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Harshita K
Student, Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Harshita K
Student, Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India

Monk fruit (*Siraitia grosvenorii*): A comprehensive review of its sweetness, health benefits, and applications as a natural sweetener

Harshita K

Abstract
The market is observing a change in customer attitudes about sugar and other sugar-based goods as a result of consumers opting for more nutritious culinary options. Consumer preference for low- or zero-calorie sugar substitutes throughout the world is boosting market demand. Monk fruit (*Siraitia grosvenorii*), a fruit that is native to Southeast Asia, has drawn a lot of interest as a natural sweetener. This comprehensive review paper aims to provide a detailed analysis of monk fruit's sweetness, health benefits, and applications as a natural sweetener. The presence of mogrosides, in particular mogroside V, which is said to be around 300 times sweeter than sugar, is chiefly responsible for the high sweetness of monk fruit. Monk fruit is an intriguing substitute for conventional sweeteners for people trying to cut back on their sugar intake or control diabetes and weight since it has exceptional sweetness while having zero calories and a low glycaemic index. The mogrosides in monk fruit are also said to have antioxidant properties, including anti-inflammatory and anti-carcinogenic effects. This review also explores the wide range of applications of monk fruit sweeteners in various products. Monk fruit sweeteners are heat stable, making them suitable for cooking and baking.

Keywords: Monk fruit, mogrosides, natural sweeteners, zero calories

Introduction

Monk fruit (*Siraitia grosvenorii*), also referred to as Luo Han Guo or swingle fruit, is an herbaceous perennial plant that is native to the southern parts of China, prevalent in Yongfu, Longsheng, and Lingui counties in northern Guangxi province, and also distributed in Guizhou, Hunan, Guangdong, and Jiangxi provinces (Shivani *et al*., 2021) [1]. Numerous substances of various kinds, including polysaccharides, amino acids, essential oils, flavonoids, triterpenoids, nucleosides, etc., have been discovered and isolated from different portions of monk fruit. Glycosides, a group of triterpenoids are often regarded as one of the principles biologically active components of monk fruit. In monk fruit, cucurbitane glycoside formation begins at a certain time after pollination. Monk fruit is typically harvested once it has fully ripened, and distinct mogrosides begin to emerge at different times following pollination and during maturity. Monk fruit has up to thirty cucurbitane glycosides that have been observed so far (Li *et al*., 2014) [2]. Only a limited number of compounds, including mogroside III, IV, V, and siamenode I, were investigated for their functional qualities (Jin and Lee, 2012) [3].

Monk fruit planting locations are typically dispersed at altitudes between 200 and 800 m with gradients greater than 15° (Zeng, 2011) [4]. It has been grown in specific areas of China for more than 200 years (Shivani *et al*., 2021) [1]. The fruit, which is the species' main source of income, includes a sweet, fleshy, and edible pulp that has been used for more than 300 years in traditional Chinese medicine to cure lung congestion, colds, and sore throats (Li *et al*., 2014) [2]. Monk fruit was recognized as a food source and medicinal by China's Ministry of Health in 1987. As nutritional supplements, monk fruit products have also received approval from nations including Australia, Japan, the United States, and New Zealand. Mogroside V was given the go-ahead in Japan as a natural sweetener. In contrast, monk fruit extract was authorized as generally recognized as safe (GRAS) in the USA in 2010 for non-nutritive sweetening and taste enhancing purposes (Tu *et al*., 2017) [5].

The demand for natural sweeteners has been steadily increasing in recent years due to growing consumer awareness and preferences for healthier food and beverage choices. The growing interest in vegan, vegetarian, and plant-based diets has further accelerated the demand for natural sweeteners that align with these dietary choices. Natural sweeteners, such as monkfruit, stevia, and agave, offer a sweet taste while often having lower calorie content and a reduced impact on blood sugar levels. Applications of monkfruit sweeteners in various products like beverages, baked goods, confectionery, dairy products, snack foods, condiments, sauces, and nutritional supplements, providing a healthier option without compromising taste or flavour. The Food and Drug Administration (FDA) has approved the use of monk fruit in food and beverages and has determined that it is safe for all consumers, including children and pregnant women (Lamkhade *et al*., 2022) [6].

