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REVIEW ARTICLE

Effect of processing on bioactive compounds of Mandarin and blood orange: a review

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ABSTRACT

Citrus fruits are a rich source of compounds that influence the sensorial acceptance of juices and other value-added products prepared from it, such as organic acids, phenols and sugars. The strong antioxidant properties are influenced by the presence of bioactive compounds such as flavonoids, phenolic acids, limonoids and adrenergic amines where benzoic and hydroxycinnamic acids form a major part of phenolic compounds while Naringin, Neohesperidin, Narirutin and Hesperidin are present in major quantities. These compounds play an important role in human metabolism through their health-promoting benefits. Given this background, while this review paper acknowledges the research works carried out in this field, it highlights the changes in the bioactive compounds of mandarin and blood oranges when they undergo various processing methods and technologies and at the same time encourages more and rigorous studies especially in the line of blood oranges. It is also worth mentioning here that although the value-added products of mandarin and blood oranges exist in the market, yet, scientific research works to determine the optimized process, formulations or venturing technologies for improved processing is scarce.

Keywords: Mandarin fruit, blood orange, citrus fruit, bioactive compounds

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INTRODUCTION

The genus Citrus covers a range of orange types – sweet and sour orange, tangerines (Mandarins), tangors and tangelos (Moulehi et al., 2012; Cassano et al., 2009). Citrus fruits are a rich source of compounds that influence the sensorial acceptance of juices prepared from it, such as organic acids, phenols and sugars (Legua et al., 2014). Among the healthy drinks, citrus juices are one of the popular drinks in the world. However, the strong antioxidant properties are influenced by the presence of bioactive compounds such as flavonoids, phenolic acids, limonoids and adrenergic amines (Ye et al., 2011) where benzoic and hydroxycinnamic acids form a major part of phenolic compounds (Sdiri et al., 2012) while Naringin, Neohesperidin, Narirutin and Hesperidin are present in major quantities (Jo et al., 2018). Legua et al. (2014) claimed that the difference in the content of bioactive compounds is based on the citrus rootstock. Even the peels of citrus fruits that are normally discarded are good sources of bioactive compounds and Wang et al. (2016) opined that peel had the highest content of phenolics, flavonoids and strong antioxidant activity. These fruits play an important role in human metabolism through their health-promoting benefits offered by the bioactive compounds which include ascorbic acid, phenolic compounds and carotenoids along with organic acids, amino acids, sugars, minerals and others (Putnik et al., 2018). Although citrus fruits are

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usually consumed fresh, the major product obtained from it are juices wherein about 80% of the harvested fruits are being passed to the juice industry (Moulehi et al., 2012). Citrus juices are dominated by the presence of citric and malic acids among the organic acids along with Sucrose (Legua et al., 2014). The phytochemicals in Mandarin also contribute towards the development of characteristic flavor, colour and aroma of the fruit (Akdaş and Başlar, 2015). Some bioactive compounds are sensitive and are susceptible to degradation. But these are the same compounds that are essentially important in reducing disease related issues such as cancer, cardiovascular disease. Hence, whatever processing condition and treatment applied, it should be optimized in such a way by taking into consideration the changes in their composition and nutritional facts. As mentioned above, there are various types of citrus fruits but in this paper, we have chosen to highlight just two, namely Mandarin and blood oranges. These two fruits have extreme distinguished natures although of the same kind. While Mandarin orange is very popular and is well known but the public's awareness on blood oranges however is concise and at the same time, this fruit offers so much of health benefits through the presence of various bioactive compounds.

