e-ISSN 2581-0405
Asian Journal of Applied Research for Community Development and Empowerment
Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Encapsulation of Anthocyanins and the Factors Affecting Their Stability as Natural Colorants in Food Products

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ARTICLE INFO

Article History:
Received: 11 August 2025
Final Revision: 27 August 2025
Accepted: 31 August 2025
Online Publication: 04 September 2025

KEYWORDS

c, anthocyanins, natural colorants, stability, food applications

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A B S T R A C T

Colorants are commonly added to food products to enhance their visual appeal and increase consumer interest. Among the various types of natural pigments, anthocyanins—derived from fruits, vegetables, flowers, and tuberous plants—have garnered significant scientific interest due to their vivid coloration and associated health-promoting properties. Nevertheless, anthocyanins exhibit considerable sensitivity to environmental variables, including temperature, pH, oxygen exposure, ultraviolet (UV) radiation, and interactions with other molecular constituents. A range of environmental stressors can accelerate the deterioration of anthocyanin pigments during processing and storage, leading to a decrease in colour intensity. To counteract these destabilizing influences, various encapsulation strategies have been developed to protect anthocyanins from degradation. Among these, spray drying is widely recognized for its efficacy in maintaining both the physicochemical integrity and biofunctional performance of anthocyanin molecules. This review discusses the strategic importance of encapsulation in enhancing anthocyanin stability and examines the primary degradation mechanisms relevant to their application in food systems.

Contribution to Sustainable Development Goals (SDGs):
SDG 3: Good Health and Well-Being
SDG 9: Industry, Innovation and Infrastructure
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Color represents a fundamental quality parameter in food and beverage products, exerting a substantial influence on consumer perception and purchasing decisions. The strategic incorporation of food colorants is widely adopted in the industry to enhance product appearance and elevate market appeal [1,2]. Visual characteristics, particularly color, serve as powerful sensory cues that shape consumer expectations and may significantly alter perceived taste and overall acceptance [3]. However, natural pigments are prone to degradation when subjected to food processing operations involving heat, freezing, or dehydration, thereby reinforcing the need for colorants with enhanced stability under such conditions [4].

In terms of classification, food colourants are broadly divided into two main categories—natural and synthetic—based on their origin [5]. Natural colorants encompass a wide spectrum of bioactive molecules, among which anthocyanins are particularly notable for their intense pigmentation and associated health benefits. These naturally occurring compounds are commonly derived from deeply colored plant materials, including blueberries, blackcurrants, purple grapes, and eggplants. Other notable natural pigments include β-carotene, a provitamin A compound abundant in orange vegetables like carrots and pumpkins, and chlorophyll, the primary pigment associated with photosynthesis, derived from leafy greens such as spinach and kale. Additionally, curcumin, a bright yellow polyphenolic compound obtained from turmeric, and carotenoids found in

maize, yellow squash, and orange-fleshed sweet potatoes further contribute to the natural pigment repertoire. Conversely, synthetic dyes such as Tartrazine (E102), Sunset Yellow (E110), and Allura Red (E129) are extensively utilized in the production of processed foods and beverages to enhance visual intensity and uniformity [2, 6].

Among the various classes of naturally derived pigments, anthocyanins have emerged as compounds of considerable interest due to their vibrant hues—spanning from red to blue—and their broad spectrum of biological functionalities [7] As a branch of the flavonoid family, anthocyanins exhibit distinct sensitivity to pH fluctuations, undergoing significant color shifts depending on the acidity or alkalinity of their environment. In strongly acidic media (pH 2–4), these pigments are predominantly red; however, increasing the pH toward neutral or alkaline levels leads to gradual transitions into blue, yellow, or even colourless forms. This remarkable pH-responsive behavior makes anthocyanins highly suitable for incorporation into acidic food products, particularly in beverage formulations [8]. Beyond their role as natural colourants, anthocyanins are widely recognised for their potent antioxidant capacity, which underpins various health-promoting effects. Through their ability to neutralise reactive oxygen species (ROS), anthocyanins contribute to mitigating oxidative stress, a key pathological mechanism involved in the development of chronic conditions, including cardiovascular disease, certain cancers, and premature ageing at the cellular level [6].

2. MATERIALS AND METHODS

This review is based on a structured and comprehensive analysis of peer-reviewed publications that explore the encapsulation of anthocyanins and their practical applications in food-related systems. The primary goal of this work is to integrate existing scientific perspectives on the potential use of tamarillo (Solanum betaceum) as a functional food ingredient, with an emphasis on its anthocyanin composition and stability characteristics. A total of 68 relevant scholarly articles were rigorously reviewed, encompassing both national and international journal publications indexed in major scientific databases, including Scopus.