Monk fruit is crushed, its seeds and peel are removed, and the fruit's sweet parts are filtered and extracted to yield liquid and powdered monk fruit sweeteners. Monk fruit extract is frequently combined with erythritol during the manufacture of monk fruit sweeteners to make it taste and appear more like table sugar. Erythritol, a particular polyol also known as a sugar alcohol, has zero calories per gram (USFDA, 2016) [7]. Polyols, such as erythritol, mannitol, and xylitol, are naturally occurring sweeteners. In addition to occurring naturally in fruits and vegetables, mono or disaccharides may also be used to synthesize them (Edwards *et al*., 2016) [8]. The sweetest polyol, xylitol, a five-carbon substance produced by hydrogenating xylose, only has 2.4 kcal per gram (about 5% of the calories in sugar) less enticing than sugar. Salivation, cavity prevention, and bacterial load reduction are all advantages of xylitol. Carocho *et al*. (2017) [9] explained the market for xylitol is thought to be worth $670 million USD and is expected to grow as more commercial items, such as soft drinks, gum, candy, and baked goods, include it into their formulations. The wider population is still fewer acquainted with xylitol than they are with stevia or other artificial sweeteners (such as sucralose, aspartame, and saccharin) (Mora and Dando, 2021) [10]. The monk fruit extract contains varying levels of mogrosides, which possess non-nutritive and characteristic sweetener properties. The SGFE extracts powder is heat-stable. It is 100-250 times sweeter than sucrose (Chandan and Kilara, 2015) [11]. In addition to mogrosides, fresh fruit also includes rutin, kaempferol, and quercetin, which are responsible for its antioxidant, antimicrobial, and anti-inflammatory effects (Świąder *et al*., 2019) [12].

Production of monk fruit extract

The production process of monk fruit extract is described below:

- Multi-stage solid-liquid extraction process to extract mogroside V from the mechanically crushed or shredded pulp of the fruit. The extract solutions from each stage are combined.
- Precipitation of protein compounds by heating to 100 ºC, which are then removed by centrifugation, resulting in a clear solution.
- Filtration to remove pectin.
- Solid-phase extraction, involving:
- ✓ Adsorption of mogrosides onto a food-grade copolymer resin column. Unwanted compounds including salts and sugars pass through the column and are disposed of.
- ✓ Desorption of the target compounds from the column using a food-grade 60% ethanol solution, followed by distillation to remove the ethanol.
- A second solid-phase extraction using a copolymer resin column, adsorbing any unwanted non-triterpene glycosides and allowing the desired triterpene glycosides to pass through the column. This also decolours the solution.
- Vacuum concentration of the solution to approximately 20% solid content. This also removes most of the remaining ethanol.
- Spray drying at 120ºC to form a dry powder and remove any final traces of ethanol and most of the water content [13].

