

Chapter 2

Literature Review

2.1 Anthocyanins

Anthocyanins, a subgroup of water-soluble flavonoids which occur naturally in the plant kingdom, are responsible for many of the colors observed in nature (Pazmiño-Durán et al. 2001a). The basic structure of anthocyanins consists of two or three chemical units: an aglycon base (also termed “anthocyanidin”), sugars, and organic acids in the case of acylated anthocyanins (Manach et al. 2004; Mercadante and Bobbio 2008; Merken and Beecher 2000). Anthocyanidins consist of three rings: the A-ring is an aromatic ring and it is bonded to a heterocyclic, oxygen-containing C-ring, which is in turn bonded by a carbon-carbon bond to the aromatic B-ring (Fig. 2.1). Their basic skeletons can therefore be described as C6–C3–C6, a total of 15 carbons (Cavalcanti et al. 2011). When linked to sugar moieties, anthocyanidins become known as anthocyanins (Castañeda-Ovando et al. 2009).

Anthocyanin structures can vary at the sugar moieties as well as at the anthocyanidins. The nature of sugar moieties can vary, for example in terms of the type and locations of carboxylates bonded to them. Although some rare anthocyanidins deviate from the aforementioned C6–C3–C6 skeletal structure, it is more common for anthocyanidins to vary in terms of the number of hydroxylated groups and sugars bonded to them (Castañeda-Ovando et al. 2009). Each aglycon base can be glycosylated or acylated by a unique combination of sugar moieties and phenolic or aliphatic acids, producing different anthocyanins (Bueno et al. 2012). In fact, more than 700 anthocyanin structures have been identified from plant extracts, and almost 200 different anthocyanins have been presented with tentative structures (Andersen and Jordheim 2014). Among these, the most commonly found anthocyanins are based on six anthocyanidins: cyanidin, delphinidin, malvidin, pelargonidin, peonidin, and petunidin (Fig. 2.2) (Fernandes et al. 2013).

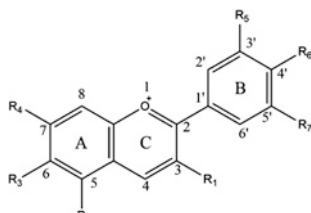


Fig. 2.1 General structure of anthocyanins

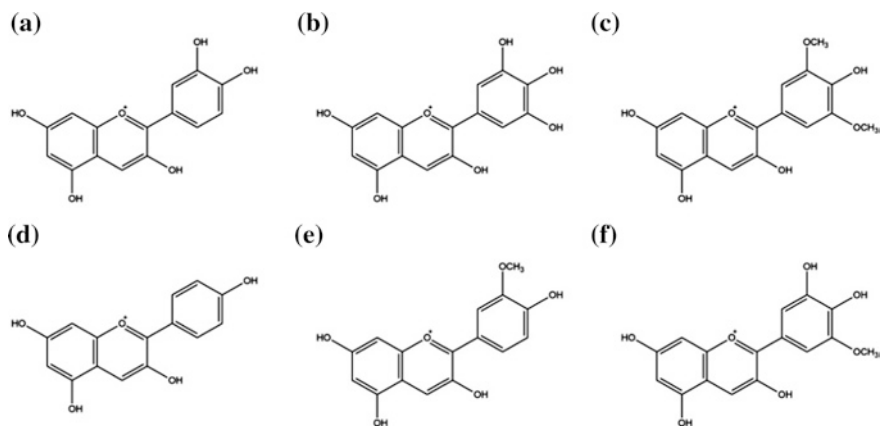


Fig. 2.2 Chemical structure of **a** cyanidin, **b** delphinidin, **c** malvidin, **d** pelargonidin, **e** peonidin, and **f** petunidin

Table 2.1 Occurrence of anthocyanins in some fruits (Patras et al. 2010)