3. RESULT AND DISCUSSION

3.1. Anthocyanins

Anthocyanins are plant-derived pigments found extensively in nature, particularly concentrated in a wide variety of fruits and vegetables [9]. These compounds, classified under the flavonoid group of polyphenols, have become the focus of numerous scientific studies due to their diverse biological functions, including antioxidant, anti-inflammatory, anticancer, and neuroprotective activities [10]. Various plant-based foods exhibit notable anthocyanin contents [11]. For instance, sweet cherries (Prunus avium) may contain from 1.03 to 179.14 mg C3G/100g, while tamarillo (Solanum betaceum) ranges from 29.70 to 481.37 mg C3G/100g. Other fruits, such as sour cherries, tomatoes, nectarines, peaches, plums, pomegranates, red currants, and red grapes, also provide varying amounts. Additional rich sources include several types of berries such as blueberries, blackberries, blackcurrants, acai, and raspberries [12]. The typical molecular structure of anthocyanins is shown in Figure 1.

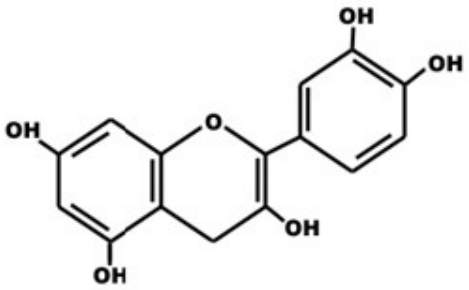

Fig. 1. Chemical structure of anthocyanins [13]

To date, six primary anthocyanidins—cyanidin, pelargonidin, delphinidin, peonidin, petunidin, and malvidin—have been identified as constituting roughly 90% of anthocyanin compounds found in plants [14]. Cyanidin, the most abundant, imparts red to purplish tones in berries and red vegetables. Pelargonidin contributes bright red to orange shades, notably in strawberries and red-hued flowers. Delphinidin is associated with the blue to purple pigmentation found in violet-coloured species. Methylated forms such as peonidin and petunidin are prevalent in grapes and blackcurrants, while malvidin is chiefly responsible for the intense purple tones in red wine and certain flowers [6, 15]. A comparative overview is provided in Table 1.

Anthocyanins are generally classified into two forms: acylated and non-acylated. Acylated types, conjugated with organic acids like acetic, p-coumaric, or cinnamic acid, form stable intramolecular co-pigmentation complexes, enhancing pigment resilience [38]. Examples include malvidin-3-O-coumaroylglucoside and sinensetin-3-O-sinamate. Conversely, non-acylated anthocyanins—such as cyanidin-3-glucoside and pelargonidin-3-glucoside—lack such modifications and exhibit lower stability under thermal and oxidative stress [9]. The degree of acylation significantly affects solubility, structural integrity, bioaccessibility, and functional performance in food applications [39, 40, 41].

Within the food industry, anthocyanins are widely used as natural pigments in various beverages, including fruit juices, carbonated drinks, teas, and fortified formulations, providing both aesthetic enhancement and antioxidant functionality [8,9]. Their application also spans frozen dairy desserts, bakery products, and functional snacks, presenting natural alternatives to synthetic dyes while delivering additional health benefits [42,43,44,45,46].

https://doi.org/10.29165/ajarcde.v9i3.586

Table 1. Common Types of Anthocyanins and Their Natural Sources

No	Type of Anthocyanin	Sources	Ref.
1.	Cyanidin	*Blueberries, blackberries, raspberries*, red grapes, red cherries, red apples, pomegranates, purple eggplants, purple cabbage, red spinach, shallots, and purple oranges.	[16,17,18, 19]
2.	Delphinidin	*Blueberries, cranberries, blackcurrants*, purple grapes, purple eggplants, purple cabbage, red spinach, aubergines, plums, cherries, and strawberries	[20,21, 22]
3.	Malvidin	Red wine, purple eggplant, purple cabbage, and red spinach, *blackberries, blueberries, and raspberries.*	[23,24,25, 26,27]
4.	Pelargonidin	Strawberries, red geraniums, red roses, pink roses, *raspberries, blueberries, cranberries, saskatoon berries, chockberries*, plums, pomegranates, kidney beans, and telang flowers.	[28,23,29,30, 31,32]
.	Peonidin	Cranberries, blueberries, plums, grapes, purple sweet potatoes, black rice, and black bananas.	[33,34]
6.	Petunidin	*Blackberries, blueberries*, pomegranates, rosella flowers, purple sweet potatoes, and red wine.	[35,36, 37]

3.2. Anthocyanins Encapsulation

Encapsulation represents a strategic technological advancement that aims to enclose bioactive compounds within a stabilising carrier system, thereby shielding them from adverse physicochemical conditions. In the context of anthocyanins—naturally derived pigments that confer red to blue hues in various plant-based sources—encapsulation has been shown to markedly enhance both their chemical stability and bioavailability [47]. The primary objective of this approach is to maintain the molecular and functional integrity of anthocyanins by mitigating degradation processes triggered by environmental stressors, such as light exposure, oxidative reactions, thermal treatment, and fluctuations in pH—factors that are well-documented to impair their antioxidant efficacy and biological functionality [48, 3]. A variety of encapsulation techniques have been progressively developed and optimized to ensure anthocyanin stability, with the most widely applied methods outlined in Table 2.

