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Citrus As A Multivitamin Treasure Trove: A Review

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Abstract

Citrus is popularly known as the source of beneficial and essential nutrients for human health, including vitamins. The current review revealed the content of multivitamins, not only vitamin C but also vitamins A, B, and E that are not widely acknowledged within *Citrus*. Numerous *Citrus* genotypes contain vitamin C, with the grapefruit (*Citrus paradisi*) being the richest, and citron (*C. medica*) the poorest. Vitamin A in the form of β-carotene, α-carotene, and β-cryptoxanthin is commonly found within *Citrus*, especially in several coloured flesh species such as grapefruit, mandarin (*C. reticulate*), and orange (*C. sinensis*). In terms of vitamin B, orange and grapefruit are proven to contain B-complex, including thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), inositol (B8) and folate (B9). Vitamin E in the form of α-tocopherol was detected in leaf kaffir lime (*C. hystrix*) and orange (*C. sinensis*), lemon (C. limon), mandarin (*C. reticulate*), and tangerine (C. nobilis) fruit. This review summarizes the nutritional content of *Citrus*: *Citrus* contains not only vitamin C but also other vitamins beneficial to human health, therefore *Citrus* consumption is highly recommended.

Keywords: antioxidant, grapefruit, mandarin, orange, tangerine.

Introduction

Fruit consumption is reported to reduce the risk of cardiovascular disease (Lapuente et al., 2019), in contrast with fast-food consumption (Auestad et al., 2015). Among numerous fruits, *Citrus* has become one of the most economically important and popular horticulture produce worldwide (FAO, 2016). Total citrus (tangerines/mandarin) production worldwide increased yearly, from 30,346,000 tons in 2016/2017 to 37,933,000 tons in 2021/2022 (USDA, 2022). Increased citrus production is due to increasing demand. Similarly, in Indonesia there is a significant increase in citrus consumption from 1995 to 2020 due to population growth and better health awareness (Hanif et al., 2021).

Although citrus fruits are highly demanded worldwide, the production area is centered in only a few countries. *Citrus* was reported to spread worldwide, with a route from Southeast Asia to the Mediterranean (Langgut, 2017). Similarly, the latest genomic study revealed that Citrus originated from the Southeastern Himalayan valley, including Western Yunnan, Northern Myanmar, and Eastern Assam, before it eventually spread worldwide (Wu et al., 2018). An earlier study by (Liu et al., 2012) also confirmed that *Citrus* is native to tropical and subtropical Asian regions, i.e., China, the Malay Archipelago, and South Asia.

Citrus is split into two groups based on their market popularity, i.e., major and minor citrus. Kaffir lime is an example of minor citrus from Southeast Asian countries (Araujo et al., 2003; Mabberley, 2004), with the leaf used as a cooking spice (Budiarto et al., 2022a, 2022b, 2022c, 2021a, 2021b, 2019a, 2019b, Efendi et al., 2021). Rough lemon (*C. jambhiri*), citron, flying dragon (*C. trifoliata*), Japansche citroen (*C. limonia*), kasturi (*C. madurensis*), Khasi papeda (*C. latipes*) and limau (*C. amblycarpa*) are other examples of minor citrus (Budiarto et al., 2017; Efendi and Budiarto, 2022).

Orange (*C. sinensis*), however, one of the most popular *Citrus* species cultivated (by about 80% worldwide), is categorized as major *Citrus* (Turner and Burri, 2013). Mandarin, tangerine, and pummelo are three major *Citrus* popularly consumed as table fruit (Budiarto et al., 2018; Efendi and Budiarto, 2022; Hanif et al., 2021). Lime (*C. aurantifolia*) and lemon are also members of the major citrus group, and both are actively traded on the world market (Budiarto and Pratita, 2022). *Citrus* trading activity is highly affected by the balance of supply and demand.

Citrus demand is associated with the role of this fruit as a functional food due to its rich nutritional content (Lu et al., 2021; Saini et al., 2022; Zhang et al., 2021). Various beneficial phytochemicals found in *Citrus* have beneficial bioactivities such as cancer prevention (Kaur and Kaur, 2015), antioxidant (Adenaike and Abakpa, 2021), antibacterial, antifungal, and antiviral activities (Abobatta, 2019). Previous review studies have concluded that *Citrus* consumption could increase the body's antioxidant status, immune function, and cardiovascular health (Saeid and Ahmed, 2021; Turner and Burri, 2013).

