anthocyanins through - stacking and hydrogen" bonding. It was demonstrated that adding phenolic acids (ferulic, cinnamic and coumaric) to roselle anthocyanin extracts increased anthocyanin levels and improved color stability during storage and also showed noticeable antioxidant and antimicrobial activities (66). Similarly, in their Copigmentation experiments of *H. sabdariffa* anthocyanin extract with ferulic acid (96) found that ferulic acid significantly enhanced the heat stability of anthocyanins. It was showed that β-carotene bleaching assay and higher color stability during storage at 25 °C, 40 °C and 60 °C than original blueberry anthocyanins (97).

**Effect of stability on the medicinal value of anthocyanin**

Rich anthocyanin foods can enhance overall health by providing nutrients. Its poor environmental stability complicates the incorporation of anthocyanin into food and medicinal items (71). Some studies have shown that anthocyanins, a healthy food ingredient used throughout the globe, may pose significant risks to public health (cardiovascular disease, inflammation, obesity and diabetes) from food additive chemical synthesis (90, 98). Furthermore, anthocyanin degradation can also result in benzene ring aldehyde, posing health issues (99). Anthocyanins' pharmacological and other functions are directly proportional to their antioxidant activity, which can also be lost due to stability issues. Anthocyanin isolates and Flavonoids-rich mixtures can protect against DNA cleavage, estrogen activity, inhibition of the enzyme, enhanced cytokines synthesis (i.e., regulatory immune), anti-inflammation, lipid Peroxidation, reducing the capillary permeability and membrane improvements (100, 101).

**Post-harvest deterioration mechanism**

Post harvest degradation refers to several unwanted physical and biochemical modifications that reduce the shelf life and durability of the products and make them inappropriate for consumption (102). Post-harvest is the last step in crop production that includes harvesting, processing, decorating, washing, pre-cooling, grading at packaging, storage, transportation and post harvest treatments. When a crop is harvested from the parent plant, it starts to deteriorate (103). Both the plants, after harvesting, are still living entities; hence they are deprived of a supply of hormones, nutrients and water. Therefore they should be treated carefully and these perishables are very vulnerable to injury.

There are two differentiated mechanisms for deterioration: physiological or primary and secondary or microbiological (104). The fundamental cause of the decline of calyx and widespread brown color, leading to shelf life and decreased inconsistency, is physiological degradation (105–107). Primary degradation includes an increase in the function of phenolic oxidative enzymes, including catechin and anthocyaninid, that eventually polymerize into condensed tannins (108–110). Mechanical damage, an inevitable consequence of harvesting, causes physiological post harvest degradation. Calyx was typically injured during decoring, i.e., removing roselle calyx from the seeds, resulting in stress production, anthocyanin instability and ultimately, pathogenic decay, fermentation, or calyx softening (111, 112). Secondary post harvest deterioration sometimes happens when a calyx has moderate to substantial injury from a wide variety of pathogens, typically 5 to 7 days later (113, 114). The gene coding for Catalase, ascorbate peroxidases and secretive peroxides catalyzes the reduction of H₂O₂ by utilizing ascorbate or a variety of organic or inorganic substances as an electron donor is expressed during post harvest physiological deterioration (PPD) in cassava (115), (112, 113), Also, Hydroxyprolinerich glycoprotein HRGP1 (111), and two Cytochrome P450 and CYP79D2 (AAF27289 and AAF27290;(115) previously expressed during post harvest storage. Quantitative and qualitative losses for crops between harvest and consumption are unavoidable natural processes. Human involvement is required to mitigate this loss (116). For a global population of about 9.8 billion predicted to hit 2050 (117), food shortages, waste or both would further intensify food security issues globally. The average losses recorded in Malaysia for fruit and vegetables are still about 20% (103). Sufficient efforts should be made that would revamp existing procedures to reduce food waste and losses.

**Role of anthocyanin in post-harvest deterioration**

Anthocyanins can also play a significant role in enhancing post harvest processes and protective effects by preserving membrane integrity to decrease cell senescence and inhibiting lipid peroxidation (118). Anthocyanins improve fruit's antioxidant capacity, eliminating reactive oxygen species (ROS) activity and signaling mechanism. Therefore, it may delay over-breaking, limiting cell death induction and fungal spread (53). Due to its extraordinary antioxidant power, anthocyanins were more widely used during the past 20 years (112, 119, 120) and anthocyanins are widely considered to contribute to *Hibiscus sabdariffa* preventive impact significantly. A correlation between roselle antioxidant activity and anthocyanin content has also been identified, indicating that these compounds may contribute to ro-

https://plantsciencetoday.online
Roselle's antioxidant impact (120). In addition to protecting plants from oxidative stress, anthocyanins may donate hydrogen atoms to free radicals, balancing the unpaired electrons. Furthermore, pathways by which anthocyanins help plants in the control of abiotic stress are becoming increasingly understandable. Many functions, including ROS scavengers, were forecast for anthocyanins generated during abiotic stress, photoprotectants, stress signals (121–123), xenohormesis (e.g., therapeutic stress). As a result of the growing interest in mechanisms by which abiotic stress-tolerating anthocyanins help plants cope with abiotic stress (124–127) it has been reported that inductive anthocyanin synthesis is the result of gene activation, which enhances the plant's response to antioxidants so that tissues that are directly or indirectly affected by stress maintain their physiological status. According to a study, the genes of particular plants are also activated under these circumstances and regulate the production of flavonoids, such as anthocyanins, resulting in a rise in phytochemicals under stress exposure (11).

Conclusion and future developments

Roselle anthocyanin has multiple roles due to its antioxidant activity, including food coloring, free radical scavenging, pharmacological and medicinal properties. They are considered very unstable due to pH, temperature, light, enzymes and storage. From this review, anthocyanin is more stable in cold storage and low pH. A low pH and temperature are required to keep anthocyanins stable. Other methods of stabilizing anthocyanins include glycosylating, copigmenting, acylating and encapsulating the pigments. Roselle calyx is protected from post harvest deterioration by scavenging free radicals by anthocyanin. It may also indicate degradation throughout the detection of high levels of anthocyanin in the harvested calyx. To this date, there is no study available in the literature on roselle post harvest deterioration biomarkers. Still, in other plants like cassava, they reported that PPD might be a peroxidase-mediated process. So, the identification of significant anthocyanin biosynthesis genes such as CHS and F3H may serve as a potential biomarker of post harvest deterioration.

Acknowledgements

This work is supported by UniSZA/2020/LABMAT/01. Special appreciation goes to the fundamental research grant scheme Malaysia (FGRS) for reviewing the work to finance future research.

Authors contributions

AAL wrote the manuscript. NSM brought the research idea and supervised the writing of the manuscript MMK reviewed the manuscript and made corrections while MAD proofread the manuscript and participated in the manuscript report.

Compliance with ethical standards

Conflict of interest: The authors state that they have no competing interests in connection with this article.

Ethical issues: None.

References

16. Werlein H-D, Kutemeyer C, Schatton G, Hubbermann EM, Schwarz K. Influence of elderberry and blackcurrant concent-


31. WHO. Global strategy on diet, physical activity, and health: promoting fruit and vegetable consumption around the world. 2004.


52. Oren-Shamir M. Does anthocyanin degradation play a significant


102. Mayani JN, Desai CS, Desai SC, Bagadia S. Post harvest management of horticultural crops. Post harvest management of horticultural crops. Jaya publishing house Delhi-110095 (India); 2016;


119. Yuzhi Jiao. Studies on antioxidant capacity of anthocyanin ex-


§§§