MANDARIN ORANGE

Mandarins oranges (*Citrus reticulate*), which are good sources of organic acids and phenols (Betoret et al., 2017) are differentiable from oranges as characterized by their shape, small size and in terms of the large open cores (Nam et al., 2019) and have the shortest storage life among all citrus fruits (Shah et al., 2015). Mandarin oranges are harvested during late autumn and middle winter. It cannot withstand the adverse climatic condition during storage due to its high moisture content of 80-85% (Hong et al., 2007). Apart from the antioxidants, (e.g., ascorbic acid, carotenoids, and phenolic compounds), Mandarins are also rich in sugars, organic acids, amino acids, pectin, minerals, and volatile organic compounds (Legua et al., 2014; Ye et al., 2011; De Ancos et al., 2017; Sdiri et al., 2012). Besides, different volatile components contribute to the development of a characteristic aroma of mandarin and (Pérez et al., 2005) could identify 32 volatile compounds in the juice of freshly harvested mandarin fruit. These volatile compounds which contribute to the characteristic flavor and aroma of mandarin have varied concentration depending on the stages of maturity and it was shown that the concentration is more when the juice was prepared from whole fruit than the peeled ones (Barboni et al., 2010). Juice is the most common form of a value-added product of Mandarin fruit supported by the evidence that it is the most studied form of Mandarin product in various research studies. The major quality control parameters assessed by the industry for developing a quality juice include Total Soluble Solid (TSS), Titratable acidity (TA), Ripening index, the ratio between TSS and TA of the juice (Legua et al., 2014) and the concentration of Vitamin C (Nam et al., 2019). However, the major challenge in mandarin juice processing is the development of a bitter taste (Pareek et al., 2011; Ilame and Singh, 2018). During the processing of juice and in particular, the process of pasteurization and storage, there is always a loss in the concentration of volatile compounds accompanied by the formation of α-terpineol and terpineol-4; the off-flavor components (Barboni et al., 2010). Considering the richness of bioactive compounds in Mandarin oranges, even the normally discarded immature fruits that are a result of physiological dropping have been identified as a potential source of nutraceutical compounds that contribute towards the promotion of human health, with the free and ester form of phenolic acids dominating over the bound phenols (Ye et al., 2011).

EFFECTS OF PROCESSING ON THE BIOACTIVE COMPOUNDS OF MANDARIN ORANGE

Canning

Mandarin is usually eaten in its fresh form but storing it for a longer period can affect its quality and is more likely to decay through the action of microorganisms (Nam et al., 2019). To prolong its storage period, Can processing was evaluated by (Zhang et al., 2011) who reported that although it resulted in an overall decrease in the content of Phenolic acid, ascorbic acid and the loss of almost half of the Flavanone Glycosides (FG) and total antioxidant capacity (TAC) in the Mandarin segments, the syrup, however, was found to retain a considerable proportion of phenolic compounds and ascorbic acid thereby concluding that mandarins can be made available even in off-seasons in the form of canned mandarins. Further, it was highlighted that this sterilization on mandarin segments had less effect on the phenolic compound, Ascorbic acid and TAC when the phenolic compound had been moved to the syrup portion. The type of preservation liquids used for canning also has a role in determining the changes in the bioavailability and bioactive components of canned mandarin. In a study by (Perez-Lopez, 2010), different types of preservation liquids were used at different TSS, that is, 10, 12, 14 ºBrix. The solutions studied include sucrose solution, sucrose and ascorbic acid solution, grape, and grapefruit juices. It was found that grapefruit juice could be considered as the best preservation liquid for canned Mandarin yielding the highest Vitamin C and total Carotenoids as compared to other solutions.

Curing

Curing has been adopted as a post-harvest control for preventing diseases and decay in Mandarin oranges and the integration of other treatments for supplementary effects has been studied in the past. The combination of treatments was reported to be much effective as compared to individual treatments done alone such as curing followed by fumigation by acetic acid vapor (Venditti et al., 2009) and the integration of curing with degreening (Plaza et al., 2004). As a method of preventing fruit decay, Intermittent curing (IC) was investigated by Pérez et al. (2005) who carried it out at 97±1 % RH and a three-cycle temperature program, that is, 18 h at 38^{o}C, 6h at 20^{o}C and 18h at 38^{o}C. This technological application which was carried out as Intermittent Curing plus cold storage (IC cold) and Intermittent Curing plus room temperature storage (IC room T) was compared with the outcome of Cold storage (5^{o}C) and Room temperature storage (20^{o}C). It was found that about 2% of fruit decay was found in IC cold-stored fruits while it was 4% in IC room T in comparison with 5% and 25% in cold storage and room temperature storage fruit samples. Although the acetaldehyde and ethanol content of the juices of IC cold and IC room T were significantly higher than the others, both the treatments did not result in its overproduction that could lead to off-flavor development. The two organic acids under review, malic acid and citric acid were not shown to be significantly affected by IC treatment while the Vitamin C content showed a marked decrease at the end of the IC room T storage which is due to the sensitivity and instability of ascorbic acid towards thermal action.