Healthier lifestyles are currently on the increase due to the Covid-19 outbreak (Rothan and Byrareddy, 2020). Uncertain living conditions amidst the Covid-19 lockdown prompted society to adapt, with increased fruit consumption as one such adaptation, especially vitamin-rich fruit. Numerous reports have highlighted the importance of a vitamin-rich diet to improve the immune system during the Covid-19 pandemic era and to boost the post-infection period's recovery process (Galanakis, 2020). Therefore, a healthy habit of fresh fruit, such as *Citrus*, is important.

As a functional fruit, *Citrus* is often seen only as a source of vitamin C. It is not widely acknowledged that *Citrus* is multivitamin fruit, containing not only vitamin C but also vitamin A, B, and E (Zhou, 2012). Multivitamins are required to boost the immune system (Pantelidis et al., 2007), especially during the pandemic of Covid-19 (Bae and Kim, 2020; Galanakis, 2020). Thus, vitamins are one of the important aspects of nutritional quality in fruit (Vittori et al., 2018). However, there is still limited information regarding the multivitamin content of *Citrus*. Therefore, this paper is aimed at reviewing the multivitamin content found in numerous *Citrus* species.

Vitamin C

It is important to increase fruit and vegetable consumption by more than 90% to fulfill the daily requirement of vitamin C (Citak and Sonmez, 2010). Vitamin C, also known as ascorbic acid in the human diet is mainly derived from fruit commodities (Fenech et al., 2019). The content of vitamin C in *Citrus* is lower than in guava, i.e., 140 to 146 mg per 100 g (Widyastuti, et al., 2022; Widyastuti, et al., 2022); however, it is higher than other fruit commodities, namely soursop, banana, grape, and rose apple (Silva and Sirasa, 2018). Therefore, *Citrus* and its derivative products are still well known as the source of vitamin C in the human diet (Ting, 1980). Vitamin C is often an important indicator of *Citrus* nutritional quality (Chen et al., 2016, 2019; Gambetta et al., 2014; Ghorbani et al., 2018; Lado et al., 2018; Magwaza et al., 2017). Vitamin C is commonly found in the peel and flesh of Citrus fruit, which is biosynthesized through both L-galactose and D-galacturonic acid pathways (Zhang et al., 2015).

Vitamin C is also the most popular water-soluble antioxidant (Maggini et al., 2010; Martí et al., 2009) for reducing oxidative stress (Zou et al., 2016). The lack of vitamin C supplementation is associated with weakened immune systems and a slower body recovery during the post-infection period (Maggini et al., 2010). Additional vitamin C intake can significantly shorten the duration of the common cold (Ran et al., 2018). Multiple studies have concluded that a vitamin C-rich diet could enhance the body's immune systems during malaria (Qin et al., 2019), Covid-19 (Bae and Kim, 2020; Hiedra et al., 2020), influenza (Kim et al., 2016) and any other virus-induced respiratory infections (Gorton and Jarvis, 1999). Due to its importance, the recommended dietary allowance (RDA) for vitamin C is 60 mg per day (Carr and Frei, 1999). More specific to adult women and men, the RDA is determined as much as 75 mg/day and 90 mg/day respectively (Institute of Medicine Panel on Dietary Antioxidants and Related Compounds, 2000). The latest study on the effects of high vitamin C dosage (24 g day^{-1}) medication on Covid-19 patients for seven days revealed that a high dosage of vitamin C accelerated the Covid-19 patient's recovery process (Carr, 2020, J. Zhang et al., 2021, Zhao et al., 2021). Numerous studies have also previously reported the success of vitamin C therapy for Covid-19 patients (Carr and Rowe, 2020; Farjana et al., 2020; Holford et al., 2020; Kumari et al., 2020). Moreover, less adequate vitamin C intake is associated with severe pneumonia (Patterson et al., 2021).