Sources	Major anthocyanin	Minor anthocyanins
Strawberry	Cyanidin-3-glucoside	Pelargonidin-3-rutinoside
Blackberry	Cyanidin-3-glucoside	Cyanidin-3-rutinoside, malvidin-3-glucoside
Raspberry	Cyanidin-3-glucoside	Pelargonidin-3-glucoside, pelargonidin-3-rutinoside
Sweet cherry	Cyanidin-3-rutinoside	Cyanidin-3-glucoside, peonidin-3-rutinoside
Blackcurrant	Cyanidin-3-rutinoside	Cyanidin-3-glucoside, delphinidin-3-glucoside
Bilberry	Delphinidin-3-galactoside	Pelargonidin-3-glucoside, pelargonidin-3-galactoside

The distribution of the six most common anthocyanidins in fruits and vegetables is approximately as follows: cyanidin 50 %, delphinidin 12 %, pelargonidin 12 %, peonidin 12 %, petunidin 7 % and malvidin 7 % (Kong et al. 2003). The predominant anthocyanins in fruits are cyanidin-3-glucoside, delphinidin-3-glucoside, malvidin-3-glucoside, pelargonidin-3-glucoside, and petunidin-3-glucoside

(Dugo et al. 2003; Hillebrand et al. 2004). The glycoside derivatives that more widespread in nature are 3-monosides, 3-biosides, 3,5- and 3,7-diglucosides. The presence of the 3-glucoside derivatives is about 2.5 more frequent than the 3,5-diglucosides and the most common anthocyanin is cyaniding-3-glucoside (Kong et al. 2003). Table 2.1 shows the distribution of anthocyanins in some fruits.

2.2 Color of Anthocyanins

Anthocyanins give plants their colors, which is important for their survival as they attract pollinators (Glover and Martin 2012). The resonant structure of anthocyanidin, comprising the flavylium cation (also known as 2-phenylbenzopyrylium) enables anthocyanins to act as colorants (Castañeda-Ovando et al. 2009). Within the same class of anthocyanins, there is a variation in color. For example, the increase of hydroxylation pattern in the B-ring results in a bathochromatic shift from red to violet (pelargonidin → cyanidin → delphinidin) (Mateus and de Freitas 2009). It has also been reported that the color of anthocyanins varies with pH, in a series of equilibria (Andersen et al. 2014; Castañeda-Ovando et al. 2009; Fernandes et al. 2014; Mateus et al. 2009). Their range of brilliant colors has led to industrial use of anthocyanins as natural colorants in foods as substitutes to synthetic food colorants, and they have been recognised as one of the nine European Union selected natural color classes. Their use as coloring agents dates back to the ancient Romans, who used highly-colored berries to color wines (Durge et al. 2013; Navas et al. 2012).

2.3 Function of Anthocyanins

In plants, anthocyanins also act as photoprotectants by scavenging free radicals that are produced during photosynthesis (Hiemori et al. 2009). This function is attributed to their ability to donate protons to highly reactive free radicals (Castañeda-Ovando et al. 2009), which is conferred by the anthocyanins' structure—the number and organisation of the phenyl groups, the availability of electron-donating and electron-withdrawing groups in the ring structure, the degree of structural conjugation and the positive charge of anthocyanins. In doing so, they prevent further radical generation and protect cells from oxidative damage which has often been associated with aging and various diseases caused by oxidative stress (Bueno et al. 2012). Studies have demonstrated that anthocyanins can help in the prevention of cardiovascular and neurological diseases, cancer and inflammation (Konczak and Zhang 2004). They have also been shown to be effective in obesity and diabetes control, and in improving visual functions (Tsuda 2012). Owing to their antioxidant capacity and the associated health benefits, anthocyanins have gained increased attention in recent years.