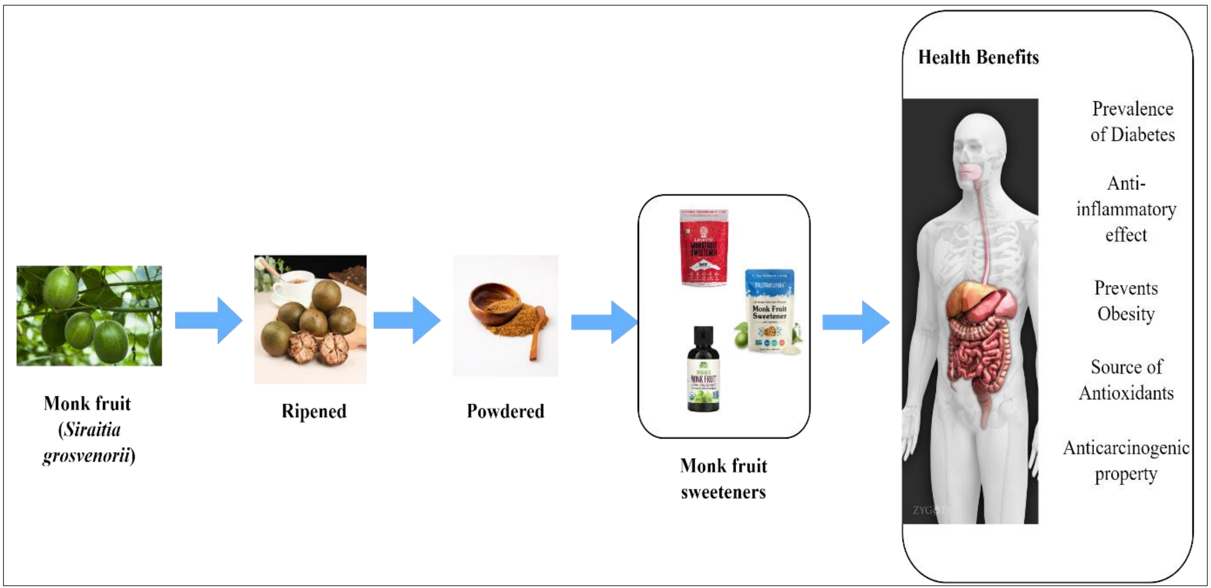

Fig 1: Evolution of monk fruit as sweetener and its health benefits

Potential health benefits of monk fruit

To date, the antitussive, anti-asthmatic, antioxidant, liver-protective, glucose-lowering, immunoregulating, and perhaps anticarcinogenic activities of monk fruit have been demonstrated (Ban *et al*., 2020) [14]. Studies about some of its pharmaceutical properties have been reported below.

1. Antidiabetic and anti-hyperglycaemic property

Ban *et al*. (2022) [15] demonstrated the effect of synbiotic yogurt fortified with monk fruit extract on hepatic lipid biomarkers and metabolism in rats with type 2 diabetes. It was found that MFE-sweetened synbiotic yogurt played an active role in improving type 2 diabetes mellitus liver lipid biomarkers. In addition, the MFE-sweetened synbiotic yogurt improved the phospholipids and FAHFA profiles of the livers, indicating that they can be used as lipid biomarkers. Furthermore, multiomics studies confirmed that the MFE-sweetened synbiotic yogurt regulated fatty acid biosynthesis, bile secretion, and glyoxylate and dicarboxylate metabolism, thus altering the levels of lipid biomarkers in the livers of the T2DM rats.

S. grosvenorii Swingle extract exhibited an antidiabetic effect on spontaneous type 2 diabetic Goto–Kakizaki rat specimens. It caused an improvement in the insulin response in the oral glucose tolerance test, an accumulation of insulin in the pancreas in the fasting state, amelioration of kidney function, and enhancement of antioxidative properties in the liver and plasma (Suzuki *et al*. 2007) [16]. Over the past decade, a number of in-vitro and in-vivo research have been carried out to examine the effects of monk fruit extract and mogrosides on blood glucose levels and diabetes.

2. Anticarcinogenic activity

Liu *et al*. (2016) [17] examined antiproliferative activity of triterpene glycoside nutrient from monk fruit in colorectal cancer and throat cancer. The results indicated that mogroside IVe, a triterpenoid glycoside from monk fruit used as a strong sweetener, has a potential to prevent the development of colorectal and laryngeal cancers because it significantly inhibited the proliferation of HT29 and Hep-2 cells *in vitro*, and, consistently, demonstrated an anticancer effect in mice with HT29- and Hep-2-derived xenografted tumor. Mogroside IVe has the ability to suppress the proliferation of colorectal cancer and throat cancer cells by inducing apoptosis through upregulation of p53, and downregulation of p-ERK1/2 and MMP-9 levels, strongly indicating anticancer activity. The study highlighted the function and mechanism of mogroside IVe, as a phytochemical with potential to fight throat and colorectal cancer. In terms of cancer preventive effects and user compliance, the use of mogroside IVe as a dietary supplement may be preferable to that of conventional medications because it has no side effects and is a common sweetener in low-calorie meals and beverages.

Table 1: Pharmaceutical properties of monk fruit

Pharmaceutical aspects	Model	Animal use	Dosage/ Quantity	Reference
Antidiabetic and anti-hyperglycaemic property	Normal diet and high-fat diet (supplemented with monkfruit extract powder)	Rats	6 weeks	Ban *et al*. (2022) [15]
Anticarcinogenic activity	In-vitro (infusion of mogroside IVe)	Mice	5 weeks	Liu *et al*. (2016) [17]
Antibacterial activity	In-vitro (compounds from monk fruit and its leaves)	Bacterial species- *Streptococcus mutans* *Fusobacterium nucleatum* *Actinobacillus actinomycetemcomitans* Yeast species- *Candida albicans*	–	Suri *et al*. (2020) [18]
Anti-obese property	High- fat diet (water extracts of SG powder)	Mice	18 weeks	Lu *et al*. (2022)
Antioxidant activity	In-vitro (mogroside- based products)	–	72 hrs	Konno *et al*. (2022) [21]