Vitamin C content within *Citrus* fruit is strongly influenced by genetic factors (Escobedo-Avellaneda et al., 2014; Magwaza et al., 2017; Sdiri et al., 2012) with multigenic inheritance (Fanciullino et al., 2006) leading to multiple genes being involved in vitamin C biosynthesis (Alós et al., 2014). Numerous studies reported the vitamin C content variation found within different *Citrus* genera species (Krehl and Cowgill, 1950; Kumar et al., 2019; Sharma et al., 2006). The vitamin C content of seven *Citrus* species ranked from lowest to highest per 100 ml of juice is as follows; citron (20.65 mg), sweet orange (25.13 mg), mandarin (30.42 mg), lemon (34.67 mg), lime (38.70 mg), pomelo (40.50 mg) and grapefruit (53.64 mg) (Kumar et al., 2019). Moreover, the variation in vitamin C content is found not only at the inter-species level but also within the intra-species level. Different varieties of the same orange species (*C. sinensis*) could have different vitamin C content (Proteggente et al., 2003).

Aside from the genetic factors, vitamin C is also known to be affected by climate, growing location and the culture practices. An earlier review highlighted the effects of temperature on the fruit vitamin C; fruits in the cooler temperatures had higher vitamin C than those in the warmer regions (Nagy, 1980). Mudambi and Rajagopal (1977) also reported that the Nigerian sweet oranges grown in high temperatures had lower vitamin C. Growing and cultural practices in the field, such as growing cycle and crop nutrition (Caruso et al., 2011), application of plant growth regulator (PGR), and harvesting season, fruit maturity, and fruit positions on the tree, affect the fruit vitamin C content. Exogenous application of PGR significantly decreased fruit drop and increased vitamin C (Nawaz et al., 2008). Previous research has shown that gibberellic acid (GA_3) application correlates with kumquat (*C. japonica*) fruit vitamin C (Cai et al., 2021). A similar finding was reported by Rokaya et al. (2016) : GA_3-treated mandarin Citrus has higher vitamin C content than control fruit. These findings followed previous studies on 'Baramasi' lemon (Sindhu and Singhrot, 1993) and 'Balady' mandarin (El-Shereif et al., 2017). In addition, the application of 1-Methylcyclopropene (1-MCP) solely or combined with GA_3 successfully prevented vitamin C breakdown metabolism (Taş et al., 2021). The fruit should be cultured under organic farming systems to produce higher vitamin C content (Conti et al., 2014; Oliveira et al., 2013) or treated with plant growth-promoting rhizobacteria (PGPR) (Erturk et al., 2012), and excessive nitrogen fertilization should be avoided since it could reduce fruit vitamin C content (Rupp and Tränkle, 2000). Continuous decline of vitamin C content, specifically ascorbic acid, as the fruit ripens (Alvarez-Suarez et al., 2014; Nagy, 1980) is caused by an enzymatic process that converts L-ascorbic acid to 2-3-deoxy–L-gluconic acid (Mapson, 1970). The decline of vitamin C was also observed in the late harvest season (Rokaya et al., 2016). Late-season oranges have lower vitamin C than early and mid-season oranges (Ting, 1980). These findings confirmed the opinion (Caruso et al., 2011) that the growing season influences vitamin C content within fruits. Lastly, the fruit position in the tree canopy can influence vitamin C content. Sun-exposed fruits have higher vitamin C than those in the shade (Lee and Kader, 2000).

Vitamin A

In addition to vitamin C, *Citrus* is also a remarkable source of vitamin A. *Citrus* can be an alternative solution for vitamin A deficiency, which is still the most prevalent disorder worldwide (Priyadarshani, 2017). An earlier report by the Institute of Medicine Panel on Micronutrients (2001) showed the RDA for women and men to be about 700 and 900 µg retinol activity equivalents (RAE) per day respectively. Additionally, the consumption of 100 g of tangerine helps to meet 72% of the vitamin A RDA of children (Turner, 2012).

Vitamin A is a fat-soluble organic phytochemical, as are several carotenoids with provitamin A activity, retinal retinol, and retinoic acid (Amitava, 2014). Vitamin A is highly beneficial for maintaining healthy vision, the body's immune system, and bone formation (Turner and Burri, 2013). Vitamin A or its precursor (provitamin A) is known to be varied within a fruit depending on the plant's genetic material.