Previous studies showed that the daily intake of anthocyanins in the U.S. diet was estimated to be between 180 and 215 mg, whereas the intake of other dietary flavonoids such as genistein, quercetin and apigenin was only 20–25 mg/day (Hertog et al. 1993; Kuehnau 1976). However, a recent study, based on the National Health and Nutrition Examination Survey (NHANES) 2001–2002, highlighted the inaccurate food intake data in previous studies, and gave out that the average intake of anthocyanins in U.S. was much lower and estimated to be at 12.5 mg/day. Of the different aglycones, cyanidin, delphinidin, and malvidin were estimated to contribute 45, 21, and 15 %, respectively, of total intake per day. For anthocyanins with nonacylated versus acylated groups, nonacylated anthocyanins are predominant, contributing 77 % compared to 23 % from acylated anthocyanins of total intake per day (Wu et al. 2006).

Potential use of natural “green” plant extracted anthocyanins could offer the food processing industry an alternative solution to synthetic chemical antimicrobials and antioxidants. Therefore, considering also the beneficial effect of these molecules on health, their incorporation in food products is of important value (Cevallos-Casals and Cisneros-Zevallos 2004).

2.4 Stability of Anthocyanins

The stability of anthocyanins is dependent on several factors including the structure of the anthocyanins, temperature, pH, light intensity, oxygen availability and presence of enzyme, ascorbic acid, sugar and metal ion in the system (Roobha et al. 2011). Isolated anthocyanins are very unstable and highly susceptible to degradation (Giusti and Wrolstad 2003).

2.4.1 Structure Influence

The stability of anthocyanins is influenced by the ring B (Fig. 2.1) substituents and the presence of additional hydroxyl (–OH) or methoxyl (–OCH₃) groups which decrease the aglycon stability in neutral media; therefore, pelargonidin is the most stable anthocyanidin (Fleschhut et al. 2006).

Acylated anthocyanins are more stable than the corresponding non-acylated ones. Acylated anthocyanins appear to prolong their half-life and slow down their decaying process under thermal treatment compared to nonacylated derivatives, and a higher degree of hydroxylation in the B-ring would decrease their half-life (Sadilova et al. 2006). Acylation of the molecule is believed to improve anthocyanin stability by protecting it from hydration (Goto et al. 1979; Raymond 1981).

2.4.2 Co-pigmentation Influence

Co-pigmentation is a phenomenon in which the pigments and other colorless organic compounds, or metallic ions, form molecular or complex associations, generating a change or an increment in the color intensity (Boulton 2001). Some investigations suggest that the co-pigmentation of anthocyanins with other compounds is the main mechanism of stabilization of color in plants (Davies and Mazza 1993; Mazza and Brouillard 1990). The magnitude of the co-pigmentation effect is pH dependent. The co-pigment effect is evident under weakly acid conditions (pH 4–6) (Castañeda-Ovando et al. 2009).

Anthocyanin molecules with complex patterns of glycosylation and acylation exhibit remarkable stability to pH changes, heat treatment and light exposure (Dangles et al. 1993; Francis 1992; Murai and Wilkins 1990). The improved stabilization has been attributed to intra-molecular and intermolecular co-pigmentation, self-association, metal complexing and presence of inorganic salts (Goto 1987; Malien-Aubert et al. 2000; Raymond 1983). A study reported that greater thermal stability of anthocyanins was present in red cabbage compared to blackcurrant, grape skin and elderberry anthocyanins in a soft drink model system due to the protection of flavylium system through co-pigmentation (Dyrby et al. 2001).

2.4.3 pH Influence

Anthocyanins are found to be typically more stable in acidic media at low pH values than alkaline solutions with high pH values. For example, Torskangerpoll and Andersen (2005) found that 0.05 and 0.15 mM aqueous solutions of cyanidin-3-glucoside, cyanidin-3-(2''-glucosylglucoside)-5-glucoside, and cyanidin-3-(2''-(2''-sinapoylglucosyl)-6''sinapoylglucoside-5-glucoside retained their colors at pH 1.1 over a storage period of 98 days at 10 °C, but displayed dramatic color changes in most alkaline solutions of pH up to 10.5. Cabrita et al. (2000) showed that even though six common anthocyanin 3-glucosides (i.e. pelargonidin, peonidin, malvidin, cyanidin, petunidin and delphinidin) displayed the most intense red coloration and the highest stability in aqueous solutions of pH 1–3, however, the first three also exhibited intense and stable bluish colors at pH 8–9, highlighting the possibility of using them as colorants in alkaline food products.