Irradiation

Irradiation, also known as cold pasteurization, is another emerging technology which can be applied for various reasons in the food industry and the likes of gamma rays, electron beams (Nam et al., 2019) and X-ray (Rojas-Argudo et al., 2012) have been mostly identified as alternative treatment procedures bypassing the thermal and chemical treatments. (Jo et al., 2018) reported that the application of gamma-ray irradiation to the level of less than 1kGy has a potential for post-harvest treatments. The Vitamin C and Flavanone Glycoside levels of Mandarin juice were not significantly affected at doses of 510 and 875 Gy of the applied X-ray (Rojas-Argudo et al., 2012). Similarly, when Mandarin was subjected to 1kGy and 0.4 kGy electron beam irradiation, the content of Vitamin C and the Total Phenolic content were not affected as well in a study conducted by Nam et al. (2019). Moreover, mandarins irradiated at 0.3 kGy had a beneficial effect on sensorial and nutritive properties. Irradiated fruits were found to be sweeter and had higher contents of vitamin C and total phenolic compounds (Mahrouz et al., 2002). Further, the authors highlighted the advantage of applying an electron beam over the gamma-ray irradiation in that, the former does not produce radioactive waste. The application of microwave technology was found to increase the antioxidant activity through the liberation of phenolic compounds but these were degraded when higher Power levels and longer treatment time was applied (Hayat et al., 2010). The Flavanol Compounds however showed an increasing trend with increasing power but with longer treatment time there was a degradation of Flavanol compounds. The contribution of the bioactive compounds towards human health has resulted in such research to find out the ways and means of improving the bioavailability of such compounds.

Drying technology

Drying is one of the most common unit operations in food engineering and a method of extending the shelf life. As we are aware, drying does not remove only the moisture from the product but can also result in loss of volatile compounds present and hence, changes in its quality. During the drying process, the thermal degradation of the phenolic compounds takes place (Akdaş and Başlar, 2015). For this reason, various drying techniques were adopted and studied. For instance, oven drying at 55ºC, 65ºC and 75ºC was compared with vacuum drying involving 1.3 m/s constant air velocity and yielded different results in a study by Akdaş and Başlar (2015). They found that although the drying time of vacuum drying was less, the degradation of total phenolic content and the total flavonoid content was more as compared to oven drying stating the reason that it could be due to the evaporation of volatile and semi-volatile phenolic compounds along with moisture. When the time for drying was increased, the degradation was also more. However, in terms of the Vitamin C content, oven drying resulted in the degradation of about two times as compared to vacuum drying. The other drying technique that can be listed here is foam mat drying as studied by (Kadam et al., 2011) using egg white, milk and carboxymethyl cellulose as foaming agents at different concentrations. The mix was then subjected to drying at 65, 75 and 85 °C. Foam mat drying like other drying techniques resulted in a considerable loss of Ascorbic acid from 31.9 mg /100 mL in fresh Mandarin to a range of 2.89 to 7.40 mg /100 mL in reconstituted dried Mandarin powder. It was concluded that this drying technique did not result in much losses in nutritive quality of the powder thus obtained and the results of the testing of parameters such as titratable acidity and pH (for organic acids), microbial load and shelf life revealed that the best foaming agent was CMC at 0.5-1% concentration and drying temperature of 75 °C.

High-pressure processing

High-Pressure processing is one of the emerging and novel food processing technologies being adopted particularly for food items that are thermally unstable or those that deteriorate in quality due to heat. High-pressure homogenization (HPH) can also improve the nutritional properties as indicated by Sentandreu et al. (2020). In this research, the retention of ascorbic acid was improved by HPH (150 MPa) and while there was a marked decrease in the content of carotenoids, there was however a 5 fold enhancement in the bioaccessibility of total carotenoids. In a different concept, High-Pressure Carbon dioxide (HPCD) treatment was used for processing Mandarin juice (Lim et al., 2006) wherein, the juice was pressurized to 6.89 MPa and at the same pressure, CO_2 was introduced. There were no differences observed in pH and ºBrix between the pressure treated and untreated mandarin juice but the titratable acidity was more. Although there was a marked decrease in the content of flavonoid which was greater as higher pressures were applied, the addition of trehalose to the high pressure homogenized mandarin orange juice sample resulted in reduced degradation during storage periods in the works of Betoret et al. (2017).