Table 2. Common Methods of Anthocyanin Encapsulation

No.	Method	Description	References
1.	*Spray Drying*	An anthocyanin solution is dispersed in a carrier matrix and atomised into hot air, resulting in a powder.	[49,50]
2.	*Coacervation*	Encapsulation is achieved through the deposition of polymers or proteins around the anthocyanin solution. This is typically induced via pH shifts or the addition of coacervating agents.	[51,52]
3.	*Emulsifikasi*	Anthocyanins are dispersed in an oil phase and emulsified in water using surfactants to create encapsulated droplets of adjustable size.	[3,53]
4.	*Liposomisasi*	Lipid vesicles are formed containing anthocyanins. This enhances their solubility and offers protection against environmental degradation.	[54,55]
5.	*Freeze-Drying* (Lyophilization)	Anthocyanin solutions are frozen and dehydrated via sublimation. This method effectively preserves biological activity.	[56,47]
6.	*Electrospinning*	Nanofibers are created from anthocyanin solutions using an electric field. This technique generates encapsulated structures at the nanoscale.	[57,58]

The choice of encapsulation method is primarily determined by the physicochemical traits of anthocyanins, their intended role in the food matrix, and specific formulation targets. An optimised process enhances solubility, stability, and functional performance, while enabling controlled release in various applications [48,57]. Spray drying remains the most common and cost-effective technique for producing anthocyanin-rich powders at an industrial scale, yielding uniform particles with superior rehydration capacity and enhanced stability—attributes that are advantageous for commercial food production [59,60,61].

Equally important is the judicious selection of encapsulating agents, which critically influences both the stability and functional delivery of anthocyanins. A broad range of encapsulation materials has been evaluated to date. Polysaccharide-based matrices—such as chitosan, alginate, and modified starches like maltodextrin—are frequently utilised due to their excellent film-forming properties and ability to limit anthocyanin degradation by serving as physical barriers [54,60]. Lipid-based systems, including vegetable oils, phospholipids, and other hydrophobic compounds, provide protection by creating nonpolar matrices that hinder oxidative and thermal degradation [62]. Additionally, protein-derived carriers, such as whey protein isolate, casein, and soy protein, possess favourable emulsifying and gel-forming properties, which enhance anthocyanin

dispersion and solubility in aqueous environments [63]. Recent studies have highlighted the potential of niosomes—nanostructured vesicles derived from non-ionic surfactants—as advanced delivery systems that can maintain anthocyanin stability and protect them against various physicochemical stressors [64].

3.3. Anthocyanin Stability

The physicochemical stability of anthocyanins is markedly influenced by multiple environmental parameters, including pH, temperature fluctuations, oxidative conditions, and ultraviolet (UV) radiation. These external stimuli can substantially compromise the structural integrity, chromatic expression, and bioactive potential of anthocyanins within food matrices. One of the defining features of anthocyanins is their pH-responsive behaviour, which induces reversible molecular rearrangements that determine the appearance and chemical resilience of the pigment. Under strongly acidic conditions (pH < 3), anthocyanins predominantly appear red to orange and exhibit enhanced structural stability. However, as the pH approaches neutrality (pH 6–7), the colour transitions toward purple. Under alkaline conditions (pH > 7), the molecules convert into quinonoidal base or chalcone forms, which are inherently unstable and often result in bluish or even colourless appearances [65]. Although these transformations may be partially reversible, prolonged exposure to non-optimal pH ranges contributes to the cumulative degradation of pigment.

Beyond pH effects, temperature constitutes a decisive factor influencing the stability of anthocyanins. Owing to their thermolabile nature, these bioactive pigments readily undergo structural breakdown when subjected to elevated heat during processing. In food manufacturing, operations such as pasteurisation, dehydration, and sterilisation have been reported to cause substantial losses in pigment integrity and a concomitant decline in antioxidant functionality [37, 3]. Conversely, low-temperature conditions, including ambient or refrigerated storage, are more conducive to anthocyanin stability. This highlights the need for rigorous temperature regulation during processing, handling, and storage to prevent loss of functional and sensory qualities.

Oxidative stress constitutes another major destabilizing factor for anthocyanins, occurring through both direct oxidation and enzyme-mediated reactions. Oxygen availability accelerates pigment breakdown, particularly in the presence of catalytic enzymes such as polyphenol oxidase (PPO) and peroxidase (POD), resulting in diminished color intensity and reduced biological efficacy (Molina et al., 2023). Mitigation can be achieved through oxygen-limiting techniques, such as vacuum sealing and modified atmosphere packaging, which effectively curb oxidative deterioration [66].