Citrus is reported to be the richest carotenoid fruit species (Kato, 2012). Numerous studies have reported the pathway of carotenoid biosynthesis and its related gene in several *Citrus* genotypes (Lu et al., 2016, 2018; Ma et al., 2018; Quian-Ulloa and Stange, 2021; Rodrigo et al., 2019; Wei et al., 2014; Zeng et al., 2013; Zhu et al., 2017). Those produced carotenoids are then transferred and accumulated in certain sites, especially in the fruit's juice sac and flavedo (Hermanns et al., 2020; Li and Yuan, 2013; Yuan et al., 2015). One of the important carotenoids for the human diet is provitamin A carotenoid (Ikoma et al., 2016). In more detail, a previous study has revealed 16 carotenoids with provitamin A activity in citrus, with β-carotene, α-carotene, and β-cryptoxanthin as the most numerous (Silalahi, 2002). β-carotene can be converted to zeaxanthin via β-cryptoxanthin, while α-carotene can be converted into lutein (Ikoma et al., 2016). An earlier study reported that β-carotene content varied in different citrus genotypes. Orange, pomelo, grapefruit, and lemon have 345, 120, 98, and 50 $\mu g.g^{-1}$ of β-carotene, respectively (Paul and Shaha, 2004). In addition to genotypes, fruit maturity stage also plays an important role in determining carotenoids containing provitamin-A, like β-carotene. Numerous studies on tomatoes revealed that as the fruit matured, there was an increase in β-carotene content within the fruit (Mubarok et al., 2015, 2019, 2021).

Aside β -carotene, *Citrus* fruit is believed to contain more zeaxanthin than other food products, such as green leafy vegetables (García-Closas et al., 2004). Genotype also influences the content of zeaxanthin within the fruit, i.e., mandarin, pomelo, calamansi, orange, and lemon have 6.46 $\mu g.g^{-1}$, 0.51 $\mu g.g^{-1}$, 36.4 $\mu g.g^{-1}$, 27.7 $\mu g.g^{-1}$, 0.81 $\mu g.g^{-1}$ of zeaxanthin, respectively (Wang et al., 2008). In addition, Citrus fruit is also believed to be a source of β-cryptoxanthin, as well as numerous other foods (Liu et al., 2012). β-cryptoxanthin is the major carotenoid found in mandarin (Kato, 2012; Zhu et al., 2017). Moreover, Matsumoto et al., (2007) classified not only mandarin but also oranges to the group of β-cryptoxanthin rich citrus. The richness level of carotenoids in *Citrus* can be preliminary monitored by the fruit colour. The red and pink flesh of grapefruit contained more provitamin A carotenoids than the white (Ting, 1980).

Additionally, the white flesh of lime, lemon, pomelo, and citron varieties are also reported to have low provitamin A carotenoids (Kato, 2012; Matsumoto et al., 2007). Future study to breed β-cryptoxanthin-rich varieties should be conducted to solve the aforementioned problem (Burri et al., 2011).

Vitamin B

Like vitamin A, vitamin B is an essential micronutrient that only our diet can provide. This water-soluble vitamin is associated with energy production and the physiological biosynthesis of important cell molecules (Schellack et al., 2019). Institute of Medicine (US) Standing Committee on the Scientific Evaluation of Dietary Reference Intakes and its Panel on Folate, Other B vitamins, and Choline (1998) revealed the daily RDA of numerous vitamin B as follows: (i) 1.2 mg/day and 1.1 mg/day of vitamin B1 for men and women, respectively; (ii) 1.1 mg/day and 1.3 mg/day of vitamin B2 for adult women and men, respectively; (iii) 16 mg/day and 14 mg/day of vitamin B3 equivalents for men and women, respectively; (iv) 1.3 mg/day of vitamin B6 for young adults; (v) 2.4 μg/day of vitamin B12 for adults; (vi) 400 μg/day of vitamin B9 equivalents for both men and women; and (vii) adequate intake (AI) of vitamin B5 and B7 for an adult was 5 mg/day and 30 μg/day, respectively. Daily fruit consumption may help provide the daily vitamin B that our body needs. Various fruits are reported to be a good source of several types of vitamin B, namely mango (Maldonado-Celis et al., 2019), Hass avocado (Dreher and Davenport, 2013), papaya (Vij and Prashar, 2015), kiwi berry (Latocha, 2017), mulberry (Yuan and Zhao, 2017), date (Khalid et al., 2017), tomato (Raiola et al., 2014), and jujube (Fard et al., 2015; Pareek, 2013; Rashwan et al., 2020). Numerous types of vitamin B, such as B1, B2, B3, B5, B6, B7, B8, and B9, were reported to be derived from *Citrus* and its derivative products, placing *Citrus* as one of the vitamin B-rich agri-food products (Liu et al., 2012).