2.4.4 Thermal Influence

Temperature, in particular, has shown to be one of the major factors in anthocyanin degradation during food processing. The stability of anthocyanins in foods was found to decrease during processing and storage as temperature rises (Maccarone et al. 1985; Mercadante et al. 2008). Many studies have been carried

out to investigate the thermal degradation of anthocyanins in roots of Chinese red radish (*Raphanus sativus* L.) (Jing et al. 2012), as well as the effects of temperature and cooking time on the stability of individual anthocyanins in black rice (Hou et al. 2013). Fischer et al. (2013) also reported that heating of pomegranate juice at 90 °C resulted in anthocyanin degradation, which caused discolorisation. Degradation of anthocyanins in juice and concentrates of blood orange (Kırca and Cemeroglu 2003) and blackberry (Wang and Xu 2007) has also been reported. Apart from fruit juices, thermal degradation resulting in reduced anthocyanin content has also been observed in other food plants including Korean purple-fleshed sweet potato (Kim et al. 2012) and black rice (Hiemori et al. 2009), when subjected to different cooking methods. Even at lower temperatures, degradation of anthocyanins is still a concern. Hellström et al. (2013) found that the half-life ($t_{1/2}$) of anthocyanins in both laboratory made and commercial berry juices was much shorter at room temperature than at 4 and 9 °C. During storage at 4 °C, Reque et al. (2014) found that anthocyanins in blueberry whole juice were degraded, although its antioxidant capacity remained stable. Other studies have similarly observed stable antioxidant capacity of foods containing degraded anthocyanins (Fischer et al. 2013; Howard et al. 2010), or even some increases due to anthocyanin degradation products (Nayak et al. 2011).

2.4.5 Solid Content Influence

The degradation rates of anthocyanins increase with increasing solid content during heating. This could be due to closeness of reacting molecules in juice with higher soluble solid content (Patras et al. 2010). In strawberry, anthocyanin degradation occurs as soon as strawberries are processed into juice or concentrate and continues during storage. This degradation of anthocyanins is greater in concentrates compared to juices (Garzón and Wrolstad 2002). Similar trends have been reported for anthocyanins in sour cherry (Cemeroglu et al. 1994).

2.4.6 Water Activity (A_w) Influence

Water activity is another factor influencing the stability of anthocyanins. Reduced water activity enhances anthocyanin stability. Anthocyanin pigments in dried forms can exhibit remarkable stability. Anthocyanins are stable when stored in dry crystalline form or on dry paper chromatograms, which leads to the hypothesis that water is involved in discoloration reactions (Markaris et al. 1957). The degradation of anthocyanins in freeze-dried strawberry puree increases when stored at high relative humidity conditions (Erlandson and Wrolstad 1972). A study also reported the same trend that increasing A_w increased the degradation rate of anthocyanins (Garzón and Wrolstad 2001).

2.4.7 Oxygen Influence

Oxygen amplifies the impact of anthocyanin degradation processes (Cavalcanti et al. 2011). Specifically, this can take place through a direct oxidative mechanism or through the action of oxidising enzymes such as polyphenol oxidase (PPO). For example, PPO catalyses the oxidation of chlorogenic acid to chlorogenoquinone, which reacts with anthocyanins to form brown condensation products (Patras et al. 2010). It was reported that oxygen-restricted atmospheres best retained initial antioxidant capacity and anthocyanin content of fresh-cut strawberries over a period of cold storage (Odriozola-Serrano et al. 2009). Although Zheng et al. (2003) reported that oxygen from 60–100 % increased anthocyanin content of freshly harvested blueberries in the initial period of cold storage (0–7 days), they later reported that a similar effect in strawberries decreased with prolonged storage (Zheng et al. 2007).