Moreover, light-induced deterioration presents another significant challenge, particularly from ultraviolet (UV) radiation. Anthocyanins are inherently photosensitive, with exposure to UV-B and UV-C known to trigger structural disruptions that impair both pigment intensity and antioxidant potency [67]. Preventative measures, including the use of UV-resistant packaging and storage in dark environments, are therefore recommended to shield these compounds from photodegradation [68].

Altogether, the sensitivity of anthocyanins to thermal, oxidative, and photonic factors necessitates a comprehensive preservation approach. Effective stabilization protocols are crucial to maintaining not only the visual appeal and chemical integrity of anthocyanin-rich food products but also their nutritional and functional value as health-promoting ingredients within contemporary food systems.

4. CONCLUSION

Food colorants are extensively incorporated into food formulations to enhance visual appeal and strengthen consumer interest. Within the category of natural pigments, anthocyanins—derived from a diverse array of botanical materials, including fruits, vegetables, flowers, and tuberous plants—have garnered considerable academic interest due to their intense colouration and documented health-promoting properties. A hallmark feature of these pigments is their pH-sensitive chromatic shift, which exhibits red hues under acidic conditions and transitions toward blue in alkaline environments. Beyond their role as aesthetic enhancers, anthocyanins possess notable antioxidant capacity, underpinning a variety of physiological benefits. However, their molecular and functional integrity is highly susceptible to environmental challenges, including temperature and pH fluctuations, oxidative stress, ultraviolet radiation, and interactions with other constituents within the food matrix. Inadequate processing or improper storage can accelerate degradation, resulting in diminished colour intensity and reduced antioxidant potential. To safeguard both the visual and bioactive properties of anthocyanins, encapsulation technologies are increasingly employed, with methods tailored to the physicochemical characteristics of the pigment source. Among the available approaches, spray drying stands out as an exceptionally efficient and industrially scalable technique, converting anthocyanins into stable powdered forms that enhance solubility, extend shelf life, and facilitate the integration of these natural and functional colourants into diverse food products.

REFERENCE

[1] Ngamwonglumlert, L., Devahastin, S., & Chiewchan, N. (2017). Natural Colorants : Pigment Stability And Extraction Yield Enhancement Via Utilization Of Appropriate Pretreatment And Extraction Methods. Critical Reviews in Food Science and Nutrition, 57(15), 3243–3259. https://doi.org/10.1080/10408398.2015.1109498

[2] Molina, A. K., Corr, C. G., Prieto, M. A., & Pereira, C. (2023). Bioactive Natural Pigments' Extraction, Isolation, and Stability in Food Applications. Molecules, 1–25.

[3] Jurić, S., Jurić, M., Król-Kilińska, Ż., Vlahoviček-Kahlina, K., Vinceković, M., Dragović-Uzelac, V., & Donsì, F. (2022). Sources, Stability, Encapsulation And Application Of Natural Pigments In Foods. Food Reviews International, 38(8), 1735–1790. https://doi.org/10.1080/87559129.2020.1837862

[4] Sari, Y., Santoni, A., & Elisabet, E. (2018). Comparative Test Of Color Stability Between Betalain Pigments Of Red Dragon Fruits And Anthocyanin Pigments From Tamarillo Fruit At Various Ph. Jurnal Kimia Sains Dan Aplikasi, 21(3), 107–112. https://doi.org/10.14710/jksa.21.3.107-112

[5] Vila, M. M. D. C., Chaud, M. V., & Balcão, V. M. (2015). Microencapsulation of Natural Anti-Oxidant Pigments. Microencapsulation and Microspheres for Food Applications, 369–389. https://doi.org/10.1016/B978-0-12-800350-3.00024-8

[6] Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins And Anthocyanins: Colored Pigments As Food, Pharmaceutical Ingredients, And The Potential Health Benefits. Food and Nutrition Research, 61. https://doi.org/10.1080/16546628.2017.1361779

[7] Tan, J., Han, Y., Han, B., Qi, X., Cai, X., Ge, S., & Xue, H. (2022). Extraction And Purification Of Anthocyanins : A Review. Journal of Agriculture and Food Research,

[8] Gérard, V., Ay, E., Morlet-Savary, F., Graff, B., Galopin, C., Ogren, T., Mutilangi, W., & Lalevée, J. (2019). Thermal and Photochemical Stability of Anthocyanins from Black Carrot, Grape Juice, and Purple Sweet Potato in Model Beverages in the Presence of Ascorbic Acid. Journal of Agricultural and Food Chemistry, 67(19), 5647–5660. https://doi.org/10.1021/acs.jafc.9b01672

[9] Vidana Gamage, G. C., Lim, Y. Y., & Choo, W. S. (2022). Sources And Relative Stabilities Of Acylated And Nonacylated Anthocyanins In Beverage Systems. Journal of Food Science and Technology, 59(3), 831–845. https://doi.org/10.1007/s13197-021-05054-z