Vitamin B1 or thiamine is abundant in *Citrus* (Ting, 1980) and is relatively stable to heat exposure (Godswill et al., 2020). Thiamine plays an important role in glucose metabolism (Ramsey and Muskin, 2013) and maintaining brain, gastrointestinal, heart, muscular function, and nervous system health (Abobatta, 2019). Different genotypes caused variations in vitamin B1 content among *Citrus*. *Citrus* ranking from the highest to lowest in vitamin B1 are orange, grapefruit, pomelo, and lemon for about 0.12, 0.12, 0.03, and 0.02 mg in 100 g fruits, respectively (Paul and Shaha, 2004). Abobatta (2019) reported that mandarin contains more thiamine (40 mg per 100g) than grapefruit (0.02 mg per 100g), lime (0.02 mg per 100g), or lemon (0.02 mg per 100 ml juice).

Vitamin B2 or riboflavin, vitamin B3 or niacin, and vitamin B5 or pantothenic acid are also found in *Citrus* juice (Ting, 1980). Riboflavin and niacin are unstable to heat exposure, while pantothenic acid displays opposite results (Godswill et al., 2020). These vitamins are responsible for energy production by converting food to energy (Bellows et al., 2012). Different citrus genotypes may contain different amounts of said vitamins. An earlier study reported that the content of riboflavin in orange was 0.05 mg per 100 g, and was higher than pomelo, grapefruit, and even lemon by about 0.03, 0.02, and 0.01 mg per 100 g, respectively (Paul and Shaha, 2004). Niacin content was higher in grapefruit (0.3 mg per 100 g) than in lime and lemon (< 0.1 mg in 100 g fruits; Abobatta, 2019).

Vitamins B6, B7, and B8, known as pyridoxine, biotin, and inositol, are also involved in human metabolic functions (Godswill et al., 2020). Pyridoxine is well-known for its role in serotonin synthesis (Stover and Field, 2015), while biotin is involved in the energy release process (Bellows et al., 2012) with a co-enzyme function (Schellack et al., 2019). In addition, inositol is needed by our bodies to maintain healthy hair (Schellack et al., 2019). An earlier study by (Krehl and Cowgill, 1950) reported the content of pyridoxine, biotin, and inositol in orange, grapefruit, and tangerine fruits. Pyridoxine content in tangerine, orange, and grapefruit ranged from 22.6-33.4, 16-32.4, and 8.0-18.2 μg per 100 ml, respectively. Orange, grapefruit, and tangerine contain 0.42-1.5, 0.36-0.97, and 0.45-0.46 μg of biotin in 100ml of juice, respectively. Grapefruit contains less inositol (88-112 mg per 100 ml) than orange (104-178 mg per 100 per ml) and tangerine (135-147 mg per 100 ml). This finding supports the idea that differences in citrus genotypes cause differences in the content of these multivitamins.

Folic acid, also known as folate or vitamin B9, is also frequently reported to be derived from *Citrus* and its derivative products, such as fruit juice. The earlier study determined that orange juice has a higher folate content than other fruit juices (Ting, 1980). Moreover, folate was fully bioavailable and highly stable in orange juice (Öhrvik and Witthöft, 2008). Folate is important due to its ability to reduce the risk of coronary heart illness (Bellows et al., 2012). Moreover, folate is known to be beneficial for a baby's brain development during pregnancy (Silalahi, 2002). Folate content in orange juice is higher than in tangerine and grapefruits, i.e. 1.3-3.2, 1.2-1.8, and 0.8-2.2 μg , respectively, in 100ml of juice (Krehl and Cowgill, 1950). Due to its health importance, folate has become the most fortified vitamin in 62 countries (Godswill et al., 2020). The consumption of 100 g citrus can supply up to 20% of daily folate needs (Saeid and Ahmed, 2021) specifically in nine year-old or younger children, while for adults, it covers up to 10% (Turner and Burri, 2013). Consumption of 750 ml orange juice daily for four weeks increased folate levels by 18% (Kurowska et al., 2000).