2.5 Degradation of Anthocyanins

Knowledge about degradation mechanisms of anthocyanins is relatively little (Patras et al. 2010; Sadilova et al. 2006). It is believed that anthocyanins are decomposed by two pathways to end up with either chalcone and coumaric acid glycosides or aldehyde and benzoic acid derivatives, respectively (Patras et al. 2010). According to previous studies, anthocyanin would decompose upon heating into a chalcone structure, the latter being further transformed into a coumarin glucoside derivative with the loss of the B-ring (Hrazdina 1971). The aglycon-sugar bond is more labile than other glycoside bonds at pH 2–4. However, at pH 1 all glycosidic bonds are accessible to hydrolysis; e.g. heating cyanidin-3-rutinoside at pH 1 results in the formation of rhamnose and glucose, but only traces of rutinose (Adams 1973).

The possible thermal degradation process of nonacylated and acylated anthocyanins was reported in the literature (Sadilova et al. 2007; Sadilova et al. 2006). Successive deglycosylation reactions represent the initial steps of anthocyanin degradation at pH 1 yielding the respective aglycones. The latter will then be cleaved into a phenolic acid and a phenolic aldehyde. In the case of acylated anthocyanins, decay is slowed down because the intermediate compounds are also colored before further degradation proceeds the same way as for anthocyanin-glycosides.

References

- Adams, J. B. (1973). Thermal degradation of anthocyanins with particular reference to the 3-glycosides of cyanidin. I. In acidified aqueous solution at 100 °C. *Journal of the Science of Food and Agriculture*, 24, 747–762.
- Andersen, Ø. M., & Jordheim, M. (2014). Basic anthocyanin chemistry and dietary sources. In T. C. Wallace & M. M. Giusti (Eds.), *Anthocyanins in health and disease*. Boca Raton: Taylor & Francis Group LLC.