[10] Teng, H., Fang, T., Lin, Q., Song, H., Liu, B., & Chen, L. (2017). Red Raspberry And Its Anthocyanins: Bioactivity Beyond Antioxidant Capacity. In Trends in Food Science and Technology (Vol. 66, pp. 153–165). Elsevier Ltd. https://doi.org/10.1016/j.tifs.2017.05.015

[11] Silva, S., Costa, E. M., Calhau, C., Morais, R. M., & Pintado, M. E. (2017). Anthocyanin Extraction From Plant Tissues : A Review. Critical Reviews in Food Science and Nutrition, 57(14), 3072–3083. https://doi.org/10.1080/10408398.2015.1087963

[12] Shaik, A., Killari, K. N., & Panda, J. (2018). A Review On Anthocyanins : A Promising Role On Phytochemistry And Pharmacology. Int. Res. J. Pharm, 1. https://doi.org/10.7897/2230-8407.0911

[13] Priska, M., Peni, N., Carvallo, L., & Dala Ngapa, Y. (2018). Review: Antosianin Dan Pemanfaatannya. Cakra Kimia (Indonesian E-Journal of Applied Chemistry (Vol. 6, Issue 2).

[14] Wallace, T.C.; Giusti, M.M. Anthocyanins—Nature's Bold, Beautiful, and Health-Promoting Colors. Foods 2019, 8, 550. doi: 10.3390/foods8110550

[15] Bendokas, V.; Skemiene, K.; Trumbeckaite, S.; Stanys, V.; Passamonti, S.; Borutaite, V.; Liobikas, J. Anthocyanins: From plant pigments to health benefits at mitochondrial level. Crit. Rev. Food Sci. Nutr. 2019, 60, 3352–3365. doi: 10.1080/10408398.2019.1687421

[16] Rahnasto-Rilla, M; Tyni, J; Huovinen, M; Jarho, E; Kulikowicz, T; Ravichandran, S; Bohr, V A; Ferrucci, L; Lahtela-Kakkonen, M; Moaddel, R (2018-03-07). Natural Polyphenols As Sirtuin 6 Modulators. Sci Rep. 7, 8 (1): 4163. doi:10.1038/s41598-018-22388-5.

[17] Klein MA, Denu JM (2020). Biological And Catalytic Functions Of Sirtuin 6 As Targets For Small-Molecule Modulators. Journal of Biological Chemistry. 295 (32): 11021–11041. doi:10.1074/jbc.REV120.011438.

[18] Tulio AZ, Reese RN, Wyzgoski FJ, Rinaldi PL, Fu R, Scheerens JC, Miller AR (2008). Cyanidin 3-Rutinoside And Cyanidin 3-Xylosylrutinoside As Primary Phenolic Antioxidants In Black Raspberry. Journal of Agricultural and Food Chemistry. 56 (6): 1880–8. doi:10.1021/jf072313k.

[19] He F, Liang NN, Mu L, Pan QH, Wang J, Reeves MJ, Duan CQ (2012). Anthocyanins And Their Variation In Red Wines I. Monomeric Anthocyanins And Their Color Expression. Molecules. 17 (2): 1571–601. doi:10.3390/molecules17021571.

[20] Afaq, F.; Syed, D. N.; Malik, A.; Hadi, N.; Sarfaraz, S.; Kweon, M.-H.; Khan, N.; Zaid, M. A.; Mukhtar, H. (2007). Delphinidin, an Anthocyanidin in Pigmented Fruits and Vegetables, Protects Human HaCaT Keratinocytes and Mouse Skin Against UVB-Mediated Oxidative Stress and Apoptosis. Journal of Investigative Dermatology. 127 (1): 222–232. doi:10.1038/sj.jid.5700510.

[21] Lätti AK, Riihinen KR, Kainulainen PS (2008). Analysis Of Anthocyanin Variation In Wild Populations Of Bilberry (Vaccinium myrtillus L.) In Finland. J Agric Food Chem. 56 (1): 190–6. doi:10.1021/jf072857m.

[22] Noda Y, Kneyuki T, Igarashi K, Mori A, Packer L (2000). Antioxidant Activity Of Nasunin, An Anthocyanin In Eggplant Peels. Toxicology. 148 (2–3): 119–23. doi:10.1016/s0300-483x(00)00202-x.

[23] Mazza G (2005). Compositional And Functional Properties Of Saskatoon Berry And Blueberry. International Journal of Fruit Science. 5 (3): 99–118. doi:10.1300/J492v05n03_10.

[24] Bakowska-barczak; Marianchuk, M; Kolodziejczyk, P (2007). Survey Of Bioactive Components In Western Canadian Berries. Canadian Journal of Physiology and Pharmacology. 85 (11): 1139–52. doi:10.1139/y07-102.

[25] Nakayama, M; Roh, MS; Uchida, K; Yamaguchi, Y; Takano, K; Koshioka, M (2000). Malvidin 3-Rutinoside As The Pigment Responsible For Bract Color In Curcuma Alismatifolia. Bioscience, Biotechnology, and Biochemistry. 64 (5): 1093–5. doi:10.1271/bbb.64.1093.