Cold plasma treatment

Cold plasma is a novel non-thermal food processing technology that uses energetic, reactive gases to inactivate contaminating microbes on meats, poultry, fruits, and vegetables. It may be worth mentioning that a survey of the literature on cold plasma treatment of Mandarin oranges across search engines gave just two relevant results which will be emphasized here indicating that more rigorous research on this effective technique is of great interest. When whole mandarin fruits are treated with cold plasma at 0.7 kPa using a microwave power cold plasma treatment system, it significantly increased the total phenolic content and antioxidant activity (Won et al., 2017). The other application of cold plasma treatment was for microbial decontamination, combining the antimicrobial washing solution CaO along with Atmospheric dielectric barrier discharge cold plasma (ADCP) as investigated by Bang et al. (2020). The favorable results revealed that *P. digitatum* was inhibited in Mandarin orange after this combined treatment thereby extending its storability in plastic packages (Table 1). Regarding its influence on bioactive compounds, this treatment gave a lower total phenolic content as compared with untreated mandarin oranges but the pH, ascorbic acid concentration and particularly, the antioxidant capacity was not affected during storage at a temperature of 4 ^{o}C and 25 ^{o}C.

Table 1: Postharvest treatment methods for microbial decontaminating and disinfestation of Mandarin and Blood oranges

Method	Major findings	Reference
Atmospheric dielectric barrier discharge cold plasma treatment (ADCP) and antimicrobial solution washing.	1. Inactivation of P. digitatum was not possible at applied voltages under 26kV 2. Exterior damage of mandarin was reported for applied voltage of 27kV and duration of over 2 min. 3. The incidence of the disease of P. digitatum was found to be significantly reduced (77.1%) by employing voltage of 27kV and treatment time of 2 min and this did not bring about exterior damage to the fruit 4. The disease incidence of P. digitatum in mandarin subjected to washing with CaO solution followed by ADCP (CaO-ADCP) was lowest (64.3%)	Bang et al. (2020)
Microwave-powered cold plasma treatment	1. The incidence of the disease of P. italicum was found to be significantly reduced (84%) by employing Nitrogen-CPT at 900W for a period of 10 min. 2. The total phenolic content and antioxidant activity of mandarin peel was significantly increased	Won et al. (2017)
Hot water dipping (HWD) for 3min at 50^{o}C and hot air treatment (HAT) at 37 ^{o}C for 48h	1. HWD did not have an impact on the firmness, taste, flavor and internal fruit quality. 2. HAT had a negative significant impact on fruit firmness, acceptance and internal quality. 3. HAT is not advisable as a means for improving the keeping quality of blood oranges following cold disinfestation for fruit fly.	Schirra et al. (2004)
Phytosanitary irradiation	1. Gamma irradiation even at low dose of 150Gy promoted fungal infections of mandarin fruit during storage, besides having a negative impact on the appearance and firmness. 2. Excluding hesperidin, phytosanitary irradiation increased the total phenolic content of mandarin	Ornelas-Paz et al. (2017)
Fertilizers and pesticides	1. Mandarin fruits that were treated with pesticides had significant increase in choline and 4-aminobutyrate 2. Citric acid, vitamin C and sucrose were lower in Mandarin fruits that were treated with pesticides	Zhang et al. (2012)

Cold treatment

Low temperature or cold storage of fruits and vegetables is a common practice to ensure that food remains edible for extended periods. Cold temperature storage of mandarin at varied temperatures and storage periods were also investigated. In the temperature range of 2 to 8 ^{o}C, there were no significant changes in juice TSS while there was an observed decrease in acidity levels thereby increasing the ratio between TSS and acidity (Tietel et al., 2012). Apart from this, studies were also conducted where mandarin fruits were initially pretreated before cold temperature storage for an extended duration. Treatment with salicylic acid did not affect the external fruit quality during storage at 5±1^{o}C for 90 days and in particular, ascorbic acid, phenolics and total antioxidant activity were highest when a concentration of 4 mM salicylic acid was used as a pretreatment before cold temperature storage (Haider et al., 2020). On another note, higher levels of carotenoids and ascorbic acid were maintained when Carboxymethylcellulose (CMC) at a concentration of 2 g/L was used for coating mandarin fruits before storing at a temperature of 5 to 7 ^{o}C and relative humidity of 90-95% (Baswal et al., 2020).