- Boulton, R. (2001). The copigmentation of anthocyanins and its role in the color of red wine: A critical review. *American Journal of Enology and Viticulture*, 52, 67–87.
- Bueno, J. M., Sáez-Plaza, P., Ramos-Escudero, F., Jimenez, A. M., Fett, R., & Asuero, A. G. (2012). Analysis and antioxidant capacity of anthocyanin pigments. Part II: Chemical structure, color, and intake of anthocyanins. *Critical Reviews in Analytical Chemistry*, 42, 126–151.
- Cabrita, L., Fossen, T., & Andersen, Ø. M. (2000). Colour and stability of the six common anthocyanidin 3-glucosides in aqueous solutions. *Food Chemistry*, 68, 101–107.
- Castañeda-Ovando, A., Pacheco-Hernández, M. D. L., Páez-Hernández, M. E., Rodríguez, J. A., & Galán-Vidal, C. A. (2009). Chemical studies of anthocyanins: A review. *Food Chemistry*, 113, 859–871.
- Cavalcanti, R. N., Santos, D. T., & Meireles, M. A. A. (2011). Non-thermal stabilization mechanisms of anthocyanins in model and food systems—an overview. *Food Research International*, 44, 499–509.
- Cemeroglu, B., Velioglu, S., & Isik, S. (1994). Degradation kinetics of anthocyanins in sour cherry juice and concentrate. *Journal of Food Science*, 59, 1216–1218.
- Cevallos-Casals, B. A., & Cisneros-Zevallos, L. (2004). Stability of anthocyanin-based aqueous extracts of Andean purple corn and red-fleshed sweet potato compared to synthetic and natural colorants. *Food Chemistry*, 86, 69–77.
- Dangles, O., Saito, N., & Brouillard, R. (1993). Anthocyanin intramolecular copigment effect. *Phytochemistry*, 34, 119–124.
- Davies, A. J., & Mazza, G. (1993). Copigmentation of simple and acylated anthocyanins with colorless phenolic compounds. *Journal of Agricultural and Food Chemistry*, 41, 716–720.
- Dugo, P., Mondello, L., Morabito, D., & Dugo, G. (2003). Characterization of the anthocyanin fraction of sicilian blood orange juice by micro-HPLC-ESI/MS. *Journal of Agricultural and Food Chemistry*, 51, 1173–1176.
- Durge, A. V., Sarkar, S., & Singhal, R. S. (2013). Stability of anthocyanins as pre-extrusion colouring of rice extrudates. *Food Research International*, 50, 641–646.
- Dyrby, M., Westergaard, N., & Stapelfeldt, H. (2001). Light and heat sensitivity of red cabbage extract in soft drink model systems. *Food Chemistry*, 72, 431–437.
- Erlandson, J. A., & Wrolstad, R. E. (1972). Degradation of anthocyanins at limited water concentration. *Journal of Food Science*, 37, 592–595.
- Fernandes, I., Faria, A., Calhau, C., de Freitas, V., & Mateus, N. (2014). Bioavailability of anthocyanins and derivatives. *Journal of Functional Foods*, 7, 54–66.
- Fernandes, I., Marques, F., de Freitas, V., & Mateus, N. (2013). Antioxidant and antiproliferative properties of methylated metabolites of anthocyanins. *Food Chemistry*, 141, 2923–2933.
- Fisher, U. A., Carle, R., & Kammerer, D. R. (2013). Thermal stability of anthocyanins and colourless phenolics in pomegranate (*Punica granatum* L.) juices and model solutions. *Food Chemistry*, 138, 1800–1809.
- Fleschhut, J., Kratzer, F., Rechkemmer, G., & Kulling, S. (2006). Stability and biotransformation of various dietary anthocyanins *in vitro*. *European Journal of Nutrition*, 45, 7–18.
- Francis, F. J. (1992). A new group of food colorants. *Trends in Food Science and Technology*, 3, 27–30.
- Garzón, G. A., & Wrolstad, R. E. (2001). The stability of pelargonidin-based anthocyanins at varying water activity. *Food Chemistry*, 75, 185–196.
- Garzón, G. A., & Wrolstad, R. E. (2002). Comparison of the stability of pelargonidin-based anthocyanins in strawberry juice and concentrate. *Journal of Food Science*, 67, 1288–1299.
- Giusti, M. M., & Wrolstad, R. E. (2003). Acylated anthocyanins from edible sources and their applications in food systems. *Biochemical Engineering Journal*, 14, 217–225.
- Glover, B. J., & Martin, C. (2012). Anthocyanins. *Current Biology*, 22, R147–R150.
- Goto, T. (1987). Structure, stability and color variation of natural anthocyanins. *Progress in the Chemistry of Organic Natural Products*, 52, 113–158.