[26] Tatsuzawa, F (1999). Acylated Malvidin 3-Rutinosides In Dusky Violet Flowers Of Petunia Integrifolia Subsp. Inflata. Phytochemistry. 52 (2): 351–355. doi:10.1016/S0031-9422(99)00095-3.

[27] Markham, Kenneth R.; Mitchell, Kevin A.; Boase, Murray R. (1997). Malvidin-3-O-Glucoside-5-O-(6-Acetylglucoside) And Its Colour Manifestation In 'Johnson's Blue' And Other 'Blue' Geraniums". Phytochemistry. 45 (2) : 417–423. doi:10.1016/S0031-9422(96)00831-X.

[28] Huihua, Wan; Chao, Yu; Yu, Han; Xuelian, Guo (2019). Determination of Flavonoids and Carotenoids and Their Contributions to Various Colors of Rose Cultivars (Rosa spp.). Frontiers in Plant Science. 10: 123. doi:10.3389/fpls.2019.00123.

[29] Lin, Long-Ze; Harnly, James M.; Pastor-Corrales, Marcial S.; Luthria, Devanand L. (2008). The polyphenolic profiles of common bean (Phaseolus vulgaris L.). Food Chemistry. 107 (1): 399 –410. doi:10.1016/j.foodchem.2007.08.038.

[30] Levisson, Mark; Patinios, Constantinios; Hein, Sascha; de Groot, Phillip A. (2018). Engineering de novo anthocyanin production in Saccharomyces cerevisiae. Microbial Cell Factories. 17 (103): 103. doi:10.1186/s12934-018-0951-6.

[31] Li, Wenfeng; Gu, Mengyuan; Gong, Pengling; Wang, Jinxia (2021). Glycosides changed the stability and antioxidant activity of pelargonidin. Lebensmittel-Wissenschaft & Technologie. 147 (3): 111581. doi:10.1016/j.lwt.2021.111581.

[32] Saito, N; Tatsuzawa, F; Yokoi, M; Kasahara, K; Iida, S; Shigihara, A; Honda, T (1996). Acylated pelargonidin glycosides in red-purple flowers of Ipomoea purpurea. Phytochemistry. 43 (6): 1365–70. doi:10.1016/s0031-9422(96)00501-8.

[33] Jung Yeon Kwon; Ki Won Lee; Haeng Jeon Hur; Hyong Joo Lee (2007). Peonidin Inhibits Phorbol-Ester-Induced COX-2 Expression and Transformation in JB6 P+ Cells by Blocking Phosphorylation of ERK-1 and -2. Annals of

the New York Academy of Sciences. 1095 (1): 513–520. doi:10.1196/annals.1397.055.

[34] Van-Den Truong; Nigel Deighton; Roger T. Thompson; Roger F. McFeeters; Lisa O. Dean; Kenneth V. Pecota & G. Craig Yencho (2009). Characterization of Anthocyanins and Anthocyanidins in Purple-Fleshed Sweetpotatoes by HPLC-DAD/ESI-MS/MS. Journal of Agricultural and Food Chemistry. 58 (1): 404–410. doi:10.1021/jf902799a.

[35] 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(11), 4069–4075. https://doi.org/10.1021/jf0603001

[36] Di Khanh, N. (2015). Advances In The Extraction Of Anthocyanin From Vegetables. Journal of Food and Nutrition Sciences, 3(1), 126. https://doi.org/10.11648/j.jfns.s.2015030102.34

[37] Enaru, B., Drețcanu, G., Pop, T. D., Stănilă, A., & Diaconeasa, Z. (2021). Anthocyanins : Factors Affecting Their Stability And Degradation. In Antioxidants (Vol. 10, Issue 12). MDPI. https://doi.org/10.3390/antiox10121967

[38] Giusti, M. M., & Wrolstad, R. E. (2003). Acylated Anthocyanins From Edible Sources And Their Applications In Food Systems. Biochemical Engineering Journal, 14(3), 217–225. https://doi.org/10.1016/S1369-703X(02)00221-8

[39] Bakowska-Barczak, A. (2005). Acylated Anthocyanins As Stable, Natural Food Colorants – a Review. Polish Journal of Food And Nutrition Sciences, 1455(2), 107–116.

