

## Plant-based pigments: Challenges and future perspectives for natural food colourants

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### Abstract

Many synthetic food colourants have been developed to improve food products quality due to increasing demands. However, synthetic additives have been associated with numerous side effects and toxicity, allergic reactions, behavioural, and neurocognitive effects. Hence, consumer demands and their preferences for food colourants from natural origins have increased tremendously over the decades. With the growing interests for naturally derived and plant-based food ingredients to replace synthetic additives, many studies were done to provide safer and more effective food colourants. Among the highly explored plant-based pigments are anthocyanins, betacyanins, and carotenoids. Recently, there is also discovery on the newly found auronidins as potential pigment for future food application. This paper highlights on the features of plant-based pigments and its challenges, opportunities, and the way forward in food industry. Continuous research in this area is important for the development of more stable and intense pigments. Recent findings could be one of the ways to increase the stability of plant-based pigments to be applied in food industry.

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### 1.0 Introduction

Synthetic food colourants have been widely used since decades, however, interest in natural colourants obtained from plant sources were recently increasing. Synthetic additives have been associated with numerous side effects and toxicity, allergic reactions, behavioural, and neurocognitive effects (Martins et al., 2016). Many synthetic food colourants have been developed to improve food products quality due to increasing demands. However, over time, many of them are no longer being used in the food industry because of the undesirable and harmful effects, and possible carcinogenic effects they might possess (Amchova et al., 2015; Carocho et al., 2014).

Meanwhile, plant-based food colourants provide higher quality and better organoleptic properties and contribute to promoting health. Several studies have revealed that high antioxidant potential of anthocyanins defence against various degenerative diseases such as cancer and cardiovascular diseases (Keppler & Humpf, 2005), and diabetes (Mojica et al., 2017), as well as protect consumers against skin aging

(Mukherjee et al., 2011). Food colourants from plant-based pigments have shown positive outcomes in terms of safer ingredients, promoting more health benefits, and featuring better organoleptic properties which contribute to functional properties such as antioxidants and preservatives to food products (Carocho et al., 2014; Delgado-Vargas & Paredes-Lopez, 2003; Rodriguez-Amaya, 2016).

With the growing interests for natural origins and plant-based food ingredients to replace synthetic additives, many studies were done to provide safer and more effective food colourants. Over the years, investigations are thoroughly carried out on the features, applications, stability, valuable properties, bioavailability and toxicological safety of these pigments to ensure safer ingredients are being used in the food industry.

Among plant-based pigments highly explored nowadays are anthocyanins, betalains, and carotenoids. Recently, there is also discovery on the newly found auronidins from land plant (Berland et al., 2019). This paper highlights on the features of plant-based

pigments and its challenges, opportunities, and the way forward in food industry.

## 2.0 Features of plant-based pigments

Many studies have been conducted on the natural sources of anthocyanins, betalains and carotenoids recently, including the list in Table 1.

These studies covered many aspects especially on the features of the plant-based pigments, its structures and active compounds, and the encapsulation technology applied to increase the stability of the pigments.

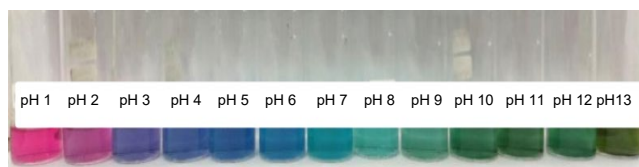
### 2.1 Anthocyanins

Anthocyanins are probably the most spectacular plant-based pigments and the most widely studied natural food colourants, being extracted from flowers, fruits, leaves, and even the whole plants. Among known good sources of anthocyanins are many berry-type fruits, red cabbage, and purple sweet potato. Many

studies have been conducted on the natural sources of anthocyanins including the list in Table 1.

Anthocyanins are structurally diverse and thus provide a wide array of colour properties for different food applications. Fig. 1 shows the range of colours as affected by pH for blue pea flower extracts. The strong acidic solution makes this pigment looks pink-purple (pH 1 to pH 2), violet-indigo (pH 3 to pH5), blue (pH 6 to pH 7), mint (pH 8 to pH 9) and green (pH10 to pH 13).

However, anthocyanins are easily degraded due to its highly reactive nature and relatively low stability to food processing conditions (Herrman et al., 2020).