VALUE-ADDED PRODUCTS FROM MANDARIN ORANGE

Mandarin juice and powder

On surveying literature across search engines about the value-added products from Mandarin oranges, we found that there is no scientific research works on jam, jelly, squash, marmalade, etc although we know fairly well that such products exist in the market. One of the most common forms of value-added products from fruits is juice and the formulations and supporting ingredients used by manufacturers determine their acceptability and success in the market. Likewise, mandarin juice exists in the global market and scientific papers studying the effect of hydrostatic pressure (Takahashi et al., 1993; Ogawa et al., 1990) on mandarin juice could be found. The high hydroxyl activity in Mandarin juice means that there exists a strong antioxidant effect which benefits Hypercholesterolemic children (Codoñer-Franch et al., 2008). When high hydrostatic pressure was applied, there were no reported changes in volatile components while inactivation of microorganisms occurred under 400 MPa for 5 min treatment (Takahashi et al., 1993). The concentration of the juice also determined the effectiveness in microbial inactivation by pressure treatment wherein, higher the concentration, the lower was the inactivation (Ogawa et al., 1990). Another development worth mentioning here is the finding that mandarin orange that was organically produced in the farm gave juice that had higher carotenoids content, Vitamin C and antioxidant activity as well as sensory acceptance (Navarro et al., 2011). However, to ease handling, making it easier to transport and store as well as to extend the shelf life and availability, it can be converted into powdered form is usually done for other fruit juices. Spray drying technique has been widely followed for obtaining spray-dried fruit juice powder. Similarly, mandarin juice spray-dried powder has been tested involving carrier agents such as maltodextrin (25-35%) at inlet temperatures 135^{o}C and 165 ^{o}C and using corn syrup (30-40%) at 120 ^{o}C and 150 ^{o}C (Lee et al., 2016). It was concluded that the preferred carrier agent was corn syrup which showed better results in terms of acceptability, color and sweetness, arriving at optimum conditions of 135 ^{o}C inlet temperature and 35% concentration of corn syrup. Moreover, the overall acceptability increased when there was a corresponding increase in the concentration of corn syrup but the reverse was true for maltodextrin.

Mandarin wine

Preparation of mandarin wine proceeded after juice extraction and straining to remove pulp and seeds after which was later followed by the addition of SO_2 (50 mg/L) and fermentation through yeast. For achieving higher content of ethanol in the finished product, sugar was added and after the fermentation period is over, SO_2 (50 mg/L) was again added (Selli et al., 2004; Kelebek and Selli, 2014). When mandarin wine was analyzed for its chemical composition, it was found that the phenolic compounds were possibly transformed into condensed forms and hence its content as well as the total antioxidant activity was lower than that of mandarin juice (Kelebek and Selli, 2014). Ethyl octanoate was found to have the highest concentration among esters while isoamyl alcohol, isobutanol and 2-phenyl ethanol were the major alcohols detected in the wine sample (Selli et al., 2004).

Mandarin candy

Osmotic dehydration gives better quality candied products which are far better than the traditionally followed method of dipping in sugar syrup and finally sun drying. To reduce wastage and to utilize the peel which has high bioactive compounds than the juice, osmotic dehydration was tried by Alam et al. (2017) to produce mandarin candy. Although the research work did not reveal the sensorial acceptance of the prepared product but focussed mainly on mass transfer kinetics, we can however emulate the process and extract few results that might be of importance for food industries that wish to test the market on a commercial scale. In this research, during the osmotic dehydration of mandarin, parameters such as temperature and the time of immersion of the fruits in the syrup play an important role in determining the water loss, mass loss and solute gain of the sample.

Mandarin jam and marmalade

Jam is another common form of value-added product and the inclusion of citrus peel, usually orange, gives marmalade. Limited kinds of literature on mandarin jam and marmalade are available although it is a common fact that such products exist and are doing fairly well in the market. Many consumers all over the world are on the constant hunt for such products but when it comes to scientific publication, Sogi and Singh (2001) tested and produced mandarin jam which had similar properties to that of other fruit jams such as TSS value of 70ºB and 1.34 % acidity with high consumer acceptance revealed by the outcome of the sensory evaluation, giving high scores of more than 8 for flavor, color and overall acceptability.

