Sweet new discoveries open up opportunities for citrus industry

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Citrus fruits and juices are commonly consumed worldwide due to their health benefits and flavor. However, recent trends in reducing carbohydrate intake have raised concerns from consumers about citrus products because of their relatively high levels of sugar content. This concern discourages repeat purchasing and consumption of citrus fruits and juice.

Citrus fruits have beneficial nutrients such as vitamins, minerals and phytonutrients that are good for long-term health. However, some food regulators still use a sugar-based grading system that ranks 100% orange juice lower than diet soda (Baldwin et al., 2014; Visvanathan and Williamson, 2021).

The public is generally aware that overconsumption of sugars is associated with obesity and obesity-related diseases such as Type 2 diabetes and metabolic syndrome. Sweeteners with low or no calories are increasingly used as sugar substitutes in various food and beverage products to meet consumers' growing demand for less sugar.

Non-food products manufactured by the pharmaceutical industry are also becoming more popular. To date, six artificial sweeteners (saccharin, aspartame, sucralose, acesulfame potassium, neotame and advantame) and only two natural sweeteners (stevia and monk fruit extract) are approved as non-caloric sugar substitutes in food by the U.S. Food and Drug Administration. Compared to synthetic sweeteners, consumers express higher interest in sugar substitutes derived from natural sources.

Controversies related to artificial sweeteners such as potential health issues and an undesirable

Table 1. Details of cultivars and experimental selections, their origin and potential use for production of sweeteners or sweet-enhancing compounds

Cultivar category	Selected cultivar	Origin (parentage)	Sweeteners or sweet-enhancing compounds in relatively high abundance				
			Oxime V	Perillaldehyde	Hernandulcin	Hesperetin	Eriodictyol
Mandarins	Bingo	[Clementine x Valencia] x Seedless Kishu		✔			✔
	LB8-9 (Sugar Belle®)	Clementine x Minneola		✔		✔	✔
	411	LB8-9 x Murcott	✔	✔			
	18A-1-26	Clementine x [Nova + Osceola] (triploid)		✔	✔		✔
	18A-4-46	Clementine x [Murcott + LB8-9]	✔	✔			
	18A-9-39	Clementine x [Murcott + LB8-9]	✔	✔		✔	
	18A-10-38	Clementine x Murcott with G1 Satsuma cytoplasm	✔	✔			✔
	13-51	LB8-9 x Murcott		✔		✔	
Sweet oranges	EV-2	Valencia sweet orange (somaclone)				✔	
	OLL-20	OLL sweet orange (somaclone)		✔		✔	
Grapefruit hybrid	UF 914	Low acid Pummelo x Ruby Red (tetraploid)	✔	✔	✔		

aftertaste (bitter or metallic) are the main concerns causing debate in the use of sweeteners in food (Dubois et al., 2012). Natural sweeteners or sweetness enhancers can help address those challenges by improving palatability and closely resembling the sensory profile of sugar.

As the highest-value fruit crop in the international trade, citrus fruits have long been utilized as flavoring to enhance food quality in addition to being consumed fresh or processed. There are several natural or semi-synthetic sweeteners and sweetness-enhancing components discovered from citrus peels, such as hesperetin, neohesperidin dihydrochalcone, hesperidin dihydrochalcone and naringin dihydrochalcone. They are reported to effectively mask the bitter taste of other compounds in citrus, thus improving the sweetness perception and overall flavor of citrus products (Wang et al., 2022). The potential of expanding the value of citrus in the development of natural sweeteners is huge. However, it also is extremely challenging due to the

Table 2. Sweeteners, sweetness enhancers or bitter-masking compounds identified from citrus

Category	Compound Name	Sweetness-Enhancing Performance
Sweeteners	Oxime V	450 times sweeter than sucrose
	Perillaldehyde	Slight sweetness
	Hernandulcin	1,000 times sweeter than sucrose
	4β-hydroxyhernandulcin	Potential sweetener without quantitative data
	ADMF[1]	Potential sweetener without quantitative data
	DAME[2]	400 times sweeter than sucrose
Sweetness enhancer	Hesperetin	41% enhancement on perception of sweetness
Bitter-masking compound	Eriodictyol	Remarkable masking effects against bitterness of caffeine

[1]ADMF is an abbreviation for 3-acetoxy-5,7-dihydroxy-4'-methoxyflavanone.
[2]DAME is abbreviation for dihydroquercetin-3-acetate-4'-methyl ether.

complexity of the chemical compositions in citrus.