Vitamin E

Vitamin E, also known as tocochromanols (Fritsche et al., 2017), is a liposoluble essential micronutrient (Colombo, 2010; G. Lee and Han, 2018) that are found in eight natural isoforms, for instance, α-, β-, γ-, δ-tocotrienol and α -, β-, γ-, δ-tocopherol (Peh et al., 2016; Poiroux-Gonord et al., 2010; Zou et al., 2016). This vitamin acts as an antioxidant (Amitava, 2014; Zingg, 2019) that prevents lipid peroxidation damage (Zou et al., 2016). Alpha-tocopherol is the major compound among other chemical vitamin E forms that has strong antioxidant activities to reduce lipid peroxidation (Niki and Abe, 2019) and maintain cell membranes' stability (Munné-Bosch and Falk, 2004). Vitamin E can support healthy aging, and prevent cardiovascular and neurological diseases (Rizvi et al., 2014; Shahidi et al., 2021). Since an earlier study by (Salinthone et al., 2013) reported the association between vitamin E and human immunity, the administration of this vitamin as a food supplement is believed to help Covid-19 patient recovery (Erol et al., 2021; Tavakol and Seifalian, 2022). A previous report by the Institute of Medicine Panel on Dietary Antioxidants and Related Compounds (2000) revealed the RDA of vitamin E is 15 mg (35 μmol)/ day of α-tocopherol daily, irrespective of gender.

In general, the main source of vitamin E in a plant-derived product can be found in seed oil (Ahsan et al., 2015; Mène-Saffrané, 2017), for instance, olive oil and sunflower oil (Cayuela and García, 2017; García-Closas et al., 2004). Vitamin E can also be found in green leafy vegetables (Cruz and Casal, 2013), fruit peels, and seeds (Zhou, 2012). An earlier study (Ornelas-Paz et al., 2017) reported the reduction of vitamin E in seedless mandarin as the effect of phytosanitary irradiation during postharvest handling. Vitamin E content can also vary between *Citrus* genotypes; for example, orange, tangerine, and lemon have 5.60, 4.50, and 11.40 $mg.kg^{-1}$ of vitamin E, respectively (Zhou, 2012). Previous studies recommended raw consumption of *Citrus* fruits to obtain the maximum amount of vitamin E since both tocopherol and tocotrienol levels can decline in response to processing treatment (Knecht et al., 2015). Other than fruits, leaves of kaffir lime contain 66.00 and 39.83 mg per 100 g of vitamin E per dry weight and fresh weight basis, respectively (Ching and Mohamed, 2001). Vitamin E content is influenced by the genetics and the environmental factors. Under certain abiotic stresses, plants may boost vitamin E production, such as toco-chromanol, which is an antioxidant to adapt to the stress (Bao et al., 2020). Xiang et al., (2019) reported the gradual accumulation of vitamin E in sweet corns treated with low-temperature stress. A study by Kruk et al. (2005) highlighted the accumulation of tocopherols, especially α-tocopherol, under high light and heat stress environment to protect photosystem. However, information on the effect of environmental factors, including applied culture practice, on multivitamin content in citrus are still limited; thus, future research should be directed to these aspects.

Conclusion

Citrus has long been lauded as a functional agri-food famous for its vitamin C content. This review highlighted not only vitamin C but also vitamins A, B, and E, found within numerous *Citrus* species, illustrating this plant as a vitamin treasure box. The variation of vitamin C content was reported in citron, orange, mandarin, tangerine, lemon, lime, kumquat, pomelo, and grapefruit. In terms of vitamin A, the red and pink flesh variety of grapefruit and yellow colored flesh of calamansi, orange, pomelo, lemon, and mandarin are rich in carotenoid-provitamin A. Orange and grapefruits are reported to contain high amounts of vitamin B, whereas tangerine, mandarin, pomelo, lemon, and lime contain small amounts. The fruits of orange, mandarin, tangerine, lemon, and the leaf of kaffir lime contain vitamin E. Those multivitamins are essential as antioxidants to enhance our immune system.

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