Coated mandarin orange

Coating of fruits is a common practice for shelf life extension by preventing shrinkage and moisture loss and improves appearance. The coating is done usually by wax by recent developments in edible coatings that are gaining importance. Long ago, effects of hormones and wax as coating agents of mandarin orange was investigated by Lodh et al. (1962) who reported that the ripening and development of color were greatly delayed by higher concentrations of 2,4-Dichlorophenoxyacetic acid (2,4-D). The 2,4-D plus wax emulsion was more effective in prolonging the storage life of the oranges than was either wax or 2,4-D alone at any storage temperature. Less effective, though of similar effect, was 2,4,5-Trichlorophenoxyacetic acid. Further, Chen et al. (2016) showed that the addition of clove oil as an antifungal component to the CMC coating had a good effect on the inhibitory growth of fungal decay, and the coating treatments significantly decreased the decay rate and weight loss. The clove oil-carboxymethyl cellulose (CO-CMC) coating significantly maintained commercial quality and inhibited respiration. The CO-CMC coating has good potential for application as an alternative to synthetic fungicides for improving postharvest quality and prolonging the shelf life of mandarin oranges during cold storage.

BLOOD ORANGE

Blood orange derives its name from the characteristic color which is rich in anthocyanin, the color intensity of which depends on the cultivar, climatic conditions and the temperature, particularly in October to November (Ingallinera et al., 2005). It has been said that blood oranges originate from the centurion long spontaneous genetic mutation (Cebadera-Miranda et al., 2019) and the three main cultivars are *Moro, Tarocco* and *Sanguinello* (Fallico et al., 2017). The richness of the anthocyanin content and the phenolic compounds in blood orange have resulted in an increased public interest (Fallico et al., 2017) and the demand for such red orange-based juices exists in the market (Scordino et al., 2015). Fallico et al. (2017) opined that the intake of ferulic, sinapic, and p coumaric acids are the offered benefits of the blood orange consumers. Anthocyanins however are very sensitive to light, air, oxygen, heat, etc. and its degradation results in the loss of the bright red coloration. Further, this degradation which follows first-order reaction kinetics (Kirca and Cemeroğlu, 2003; Cao et al., 2011) is a problem that is much evident in the juice industry that requires heat treatment as a method for preservation and processing. Hence, the processing of blood orange juice requires co-pigmentation or other ways (Kirca and Cemeroğlu, 2003) for preserving the natural color. Apart from this, it was reported by Cebadera-Miranda et al. (2019) that blood orange also has β-carotene; hesperidin and quercetin as major flavonoid, besides 10 anthocyanin compounds – 7 cyanidin derivatives and 3 delphinidin derivatives while the main organic acid is citric acid. Along with anthocyanin, the degree of heat treatment can also influence the stability of Vitamin C (Torres et al., 2011).

EFFECTS OF PROCESSING ON THE BIOACTIVE COMPOUNDS OF BLOOD ORANGE

Membrane technology

Membrane technology is widely used in the food industry and in particular in the juice processing sector for clarification. The extracted fruit juice sometimes has a cloudy or hazy appearance which could be due to the components present in it such as colloidal particles. Blood orange juice was subjected to clarification process, that is ultrafiltration by passing through different membranes with different Molecular weight cut-off (MWCO) of 100, 50 and 30 kDa. The total phenolic content and the total anthocyanin content of ultrafiltered juice decreased with a decrease in the MWCO of the membrane used, in a study by Toker et al. (2014). Despite this, the authors claimed that ultrafiltered juice still had the characteristic color imparted by the anthocyanin. The new integrated membrane process reported by Galaverna et al. (2008) comprised of ultrafiltration (initial clarification), reverse osmosis (concentration to 25-30^{o} Brix) and finally osmotic distillation (concentration 60^{o} Brix). While stability was maintained for hydroxycinnamic acid and flavanones, there was a slight decrease in the concentration of ascorbic acid and anthocyanin content. Even in this study, bright red coloration of the treated juice was still preserved indicating that membrane technology can serve as a method of juice processing for preserving its unique quality.