- Goto, T., Hoshino, T., & Takase, S. (1979). A proposed structure of commelinin, a sky-blue anthocyanin complex obtained from the flower petals of *Commelina*. *Tetrahedron Letters*, 20, 2905–2908.
- Hellström, J., Mattila, P., & Karjalainen, R. (2013). Stability of anthocyanins in berry juices stored at different temperatures. *Journal of Food Composition and Analysis*, 31, 12–19.
- Hertog, M. G. L., Hollman, P. C. H., Katan, M. B., & Kromhout, D. (1993). Intake of potentially anticarcinogenic flavonoids and their determinants in adults in The Netherlands. *Nutrition and Cancer*, 20, 21–29.
- Hiemori, M., Koh, E., & Mitchell, A. E. (2009). Influence of cooking on anthocyanins in black rice (*Oryza sativa* L. *japonica* var. SBR). *Journal of Agricultural and Food Chemistry*, 57, 1908–1914.
- Hillebrand, S., Schwarz, M., & Winterhalter, P. (2004). Characterization of anthocyanins and pyranoanthocyanins from blood orange [*Citrus sinensis* (L.) Osbeck] juice. *Journal of Agricultural and Food Chemistry*, 52, 7331–7338.
- Hou, Z., Qin, P., Zhang, Y., Cui, S., & Ren, G. (2013). Identification of anthocyanins isolated from black rice (*Oryza sativa* L.) and their degradation kinetics. *Food Research International*, 50, 691–697.
- Howard, L. R., Castrodale, C., Brownmiller, C., & Mauromoustakos, A. (2010). Jam processing and storage effects on blueberry polyphenolics and antioxidant capacity. *Journal of Agricultural and Food Chemistry*, 58, 4022–4029.
- Hrazdina, G. (1971). Reactions of the anthocyanidin-3,5-diglucosides: Formation of 3,5-di-(O- β -D-glucosyl)-7-hydroxy coumarin. *Phytochemistry*, 10, 1125–1130.
- Jing, P., Zhao, S.-J., Ruan, S.-Y., Xie, Z.-H., Dong, Y., & Yu, L. (2012). Anthocyanin and glucosinolate occurrences in the roots of Chinese red radish (*Raphanus sativus* L.), and their stability to heat and pH. *Food Chemistry*, 133, 1569–1576.
- Kim, H. W., Kim, J. B., Cho, S. M., Chung, M. N., Lee, Y. M., Chu, S. M., et al. (2012). Anthocyanin changes in the Korean purple-fleshed sweet potato, Shinzami, as affected by steaming and baking. *Food Chemistry*, 130, 966–972.
- Kırca, A., & Cemeroğlu, B. (2003). Degradation kinetics of anthocyanins in blood orange juice and concentrate. *Food Chemistry*, 81, 583–587.
- Konczak, I., & Zhang, W. (2004). Anthocyanins—more than nature's colors. *Journal of Biomedicine and Biotechnology*, 5, 239–240.
- Kong, J. M., Chia, L. S., Goh, N. K., Chia, T. F., & Brouillard, R. (2003). Analysis and biological activities of anthocyanins. *Phytochemistry*, 64, 923–933.
- Kuehnau, J. (1976). The flavonoids. A class of semi-essential food components: their role in human nutrition. *World Review of Nutrition and Dietetics*, 24, 117–191.
- Maccarone, E., Maccarrone, A., & Rapisarda, P. (1985). Stabilization of anthocyanins of blood orange fruit juice. *Journal of Food Science*, 50, 901–904.
- Malien-Aubert, C., Dangles, O., & Amiot, M. J. (2000). Color stability of commercial anthocyanin-based extracts in relation to the phenolic composition. Protective effects by intra- and intermolecular copigmentation. *Journal of Agricultural and Food Chemistry*, 49, 170–176.
- Manach, C., Scalbert, A., Morand, C., Remesy, C., & Jimenez, L. (2004). Polyphenols: Food sources and bioavailability. *American Journal of Clinical Nutrition*, 79, 727–747.
- Markaris, P., Livingston, G. E., & Fellers, C. R. (1957). Quantitative aspects of strawberry pigment degradation. *Journal of Food Science*, 22, 117–130.
- Mateus, N., & de Freitas, V. (2009). Anthocyanins as food colorants. In K. Gould, K. Davies, & C. Winefield (Eds.), *Anthocyanins: Biosynthesis, functions and applications* (pp. 283–304). New York: Springer.
- Mazza, G., & Brouillard, R. (1990). The mechanism of copigmentation of anthocyanins in aqueous solutions. *Phytochemistry*, 29, 1097–1102.
- Mercadante, A. Z., & Bobbio, F. O. (2008). Anthocyanins in foods: occurrence and physicochemical properties. In C. Socaciu (Ed.), *Food Colorants: Chemical and Functional Properties* (pp. 241–276). Taylor and Francis: Boca Raton, FL: CRC Press.