**Fig. 1:** Anthocyanins spectrum from blue pea flower extracts at various pH (adapted from Mohd Marsin, 2020)

**Table 1:** Recent studies on plant-based pigments from various plant sources

Pigment	Plant Source	Active Compounds	Authors
Anthocyanin	Roselle Calyx ( <i>Hibiscus sabdariffa</i> L.)	Delphinidin, Cyanidin, Pelargonidin	Amaya-Cruz et al. (2019)
Anthocyanin	Maqui Berries ( <i>Aristotelia chilensis</i> [Mol.] Stuntz)	Delphinidin, Cyanidin	Romero-González et al. (2020)
Anthocyanin	Coffee Cherry variety Colombia	Cyanidin	Parra-Campos et al. (2019)
Anthocyanin	Purple Sweet Potato ( <i>Ipomoea batatas</i> L.)	Cyanidin, Peonidin	Lao et al. (2020)
Anthocyanin	Black Chokeberry ( <i>Aronia melanocarpa</i> )	Malvidin	Klisurova et al. (2019)
Anthocyanin	Black Sorghum	Apigeninidin, Luteolinidin	Herrman et al. (2020)
Anthocyanin	Blue Maize	Petunidin, Cyanidin, Pelargonidin, Peonidin	Herrman et al. (2020)
Anthocyanin	Black Cowpea	Petunidin, Delphinidin, Cyanidin, Malvidin	Herrman et al. (2020)
Anthocyanin	Jaboticaba ( <i>Myrciaria jaboticaba</i> (Vell.) O. Berg.) epicarp	Delphinidin, Cyanidin	Albuquerque et al. (2020)
Betalains	<i>Basella rubra</i> L. (Basellaceae)	Gomphrenin I Betanin	Kumar et al. (2020)
Betalains	Red beetroot ( <i>Beta vulgaris</i> L.)	Betacyanins Betanin Betanidin Betaxanthins	Sawicki et al. (2016)
Carotenoids	<i>Bactris gasipaes</i> fruits	Carotene Lycopene	de Souza Mesquita et al. (2020)
Carotenoids	Microalgae ( <i>Chlorella sorokiniana</i> and <i>Scenedesmus bijuga</i> )	Carotene Neoxanthin Violaxanthin Zeaxanthin Lutein Echinenone	Fernandes et al. (2020)

## 2.2 Betalains

There is an increasing interest in the plant-based red pigments due to their preventive effects on chronic diseases. Betacyanins are intriguing natural plant-based red pigments found in fruits and vegetables that are believed to contain antioxidant properties beneficial in the prevention of cancer. Similar to anthocyanins, betalains activity is influenced by the surrounding and their chemical properties.

Red-purple colourants derived from beets, which are the betacyanins and betalains were already approved to be used safely. However, beetroot red (E162) and dehydrated beet (or beet powder) are currently the only betalain-based colourants approved for use in food products in Europe and the USA, respectively, which restricts the spectrum of shades that can be explored by the food industry.

The betalains pigments are extracted from many natural sources, namely fruit of *Hylocereus polyrhizus* (Stintzing et al., 2002; Woo et al., 2011), *Opuntia ficus-indica* (Otalora et al., 2015), *Opuntia stricta* (Obon et al., 2009) and *Rivina humilis* (Khan et al., 2014). They have been used in the food processing application such as in desserts, drinks and dairy products.

## 2.3 Carotenoids

Carotenoid is another group of naturally derived food colourant with growing demands, mainly due to their excellent colouring abilities, bioactive properties, and other health-promoting characteristics (Martins et al., 2016). Carotenoids are responsible for many of the brilliant red, orange, and yellow colours of fruits, vegetables, fungi and flowers. Among recognised plants which colours are influenced by carotenoids are saffron (*Crocus sativus* L.) and cape jasmine fruit (*Gardenia jasminoids* Ellis) (Delgado-Vargas et al., 2000). Carotenoids are also popular for their antioxidant potential and have been used as natural preservatives by the food industry. These pigments are also widely used for cosmetic, pharmaceutical and nutraceutical purposes due to their promising bioactive ingredients (Rodriguez-Amaya, 2016).

In vivo and in vitro studies have shown that carotenoid photoprotective role is related to its antioxidant activity or with modulation of other cellular antioxidants (Jimenez-Escobar et al., 2020). Also, it has been established that carotenoid structure has a great influence in its antioxidant activity; such as, astaxanthin showed better antioxidant activity than  $\beta$ -carotene and canthaxanthin (Chang et al., 2013).

## 2.4 Auronidins

Recently, Berland et al. (2019) have discovered a unique class of phenylpropanoids, that was found attached to the cell walls of liverworts. The red pigments were proposed to be categorised as auronidins. Auronidins have similar colours as anthocyanins but distinct biosynthesis, colour properties, and chemistry. Auronidins have potential to be exploited due to the outstanding capability of liverworts plant to survive in extreme environments on land. These newly discovered class of pigments could be the answers for the development of more stable and intense natural plant-based colourants.