High-pressure processing (HPP)

High-pressure processing is a novel non-thermal technique that produces food of high quality, greater safety and improved shelf life. During high-pressure processing, the loss of nutrient content of food and its texture is minimal due to its limited effect on the covalent bonds of low molecular-mass compounds such as color and flavor compounds (Oey et al., 2008). Pressure ranging between 300-700 MPa is commonly applied in high-pressure processing to kill the pathogenic bacteria that spoil food. Different combinations of temperature and pressure can also obtain desired quality such as texture, flavor and color. The demand by the consumers for nutritious, fresh like products with good organoleptic property and extended shelf life has led to the exploration of non-thermal processing of food (Fabroni et al., 2010) such as HPP. HPP of blood orange juice was done at 400, 500 and 600 MPa for 15 min in a study by Torres et al. (2011). With an increase in pressure there was a corresponding decrease in the level of ascorbic acid but to the extent of 8.1% only at 600 MPa. But anthocyanin retention after HPP was about 99% indicating that the HPP does not involve intense processing to degrade these highly sensitive compounds. Moreover, HPP blood orange juice was reported to preserve the nutritional quality by the authors and the improved shelf life over fresh blood orange juice. High-Pressure Carbon dioxide (HPCD) is another method of non-thermal processing of blood orange juice that was studied by Fabroni et al. (2010). In this study, it was found that the concentration of CO_2 used during the experiment had no significant effect on the retention of antioxidant. The anthocyanin content of HPCD at lower operative pressure (130 bar) did not show much significant difference with the untreated sample and the same result was found for the total flavanones and the total phenolic content. Further, the HPCD blood orange juice would be well accepted by the consumers as per the opinion of the trained panelists and the suggestion that it would be deemed fit for consumption within 20 days when stored at 4 ^oC.

Microwave treatment

Pasteurization is an important step to achieve food preservation in the processing of fruits and vegetables and has been applied mostly in the juice industry apart from milk processing. Microwave energy can potentiate the bioavailability of free pharmacologically active natural compounds by preventing the binding of polyphenols to the plant matrix (Gulati et al., 2003). Because of this, microwave treatment was sought out as a tool for pasteurizing blood orange juice in a study by Maccarone et al. (1985). It was carried out at 2450MHz for some time of 3 min and the support system of tartaric acid and gluthathione as additives for mild acidic conditions and antioxidant property. It was found that with microwave treatment, the intensity of the color of such juice was not altered and the addition of 250 mg of tartaric acid yielded the best result in terms of color stabilization. However, complex formation between phenolic compounds and anthocyanin resulted in the highest stability. Hayat et al. (2010) reported that the microwave treatment of citrus pomace cleaved and liberated phenolic compounds, which increased free phenolic compounds and enhancement of the antioxidant capacity of the extracts. There was also an observed increase in the content of flavanol, flavanone and flavonol compounds (FCs) with increase in the microwave power.

Thermal treatment

Thermal treatment is usually given to fruits, particularly juices for the inactivation of enzymes. This thermal treatment, however, may result in changes in the quality of a product. As mentioned earlier, anthocyanins are very sensitive compounds and so are susceptible to degradation easily. However, the total anthocyanin content in thermally treated samples, that is, blood orange juice sample subjected to pasteurization (80^oC for 1 min) and the other sample subjected to blanching of the fruit (80^oC for 6 min) and then followed by pasteurization of the extracted juice was found to be higher than the untreated sample in a study by Lo Scalzo et al. (2004). This was in contrast to the findings by Cao et al. (2011) who reported that thermal treatment resulted in the degradation of anthocyanin which followed first-order reaction kinetics. Further, it was also mentioned that visual color change could be used to predict the degradation of anthocyanin which increased with an increase in temperature and treatment time. Pasteurization can also be applied as heat treatment for the inactivation of pectin esterase enzyme although it did not result in its complete inactivation (Ingallinera et al., 2005). However, on comparing juice and concentrate, Kirca and Cemeroğlu (2003) found that a faster rate of anthocyanin degradation occurred in concentrates than in juices and accordingly the loss of anthocyanin was higher in the former. Moreover, the components that are present in blood orange also determine anthocyanin degradation. Anthocyanins degradation is accelerated by components such as sugar and ascorbic acid but flavonoid has a protective effect (Shaoqian Cao et al., 2009).

Cold treatment

Experimental evaluation of the effects of cold storage on fruits was carried out in the past. Similarly, it was also investigated for blood oranges employing different low temperatures at extended storage periods. In this context, Carmona et al. (2017) stored their samples for 45 days at temperatures 4 °C and 9 °C and Relative humidity of 90-95%. The anthocyanin accumulation increased during low-temperature storage, particularly at 9 °C. Similarly, Fabroni et al. (2020) carried out this study at 6 °C for 60 days while Pannitteri et al. (2017) extended the research to three storage temperature conditions, that is, one sample stored at 4 °C for 70 days, another at 20 °C for 70 days and the third sample were initially stored at 1 °C for 20 days followed by 4 °C for 50 days. In these research works, similar conclusions were drawn wherein, all reported the increase in anthocyanin concentration during cold temperature treatment and storage. Apart from changes in anthocyanin, there was a decrease in titratable acidity, an increase in Vitamin C content (Pannitteri et al., 2017) and a decrease in Limonin (Fabroni et al., 2020) during cold storage.