3. Antibacterial activity

The antibacterial effects of monkfruit sweetener, specifically its sweetening compounds known as mogrosides, have not been extensively studied or established. However, it is important to note that some studies have indicated that certain natural sweeteners, including monkfruit sweetener, may exhibit antimicrobial properties against specific bacteria. These studies suggest that the high-intensity sweetness and specific chemical composition of mogrosides could potentially inhibit the growth of certain bacteria. *In vitro* activity of nine anti-bacterial compounds isolated from monk fruit against the oral bacterial species such as *Streptococcus mutans*, *Fusobacterium nucleatum* and *Actinobacillus actinomycetemcomitans* and also the yeast species *Candida albicans* were determined and reported the significant antibacterial activity of the monk fruit leaves. Glucosyltransferase enzyme (GTF) of the *S. mutans* supported the metabolism and was also known to be the virulence component during the pathogenesis of dental caries (Suri *et al*., 2020) [18].

4. Anti-obese property

One of the common disorders is obesity, although its exact causes are still unknown. The International Obesity Task Force (IOTF) study states that obesity is a major lifestyle-related disease that is seen all over the world. Consuming too many high-calorie meals induces aberrant, excessive adipose tissue formation, which results in obesity (Pandey and Chauhan *et al*., 2019) [19].

In comparison to the artificial sweetener aspartame, Lu *et al*. (2022) [20] demonstrated the effects of *Siraitia grosvenorii* extracts on high fat diet-induced obese mice. The body weight gain in the control mice was levelled starting at week 8, while mice fed with HFD, HFD + SG, and HFD + ASM continued to gain weight throughout 18 weeks. However, the weight gain rate of HFD + SG-fed mice became lower compared to HFD- and HFD + ASM-fed mice around week 10. At the end of week 18, SG extract treatment led to lower body weight compared to ASM (artificial sweetener aspartame) treatment. Furthermore, the body weight gain in the SG groups (13.94±1.11) was clearly lower than that in the ASM groups (18.84±3.21, $P < 0.05$). The results showed that there were no significant differences in food intake among the groups receiving HFD feeding, however, higher FER index values were observed in the ASM groups (5.64±0.94) than in the SG group (4.17±0.38, $P < 0.05$). These findings indicated that more storage or less consumption of energy intake might contribute to the difference between SG and ASM treatments.

5. Antioxidant property

According to studies, the mogrosides in monkfruit have been identified as having antioxidant qualities. These antioxidants may have protective benefits against oxidative stress and inflammation by assisting the body in scavenging dangerous free radicals.

Konno *et al*. (2022) [21] examined the antioxidant effects of bioactive extracts from monk fruit (*Siraitia grosvenorii*) with potential clinical implications. For antioxidant study, whether LS, LME, and LLE, and MOG products would protect normal kidney cells from hydrogen peroxide (H_2O_2)-induced OXS was examined. LLC-PK1 cells were treated with H_2O_2 (65 µM) alone or with LS (500 µg/ ml), LME (500 µg/ml), LLE (3 µg/ml) or MOG (2,000 µg/ml) and cell viability was determined in 72 h. Although cell viability was reduced by ~50% with H_2O_2 in LLC-PK1 cells, the ~33% and ~25% increases in such reduced cell viability were seen with LLE and MOG, respectively. However, LS and LME had little effects against an OXS attack. These findings implied that LLE and MOG appear to have antioxidant activity that can defend healthy cells from an OXS attack.

Application of Monk fruit sweetener in food industry

Monkfruit sweeteners have gained popularity in recent years, leading to the development of various products that incorporate this natural sweetener. Unlike some other non-nutritive sweeteners, monkfruit extract does not have a bitter aftertaste. This quality contributes to its overall pleasant sensory profile and enhances its compatibility in a wide range of food and beverage applications. Following are some examples of products that have been made with the incorporation of monkfruit sweeteners:

1. Beverages

In order to enhance their dietary protein consumption, consumers have grown more and more appreciative of protein beverages in recent years. Whey proteins are a great protein source for protein beverages because they offer a full source of essential A.A. and are high in branched-chain A.A., which may help with muscle repair after exercise (Blomstrand and Saltin, 2001 [22]; Hazen, 2003 [23]; Childs *et al*., 2008 [24]).