## 3.0 Challenges and future perspectives of plant-based pigments

### 3.1 Challenges

Synthetic food colourants have been progressively substituted with natural plant-based pigments, however there are still very little studies reported for many plant-based pigments and their real functions are still unknown. Although some plant-based pigments have already been approved to replace the synthetic ones, the huge benefits and related application of many others has not been assessed yet. Therefore, knowledge obtained in the potential functions of plant-based pigments could be considered a promising step to develop more specific functional food products.

It is necessary to consider that synthetic colourants have well-known advantages based on the strong pigmentation, stability, easier processing, lower cost, and available in unlimited quantities. Sen et al. (2019) has reviewed some of the challenges faced in producing natural pigments, among others are the higher cost, the limited application, the complex process, and the inconsistent quality. Antigo et al. (2020) also mentioned that natural pigments usually have higher costs and exhibit lower stability under processing and storage conditions, depending on the specific pigments.

The main challenge faced by plant-based pigments is that their utilisation in food industry is limited due to poor stability that affects the appearance of food products. For example, limited use of anthocyanins as food colourants and functional ingredients is mainly contributed by their low stability and interaction with other compounds in the food matrix. Factors such as concentration, pH, temperature, light, oxygen, solvents used, and presence of enzymes highly affect the

anthocyanin pigment colours.

The uses of betacyanins were greatly reduced in the food industry also due to its poor stability, thus creating a significant problem comparing to the use of synthetic colourants (Cortez et al., 2017). During degradation, betacyanins possibly undergo breakdown of aldimine bond, dehydrogenation, deglycosylation, and decarboxylation (Khan, 2016). Betacyanins have to fight or slow down these changes to increase its commercial applications through stabilisation techniques. Among the promising techniques to stabilise betacyanins are complex formation, co-pigmentation, and encapsulation (Trouillas et al., 2016; Kopjar et al., 2009; Woo et al., 2011).

There is considerable commercial interest in developing strong blue anthocyanin preparations and to improve the stability of anthocyanins such that they can be used industrially as reliable, natural colourants. So far, no anthocyanin-based blue colourant is commercially available, and the only source for natural blue colours is phycocyanin from the blue algae, *Spirulina (Arthrospira platensis)* (Sigurdson et al., 2017).

Currently, the main commercial sources of anthocyanins are crude extracts from fruits or waste products from the beverage industries. These are not standardised with respect to the particular anthocyanins they contain, nor the amounts of each anthocyanin in the extract (Appelhaagen et al., 2018).

### 3.2 Opportunities and future perspectives

Motivated by potential health benefits and consumer demands, their preferences for food colourants from natural origins have increased exponentially (Rahimi et al., 2018). Since decades, consumers have shown strong preference for products from natural sources, including pigments and colourants because of health concerns. Future food with this demand on safety considerations is expected to be the trend, remarkably.

This phenomenon poses a great challenge to food industry to accommodate to the needs of safer, healthier and more beneficial functional food ingredients including food colourants. Hence, research on solving the stability limitation and bioavailability of natural pigments will continue over the years to cater the replacement of synthetic colourants. Undoubtedly, our nature provides rich plant-based colour pigments that have huge potential of colouring properties and functional abilities which are still poorly exploited.

Extensive studies need to be done for these many other plant-based pigments for their promising colouring and bioactive properties for the enhancement of technology in food industry.

The pigment research area is very wide, and natural pigments with improved characteristics such as new colours and improved stability have been discovered, and expanded application ranging from food, pharmaceutical, nutraceutical and cosmeceutical. Moreover, with the newly discovered pigment group of auronidins, more potential research area on natural pigments will be explored. These are great opportunities for researchers to discover more plant resources, not only as potential natural colourants but also with huge health benefits such as antioxidants.

In the future, a more adequate and updated legislation will provide a broad range of natural colourants, and importantly with better stability characteristics. The need to develop strong blue anthocyanin for commercial use is important and should be explored as reliable natural colourants in food industry. Moreover, with recent findings on the newly discovered red pigments of auronidins, it could be the answers for the development of more stable and intense natural plant-based colourants.

## 4.0 Conclusions

This paper highlights a fundamental aspect of the features and challenges of plant-based pigments in the food industry. This is particularly important to ensure the sustainability and concerns on the safety of food colourants used in the industry. Knowledge on the stability of natural colourants and prevention of degradation will be beneficial not only for food industry, but also for agriculture, cosmetic, pharmaceutical and nutraceutical industries. Extensive studies on effective techniques to increase the stability of plant-based pigments need to be carried out to ensure attractive appearances of the food products. Many current advances have been developed for plant-based pigments; however, many others still need to be evaluated for their colouring characteristics and promising bioactive properties for the enhancement of technology in food industry.

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