VALUE-ADDED PRODUCTS FROM BLOOD ORANGE

Blood orange Juice

Juice obtained from blood oranges differs from mandarin juice mostly in terms of its red color which is due to its characteristic and distinguished pigment compounds. Consequent to its high antioxidant activity and in particular, the presence of anthocyanins, it is believed that storing or processing such juices will have an impact on the color and shelf life since these pigments and other bioactive compounds are highly sensitive. However, oxidative damage does not determine the shelf life of such juices as reported by Zanoni et al. (2005) that it is highly dependent on the microbial phenomenon. Moreover, the degradation and depletion of ascorbic acid and color respectively are highly influenced by the temperature of storage and the degassing technique as outlined by Remini et al. (2015). The authors also suggested that to prevent the quality loss, the fruit juice industry can adopt deaeration as an alternative solution. Another suggestion was given by Torres et al. (2011) to adopt high-pressure processing at an industrial level to retain nutritional value, anthocyanin and ascorbic acid in blood orange juices.

Blood orange wine

Blood orange juice is fermented to produce wine after straining out the seeds and pulp of the fruit followed by the addition of SO_2 (40 mg/L). After the completion of the fermentation period, the wine was racked through SO_2 (40 mg/L) addition (Selli, 2007). The authors explained that such wines had reduced content of anthocyanin and ascorbic acid as compared to blood orange juice, the loss of which could be attributed to occur during fermentation. Further, the major alcohols identified were Isoamyl, isobutyl and 2-phenyl ethanol while esters were predominated by isoamyl acetate, ethyl lactate and monomethyl succinate.

Blood orange jam, jelly and marmalade

On a similar note and concept of jam and marmalade as explained for mandarin orange, blood orange jams are another class of products distinguished by a natural red color arising from anthocyanins. As claimed by Licciardello and Muratore (2011) that although blood orange marmalades cover high nutritional benefits, they are however distribution is scarce. One of the concerns about blood orange jam and marmalade is the degradation in color which will harm the perception of the consumers. Color degradation is usually related to anthocyanin which is affected by the formation of 5-hydroxymethyl-2-furaldehyde (HMF). In light of this background, the addition of cysteine will limit the formation of HMF and will serve to preserve the color of the product (Licciardello and Muratore, 2011). A study on Physicochemical characteristics of citrus jelly with non-cariogenic and functional sweeteners by Rubio-Arraez et al. (2016) showed the demonstration on jelly desserts with different citrus fruits and artificial sweeteners. From the study, it could be interpreted that blood orange may be possible to be processed into a jelly product. Blood orange can also be taken as a sample is being processed to a jelly.

Blood orange candy

Although there are no scientific publications on candied blood oranges, these products can be prepared traditionally by immersing the slices in sugar syrup followed by sun-drying after draining the excess syrup. The sun-dried candied fruits can be stored for several weeks under refrigerated conditions. To enhance the taste, these homemade products are also dipped in melted chocolate or simply coated by chocolate and eaten as deserts.

FUTURE PROSPECTS

Recognizing the popularity of Mandarin Orange and the richness of blood oranges, we feel that rigorous research still needs to be conducted in these two fruits. Moreover, novel and emerging food processing technologies such as high-pressure processing, ultrasound, radiofrequency, pulsed electric field, etc can offer advantages in conserving the nutritional benefits of the prepared products without major deterioration in overall quality, especially for blood oranges which are rich sources of the highly sensitive anthocyanins. While there are many value-added products from these two fruits that exist in the market, we feel that more research needs to be done to find out the optimum processing conditions especially for blood oranges.

CONCLUSION

To conclude, various technological inputs and processing conditions that were applied and investigated by many researchers on Mandarin and blood oranges were highlighted in this paper. The bioactive compounds are gaining popularity in recent years for their reported health benefits and the changes in their composition as a consequence of processing are also covered. Through this review, we hope that more research will be conducted in the future, employing novel and emerging food processing technologies or even perhaps, work on the existing studies but with improved methods and modifications.

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