[40] Jokioja, J., Yang, B., & Linderborg, K. M. (2021). Acylated Anthocyanins: A Review On Their Bioavailability And Effects On Postprandial Carbohydrate Metabolism And Inflammation. Comprehensive Reviews in Food Science and Food Safety, 20(6), 5570–5615. https://doi.org/10.1111/1541-4337.12836

[41] Steingass, C. B., Burkhardt, J., Bäumer, V., Kumar, K., Mibus-Schoppe, H., Zinkernagel, J., Esquivel, P., Jiménez, V. M., & Schweiggert, R. (2023). Characterisation Of Acylated Anthocyanins From Red Cabbage, Purple Sweet Potato, And Tradescantia Pallida Leaves As Natural Food Colourants By HPLC-DAD-ESI(+)-QTOF-MS/MS And ESI(+)-Msn Analysis. Food Chemistry, 416. https://doi.org/10.1016/j.foodchem.2023.135601

[42] Diep, T. T., Yoo, M. J. Y., & Rush, E. (2022). Effect of tamarillo fortification and fermentation process on physicochemical properties and nutrient and volatiles content of yoghurt. Foods, 11(1). https://doi.org/10.3390/foods11010079

[43] Fernandino, C. M., Nepomuceno, A. T., Fonseca, H. C., Bastos, R. A., & De Lima, J. P. (2021). Physicochemical properties of tamarillo pulp (Solanum betaceum) and its applicability in the production of ice cream. Brazilian Journal of Food Technology, 24. https://doi.org/10.1590/1981-6723.09020

[44] Hasni, D., Rohaya, S., & Supriana, N. (2017). Kajian Pengolahan Sorbet Campuran Terong Belanda Dan Buah Bit Sebagai Produk Pangan Fungsional. Sagu , 16(1), 21–27.

[45] Pratama, D. R., Purwati, E., Yuherman, & Melia, S. (2021). The potential of probiotic frozen yoghurt with the addition of fruits tamarillo to increase immunity. IOP Conference Series: Earth and Environmental Science, 694(1). https://doi.org/10.1088/1755-1315/694/1/012070

[46] Syu, P.-C., Zhang, Q.-F., & Lin, S.-D. (2023). Physicochemical, Antioxidant, Sensory, and Starch Digestibility Properties of Steamed Bread Fortified with Tamarillo Powder. Foods, 12(12), 2306. https://doi.org/10.3390/foods12122306

[47] Noore, S., Rastogi, N. K., O'Donnell, C., & Tiwari, B. (2021). Novel Bioactive Extraction And Nano-Encapsulation. Encyclopedia, 1(3), 632–664. https://doi.org/10.3390/encyclopedia1030052

[48] Etzbach, L., Meinert, M., Faber, T., Klein, C., Schieber, A., & Weber, F. (2020). Effects Of Carrier Agents On Powder Properties, Stability Of Carotenoids, And Encapsulation Efficiency Of Goldenberry (Physalis peruviana L.) Powder Produced By Co-Current Spray Drying. Current Research in Food Science, 3(March), 73–81. https://doi.org/10.1016/j.crfs.2020.03.002

[49] Castro-Alatorre, N. C., Gallardo-Velázquez, T., Boyano-Orozco, L. C., Téllez-Medina, D. I., Meza-Márquez, O. G., & Osorio-Revilla, G. (2021). Extraction And Microencapsulation Of Bioactive Compounds From Muicle (Justicia spicigera) And Their Use In The Formulation Of Functional Foods. Foods, 10(8). https://doi.org/10.3390/foods10081747

[50] Castro-López, C., Espinoza-González, C., Ramos-González, R., Boone-Villa, V. D., Aguilar-González, M. A., Martínez-Ávila, G. C. G., Aguilar, C. N., & Ventura-Sobrevilla, J. M. (2021). Spray-Drying Encapsulation Of Microwave-Assisted Extracted Polyphenols From Moringa Oleifera : Influence Of Tragacanth, Locust Bean, And Carboxymethyl-Cellulose Formulations. Food Research International, 144(March). https://doi.org/10.1016/j.foodres.2021.110291

[51] Dayane, P., Santos, D. F., Thaís, F., Rubio, V., Palazzolli, M., Pinho, L. S., & Favaro-trindade, C. S. (2021). Microencapsulation of carotenoid-rich materials : A review. Food Research Internationa, 147(110571), 1–25. https://doi.org/https://doi.org/10.1016/j.foodres.2021.110571

[52] Osvaldt Rosales, T. K., Pessoa da Silva, M., Lourenço, F. R., Aymoto Hassimotto, N. M., & Fabi, J. P. (2021). Nanoencapsulation Of Anthocyanins From Blackberry (Rubus Spp.) Through Pectin And Lysozyme Self-Assembling. Food Hydrocolloids, 114(June 2020). https://doi.org/10.1016/j.foodhyd.2020.106563

[53] Feitosa, B. F., Decker, B. L. A., Brito, E. S. de, Rodrigues, S., & Mariutti, L. R. B. (2023). Microencapsulation Of Anthocyanins As Natural Dye Extracted From Fruits – A Systematic Review. In Food Chemistry (Vol. 424). Elsevier Ltd. https://doi.org/10.1016/j.foodchem.2023.136361

[54] Celli, G. B., Ghanem, A., & Brooks, M. S. L. (2016). Optimized Encapsulation Of Anthocyanin-Rich Extract From Haskap Berries (Lonicera caerulea L.) In Calcium-Alginate Microparticles. Journal of Berry Research, 6(1), 1–11. https://doi.org/10.3233/JBR-150107