- Merken, H. M., & Beecher, G. R. (2000). Measurement of food flavonoids by high-performance liquid chromatography: A review. *Journal of Agricultural and Food Chemistry*, 48, 577–599.
- Murai, K., & Wilkins, D. (1990). Natural red color derived from red cabbage. *Food Technology*, 44, 131.
- Navas, M. J., Jiménez-Moreno, A. M., Bueno, J. M., Sáez-Plaza, P., & Asuero, A. G. (2012). Analysis and antioxidant capacity of anthocyanin pigments. Part IV: Extraction of anthocyanins. *Critical Reviews in Analytical Chemistry*, 42, 313–342.
- Nayak, B., Berrios, J. D. J., Powers, J. R., & Tang, J. (2011). Thermal degradation of anthocyanins from purple potato (cv. Purple Majesty) and impact on antioxidant capacity. *Journal of Agricultural and Food Chemistry*, 59, 11040–11049.
- Odriozola-Serrano, I., Soliva-Fortuny, R., & Martín-Belloso, O. (2009). Influence of storage temperature on the kinetics of the changes in anthocyanins, vitamin C, and antioxidant capacity in fresh-cut strawberries stored under high-oxygen atmospheres. *Journal of Food Science*, 74, C184–C191.
- Patras, A., Brunton, N. P., O'Donnell, C., & Tiwari, B. K. (2010). Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. *Trends in Food Science and Technology*, 21, 3–11.
- Pazmiño-Durán, A. E., Giusti, M. M., Wrolstad, R. E., & Glória, M. B. A. (2001). Anthocyanins from *Oxalis triangularis* as potential food colorants. *Food Chemistry*, 75, 211–216.
- Raymond, B. (1981). Origin of the exceptional colour stability of the Zebrina anthocyanin. *Phytochemistry*, 20, 143–145.
- Raymond, B. (1983). The *in vivo* expression of anthocyanin colour in plants. *Phytochemistry*, 22, 1311–1323.
- Reque, P. M., Steffens, R. S., Jablonski, A., Flôres, S. H., Rios, A. d. O., & de Jong, E. V. (2014). Cold storage of blueberry (*Vaccinium* spp.) fruits and juice: Anthocyanin stability and antioxidant activity. *Journal of Food Composition and Analysis*, 33, 111–116.
- Roobha, J. J., Saravanakumar, M., Aravindhana, K., & Devi, P. S. (2011). The effect of light, temperature, pH on stability of anthocyanin pigments in *Musa acuminata* bract. *Research in Plant Biology*, 1, 5–12.
- Sadilova, E., Carle, R., & Stintzing, F. C. (2007). Thermal degradation of anthocyanins and its impact on color and *in vitro* antioxidant capacity. *Molecular Nutrition and Food Research*, 51, 1461–1471.
- Sadilova, E., Stintzing, F. C., & Carle, R. (2006). Thermal degradation of acylated and non-acylated anthocyanins. *Journal of Food Science*, 71, C504–C512.
- Torskangerpoll, K., & Andersen, Ø. M. (2005). Colour stability of anthocyanins in aqueous solutions at various pH values. *Food Chemistry*, 89, 427–440.
- Tsuda, T. (2012). Dietary anthocyanin-rich plants: Biochemical basis and recent progress in health benefits studies. *Molecular Nutrition and Food Research*, 56, 159–170.
- Wang, W.-D., & Xu, S.-Y. (2007). Degradation kinetics of anthocyanins in blackberry juice and concentrate. *Journal of Food Engineering*, 82, 271–275.
- Wu, X., Beecher, G. R., Holden, J. M., Haytowitz, D. B., Gebhardt, S. E., & Prior, R. L. (2006). Concentrations of anthocyanins in common foods in the united states and estimation of normal consumption. *Journal of Agricultural and Food Chemistry*, 54, 4069–4075.
- Zheng, Y., Wang, C. Y., Wang, S. Y., & Zheng, W. (2003). Effect of high-oxygen atmospheres on blueberry phenolics, anthocyanins and antioxidant capacity. *Journal of Agricultural and Food Chemistry*, 51, 7162–7169.
- Zheng, Y., Wang, S. Y., Wang, C. Y., & Zheng, W. (2007). Changes in strawberry phenolics, anthocyanins, and antioxidant capacity in response to high oxygen treatments. *LWT Food Science and Technology*, 40, 49–57.

Impact of Food Processing on Anthocyanins

Sui, X.

2017, XXVI, 129 p. 27 illus., 8 illus. in color., Hardcover

ISBN: 978-981-10-2611-9