Parker *et al*. (2018) [25] examined consumer acceptance of natural sweeteners in protein beverages. They evaluated the sensory properties of naturally sweetened ready-to-mix (RTM) whey protein beverages using 3 temporal methods and formulated a natural non-caloric sweetener blend that could be added to RTM protein beverages to provide sweetness while still appealing in flavour to consumers. Iso-sweet concentrations of sweeteners (sucralose, sucrose, fructose, stevia, monk fruit) in RTM vanilla whey protein beverages (25 g of protein/360 mL of water) were established. One sugar-free blend (25% stevia/75% monk fruit) and 1 reduced-sugar blend (25% stevia/25% monk fruit/50% fructose) were selected for consumer testing (n = 150 consumers) in addition to 3 control RTM beverages containing sucralose, stevia, or monk fruit. Two distinct consumer clusters were identified. When ingrained, the portion of customers that care about labels favoured beverages sweetened with natural blends. Conceptually, the flavour-driven customer category favoured naturally sweetened beverages, but when ingrained, they chose sucralose-sweetened beverages. All consumers favoured a label promise that said "all natural." It is possible to create naturally sweetened protein beverages with reduced calories and appealing sensory qualities by applying these discoveries to currently available RTM protein beverages.

Li *et al*. (2015) [26] determined parents' and children's acceptance of skim chocolate milks sweetened by monk fruit and stevia leaf extracts. The optimum sweetener concentration levels in SCM for young people were determined in this study, along with the sweetness intensity perception of stevia leaf and monk fruit extracts in both water and SCM. SCM with 39.7 g/L sucrose and 46 mg/L monk fruit extract or 30 mg/L stevia extract were acceptable compared with control chocolate milk sweetened with 51.4 g/L sucrose. The reduced-sugar SCMs sweetened partially by commercially available stevia leaf and monk fruit extracts were also acceptable by both children 5 to 13 y and parents, and presentation of chocolate milk information had different effects on parental acceptance. Traditional parents preferred sucrose sweetened chocolate milk and label conscious parents preferred chocolate milk with higher sugar reduction that was partially sweetened with natural non-nutritive sweeteners.

2. Jellies

Akesowan and Choonhahirun (2021) [27] represented the use of stevia and monk fruit sweeteners for sugar replacement in green tea agar jellies. In order to reduce the risk of heart attack, diabetes, and other chronic illnesses, this study aimed to create sugar-free, healthful agar jellies. Stevia and monk fruit, two naturally occurring non-nutritive sweeteners, were investigated at various concentrations of 25%, 50%, 75%, and 100% sugar substitution based on the sweetness of sucrose equivalent. The total soluble solids, hardness, color, and syneresis of the material were evaluated. Nevertheless, a 9-point hedonic scale was used to rate the sensory qualities of color, taste, flavour, texture, and general attractiveness. The more sugar replacement lowered the total soluble solids but increased the gel firmness ($p<0.05$) and the lightness (L*). The syneresis declined in reduced-sugar jellies with stevia and monk fruit against the whole sugar jellies. The stevia and monk fruit replacement affected agar jellies' taste and flavour attributes ($p<0.05$). Jellies with 50% and 75% sugar replacement, either stevia or monk fruit, were preferred over 25% and 100% replacement. The jelly with 50% stevia was the optimal formulation.

3. Yogurt

In the human diet, camel milk is an excellent source of compounds that are favorable for health (Kaskous, 2016). Human disorders including tuberculosis, asthma, diabetes, and food allergies can all be treated using camel milk's mono- and polyunsaturated fatty acid content, lactoferrin, L-lactate, bifidobacteria, insulin, and bioactive peptides. In addition, camel milk accounts for anticarcinogenic, antihypertensive, and therapeutic qualities (Kumar *et al*., 2016 [28]; Kaskous, 2016 [29]).

The physicochemical and microbiological characteristics of camel milk yogurt as influenced by monk fruit sweetener have been studied by Buchilina and Aryana (2021) [30]. Camel milk drinking yogurt was produced with 0, 0.42, 1.27, and 2.54 g/L of monk fruit sweetener and stored for 42 d. The physicochemical characteristics and microbiological counts of yogurts were measured at d 1, 7, 14, 21, 28, 35, and 42. For the physicochemical characteristics, pH, titratable acidity, viscosity, and color [lightness-darkness (L*), red-green axis (a*), yellow-blue axis (b*), chroma (C*), and hue angle (h*)] values were evaluated. The counts of *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, *Lactobacillus acidophilus*, coliforms, and yeast and mold were determined. Three replications were conducted. The sweetener addition significantly influenced pH, viscosity, and color (a*, b*, C*, and h*) values. Control samples had significantly higher pH values, lower viscosity, lower b* and C* values, and higher h* values than the samples with 1.27 and 2.54 g/L of monk fruit sweetener. Growth of *S. thermophilus*, *L. bulgaricus*, and probiotic culture *L. acidophilus* was not affected by the incorporation of monk fruit sweetener. Monk fruit sweetener can be added in camel milk yogurts as a health-beneficial zero-calorie sweetener.