[55] Makhathini, N., Kaseke, T., & Fawole, O. A. (2023). Microencapsulation Of Organic Pomegranate Peel Extract For A Food Circular Economy: Effects Of Wall Materials On Powder Functional Attributes, Antioxidant Activity And Antimicrobial Property Against Foodborne Pathogens. Journal of Agriculture and Food Research, 14(September). https://doi.org/10.1016/j.jafr.2023.100780

[56] Velásquez-Barreto, F. F., & Velezmoro-Sánchez, C. E. (2022). Microencapsulation Of Purple Mashua Extracts Using Andean Tuber Starches Modified By Octenyl Succinic Anhydride. International Journal of Food Science, 2022. https://doi.org/10.1155/2022/8133970

[57] Šeregelj, V., Ćetković, G., Čanadanović-Brunet, J., Šaponjac, V. T., Vulić, J., Lević, S., Nedović, V.,

Brandolini, A., & Hidalgo, A. (2021). Encapsulation Of Carrot Waste Extract By Freeze And Spray Drying Techniques : An Optimization Study. Food Science and Technology, 138 (December 2020), 1–10. https://doi.org/10.1016/j.lwt.2020.110696

[58] Sharif, N., Khoshnoudi-Nia, S., & Jafari, S. M. (2020). Nano/Microencapsulation Of Anthocyanins; A Systematic Review And Meta-Analysis. Food Research International, 132. https://doi.org/10.1016/j.foodres.2020.109077

[59] Al Mubarak, A., Hamid, N., Kam, R., & Chan, H. (2019). The Effects of Spray Drying Conditions on the Physical and Bioactive Properties of New Zealand Tamarillo (Solanum betaceum) Powder. Acta Scientific Nutritional Health, 3(12), 121–131. https://doi.org/10.31080/asnh.2019.03.0545

[60] Jafari, S., Jafari, S. M., Ebrahimi, M., Kijpatanasilp, I., & Assatarakul, K. (2023). A Decade Overview And Prospect Of Spray Drying Encapsulation Of Bioactives From Fruit Products: Characterization, Food Application And In Vitro Gastrointestinal Digestion. In Food Hydrocolloids (Vol. 134). Elsevier B.V. https://doi.org/10.1016/j.foodhyd.2022.108068

[61] Jiménez-González, O., & Guerrero-Beltrán, J. Á. (2021). Extraction, Microencapsulation, Color Properties, and Experimental Design of Natural Pigments Obtained by Spray Drying. In Food Engineering Reviews (Vol. 13, Issue 4). https://doi.org/10.1007/s12393-021-09288-7

[62] Ramakrishnan, Y., Adzahan, N. M., Yusof, Y. A., & Muhammad, K. (2018). Effect Of Wall Materials On The Spray Drying Efficiency, Powder Properties And Stability Of Bioactive Compounds In Tamarillo Juice Microencapsulation. Powder Technology, 328, 406–414. https://doi.org/10.1016/j.powtec.2017.12.018

[63] Ledy Bulawan, Tjodi Harlim, L. B. (2022). Pengaruh Penambahan Alginat Pada Pembuatan Serbuk Terong Belanda (Cypomandra Betaceae). Chemical Engineering Journal, 1(1).

[64] Griep, P., da Silva, L. M., Tres, B. P., Colet, R., Junges, A., Steffens, C., Zeni, J., & Valduga, E. (2023). Effects of Encapsulating Agents and Temperature in the Microencapsulation of Carotenogenic Extracts from Sporidiobolus Salmonicolor CBS 2636 and Storage Stability. Biointerface Research in Applied Chemistry, 13(5). https://doi.org/10.33263/BRIAC135.449

[65] Hurtado, N. H., Morales, A. L., González-Miret, M. L., Escudero-Gilete, M. L., & Heredia, F. J. (2009). Colour, pH stability and Antioxidant Activity Of Anthocyanin Rutinosides Isolated From Tamarillo Fruit (Solanum betaceum Cav.). Food Chemistry, 117(1), 88–93. https://doi.org/10.1016/j.foodchem.2009.03.081

[66] 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(1), 3–11. https://doi.org/10.1016/j.tifs.2009.07.004

[67] Azman, E. M., Yusof, N., Chatzifragkou, A., & Charalampopoulos, D. (2022). Stability Enhancement of Anthocyanins from Blackcurrant (Ribes Nigrum L.) Pomace through Intermolecular Copigmentation. Molecules, 27(17), 1–18. https://doi.org/10.3390/molecules27175489

[68] Miranda, P. H. S., Santos, A. C. dos, Freitas, B. C. B. de, Martins, G. A. de S., Vilas Boas, E. V. de B., & Damiani, C. (2021). A Scientific Approach To Extraction Methods And Stability Of Pigments From Amazonian Fruits. Trends in Food Science and Technology, 113(August 2020), 335–345. https://doi.org/10.1016/j.tifs.2021.04.047