SELECTIONS STUDIED

To uncover more naturally occurring non-caloric sweet compounds from citrus, researchers from the Citrus Research and Education Center (CREC) at the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) have recently proposed an efficient strategy to identify potential sweeteners or sweetness enhancers (Wang et al., 2022). Fruits from 11 citrus cultivars (Table 1, page 13) have been selected for their unique and exceptional flavors, including a grapefruit hybrid (UF 914), two types of sweet oranges (EV-2 and OLL-20), and eight cultivars or experimental selections of mandarins (Bingo, Sugar Belle®, 411, 18A-1-26, 18A-4-46, 18A-9-39, 18A-10-38 and 13-51).

SWEETNESS SOURCES

Through the high-performance analytical technique involving systematic flavor profiling and chemical screening by searching an in-house database, eight sweeteners or sweetness-enhancing compounds were identified, seven of which are first identified from the genus *Citrus*. On top of hesperetin that has been reported to exist in citrus before, oxime V, perillaldehyde, hernandulcin, 4β-hydroxyhernandulcin, ADMF (3-acetoxy-5,7-dihydroxy-4'-methoxyflavanone), DAME (dihydroquercetin-3-acetate-4'-methyl ether) and eriodictyol were also identified with various level of sweetness potency or bitter-masking effects (Table 2).

Remarkably, the artificial oxime V, which is about 450 times sweeter than sucrose, was discovered in citrus for the first time. Furthermore, it has never been identified in a natural source.

Perillaldehyde is a volatile oil found originally in a plant called perilla. It is present during the processing of frozen concentrated orange juice. This is also the first time it has been found in citrus fruit. The application of perillaldehyde is limited because it only has a slightly sweet taste.

Hernandulcin and 4β-hydroxyhernandulcin are also two sweet components discovered first from citrus in this study. They have been found in the leaves and flowers of the plant *Lippia dulcis*. Compared to hernandulcin, which is 1,000 times sweeter than sucrose, the structurally similar compound 4β-hydroxyhernandulcin is being evaluated as sweet-tasting without any intensity level being reported.

ADMF and DAME are structurally similar, but only DAME has been reported 400 times sweeter than sucrose.

The sweetness-enhancing effect of hesperetin has been studied in a previous report. There is a 41% significant enhancement of the perceived sweetness of a sucrose solution after mixing with 100 milligrams per liter of hesperetin. As one of the predominant phytochemicals in lemons and oranges, the mechanism of its sweetness-enhancing effect is that hesperetin can bind with the sweet taste receptor without activating it, leading to an increase in the perception level of sweetness when tasting with table sugar.

Eriodictyol is a bitterness inhibitor showing a remarkable masking effect

Ideally, cultivars yielding high levels of targeted sweeteners can be selected as parents for future breeding, which could expand the citrus market and increase the sustainability of citriculture.

on caffeine without eliciting strong inherent taste characteristics. It has a similar chemical structure to hesperetin and has been detected in various plants, such as oregano, thyme and sweet basil. It is also obtained from lemon peels in previous research but has never been detected from citrus fruit directly.

In addition to the breakthrough of identifying natural sweeteners in citrus, researchers also determined the absolute content of five sweeteners in the 11 different citrus cultivars and selections collected over two continuous years (2019 and 2020). Results showed that all 11 were abundant in different sweeteners (Table 1, page 13). For example, the natural sweetener perillaldehyde was abundant in all cultivars except the sweet orange cultivar EV-2. Hernandulcin was only detected with higher abundance in mandarin 18A-1-26 and grapefruit hybrid UF 914. Eriodictyol was generally more abundant in mandarins instead of sweet oranges or grapefruit hybrids.

INDUSTRY IMPLICATIONS

Based on this information, cultivars containing a high level of specific natural sweeteners can achieve new marketing value. It will provide fruits with reduced sugar content without compensating for the overall sweetness level and palatability.

It will also give a promising direction for agricultural practice in citrus breeding once the relevant biosynthetic pathways of those sweeteners or sweetness enhancers are identified. Ideally, cultivars yielding high levels of targeted sweeteners can be selected as parents for future breeding, which could expand the citrus market and increase the sustainability of citriculture. Citrus fruits or fruit juices that can offer both a high sweet sensation and low sugar content are expected to be developed, which will help reshape and maintain the popularity and economical value of citrus.

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