Table 2: Applications of monk fruit extract for food production

Food industry type	Products	References
Beverage industry	Ready-to-mix whey protein beverage	Parker *et al*. (2018) [25]
	Skim chocolate milk	Li *et al*. (2015)
Confectionery	Green tea agar jellies	Akesowan and Choonhahirun (2021) [27]
Dairy industry	Camel milk yogurt	Buchilina and Aryana (2021) [30]
Processed grains	Breakfast cereals	Bickelhaupt and Luke *et al*. (2022) [31]
Meat industry	Braised pork	He *et al*. (2022)

4. Breakfast cereals

Bickelhaupt and Luke *et al*. (2022) [31] studied the single screw extrusion process optimization of nutritionally dense cranberry pomace infused breakfast cereal. The key objectives of this study were to first produce a desirable formulation using rice flour and varying amounts of cranberry pomace and soy flour using extrusion at 150°C, 300 rpm, and a moisture content of 30%, and second, to identify the best zero-calorie sweetener to enhance the flavour profile of the formulation that was chosen. After the optimal formula was selected (45% rice flour, 40% soy flour, and 15% cranberry pomace), a zero-calorie sweetener was integrated to provide an overall better taste profile. A sensory evaluation between five different treatments was performed, testing color, taste, texture, and overall acceptability. There were no distinguishable differences between the monk fruit percentages. However, with the 5% stevia introduction, there was a significant difference compared to all other treatments (0%, 1%, 2.5%, and 5% monk fruit extract). The sensory evaluation demonstrated this the most, with participants considerably favouring treatments containing 5% stevia and 5% monk fruit extract over lower sugar replacement concentrations ($p < .001$).

5. Braised pork

He *et al*. (2022) [32] effect of different sweeteners on the quality, fatty acid and volatile flavour compounds of braised pork. This study aimed to assess how several sweeteners (white sugar, *Siraitia grosvenorii* fruit, mogrosides, and stevia glycoside) affected the flavour, fatty acid composition, and quality of braised pork.

The findings showed that the effects of sweeteners and stewing time on the quality, fatty acids, and flavour of braised pork varied. By extending the stewing time, braised pork may lose some of its flexibility and chewability. As the muscle fiber structure altered, its sulfhydryl content increased, its carbonyl content increased, and its fatty acid content decreased in braised pork. The braised pork with SF, MG, and SG can decrease oxidation and produce secondary products by keeping sweetness and enhancing the braised pig's sensory quality. The sample with mogroside added has a lower amount of protein oxidation, the *Siraitia grosvenorii* fruit has a stronger inhibitory effect on lipid oxidation, and stevia glycoside is better at improving meat color. The SG group's braised pork included more SFA than the WS groups, and the SF and MG groups' UFA:SFA ratios were better than the WS groups. By detecting peptides, it can be more precisely determined that the peptide sequence that gives cooked meat its antioxidant effects and raises the nutritional value of braised pork contains peptides.

6. Conclusion

Monkfruit (*Siraitia grosvenorii*), also known as Luo Han Guo, is a fruit native to Southeast Asia that has gained significant attention as a natural sweetener. It has been used for centuries in traditional Chinese medicine for its medicinal properties and as a natural sweetener. Due to its intense sweetness, only a small amount of monk fruit extract is needed to achieve the desired level of sweetness in food and beverages while also imparting its therapeutic properties to the processed products like in meat products. It's typically processed and sold as a concentrated powder or liquid extract. The steps for the production of monk fruit extract include harvesting, extraction, processing, purification, concentration, purification, clarification, drying, and powdering. Monk fruit extract is commonly used as a sugar substitute and alternative sweetener in various products, including beverages, baked goods, desserts, sauces, and other processed food items. It provides a sweet taste without the added calories and carbohydrates found in sugar, making it an attractive option for people looking to reduce their sugar intake or manage conditions like diabetes and obesity. The mogrosides in monk fruit are also said to have antioxidant properties, including anti-inflammatory, anti-carcinogenic, and anti-inflammatory effects. Additionally, monk fruit extract is generally recognized as safe by regulatory bodies such as the U.S. Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA). It is considered a safe alternative to artificial sweeteners and has no known side effects when consumed in moderate amounts. However, more research and trials are also needed to promote its use in various other sections of society.

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