***Minireview Article***

**NATURAL SWEETENERS- HEALTH BENEFITS AND PROCESSING COMPATIBILITY**

**Abstract**

Natural sweeteners of plant origin are favored over synthetic alternatives for their health benefits, as they are generally low caloric, non-toxic and can be incredibly sweet - up to 10,000 times sweeter than sugar. These non-saccharide sweeteners, like Steviol glycosides in *Stevia rebaudiana*, mongrosides in *Siraitia grosvenorri* (monk fruit) or glycyrrhizin in *Glycyrrhiza glabra* (licorice root) serve as a beneficial sugar substitute, particularly for diabetic patients. Derived from various plants parts like leaves, fruits, roots etc. These sweeteners not only enhance taste but also offer pharmaceutical benefit. Common and Scientific names of these sweeteners along with their properties, chemical structure, pharmaceutical uses have been presented in this paper.

**Key words**: Natural sweetening agents, Saccharide sweeteners, non-saccharide sweeteners.

**Introduction**

Sucrose is the inseparable part of the human diet. The sweet taste offered by sugars is one of the unique features. The sugar besides providing taste has several other advantages such as preservation, texture, flavour enhancement, thickening, browning etc. in processing of food. The human body requires sucrose for energy production, hydration in body when combined with water and electrolytes, mood uplifting purposes. The sucrose is composed of equal proportion of glucose and fructose. Thus, when metabolized in body, it provides glucose to the brain and energy to the cells. The consumption of sugar is important in diet but in moderate quantity. The World Health Organization (WHO) recommends reducing free sugar intake to less than 5% of total daily energy intake.

The slow and steady shift in reduced sugar consumption paradigm in developed countries is seen due to the rising issues of non-communicable diseases such as diabetes, cardiovascular diseases, obesity and dental caries. The consumer is mindful about the reduced sugar and calorie intake. The effect of sugar replacement has remarkable variations in the taste, texture, colour, and flavour profile of food. The scientist world over are struggling to maintain a good balance between the sensory profile and reduction in calorie intake. In this regard, number of options in the natural and synthetic categories are being studied to provide a wholesome sugar replica experience with non-caloric benefits. The consumer consciousness and preference for the naturally originated sugar replacers is more as the word “natural” coils around the safety and non-synthetic origin which is close to nature. This is one of the main reasons for the review to deep dive into the natural sweeteners and their effect on processing parameters. The natural sweeteners serve dual function, one is providing sweetness and other is good source of bioactive compounds that offers additional health benefits such as antioxidants/ anti-inflammatory/ immune boosting etc.

****

Fig 1: Plant parts as sources of natural sweeteners

**Sweeteners from plant origin**

1. **Steviol Glycosides**

Stevia is considered to be one of the safest natural sweeteners and can replace sucrose in various food and beverage formulations. The sweet compounds, Steviosides, are extracted from the leaves of *Stevia rebaudiana*, a small perennial herb native to Paraguay and South Brazil, now widely cultivated in Japan, Southeast Asia and the USA. Stevioside, the primary sweet compound in Stevia, is 200-300 times sweeter than sucrose and makes up 5-15% of the dried leaves. However, it can have a slightly bitter after taste (Samuel et al., 2018). This issue is addressed by blending Steviosides with other substances or converting it to rebaudioside A (major steviol glycosides found in *Stevia rebaudiana*) which is naturally present in smaller amounts (3-4%) in the leaves and is 1.2 to 1.6 times sweeter than Stevioside and lacks the unpleasant after taste, making it more suitable for use as a sweetener (Kalakoti, 2011).

**1.1 Chemical structure of Steviol glycosides**

Steviol glycosides are diterpene glycosides primarily found in *Stevia rebaudiana*. Their chemical structure consists of a steviol backbone (ent-kaurene diterpene) esterified with varying sugar moieties, such as glucose, rhamnose, or xylose. The core structure is 13-hydroxy-16-kaurenoic acid, with glycosidic linkages at C13 and C19 positions. These glycosides, including stevioside and rebaudiosides, exhibit sweetness due to their unique spatial arrangements and interactions with human taste receptors. Out of 150-300 species in the Stevia genus, only 18 have sweetening properties, with Stevia rebaudiana being the sweetest. Its leaves naturally contain eight steviol glycosides, including dulcoside A, rebaudiosides A–E, steviolbioside, and stevioside. The total glycoside content ranges from 4% to 20%, depending on the plants genotype and growing conditions. Among these, the main sweeteners are stevioside and rebaudioside A (Tavarini, Angelini, 2013).

The yield of steviol glycosides from *Stevia rabaudiana* leaves varies based on cultivar, cultivation conditions, and extraction methods, typically ranging between 4% and 20% of dry leaf weight. High-performance liquid chromatography (HPLC) analysis reveals stevioside and rebaudioside A as dominant glycosides, with their proportions influencing the overall yield and sweetness intensity (Giahi et.al, 2016).

**1.2 Health benefits of Steviol Glycosides**

**Antidiabetic–** Diabetes affects millions worldwide, with stevia glycosides like stevioside showing promise in reducing blood glucose and insulin resistance. Stevioside stimulates insulin secretion, enhances glucose uptake, and modulates the PI3K/Akt pathway (a key intracellular signalling pathway that regulates glucose metabolism, cell growth, and survival). Rebaudioside also enhances the insulin production, acting selectively in diabetic conditions without affecting normal glucose levels.

**Anti-inflammatory–** Steviosides reduce inflammation by inhibiting NF-κB and proinflammatory cytokines like TNF-α.. It also enhances immune responses and tissue recovery, acting through TNFR-1 and TLR- 4 modulation. Stevioside and steviol show promise for treating inflammation and muscle recovery (Soni, 2020).

**Anticancer–** Stevioside and steviol exhibit anticancer potential by including apoptosis, inhibiting DNA synthesis, and targeting cancer pathway. They show efficacy against colon, breast, and gastrointestinal cancers, with selective toxicity towards cancer cells, suggesting their potential in chemotherapy development (Toyoda, 1996).

**1.3 Effects of Steviol glycosides on food product quality**

Sweetness profile and sensory impact- Steviol glycosides with sweetness 200-400 times that of sucrose, may introduce bitter or metallic aftertastes, necessitating the use of masking agents or sweetener blends. They can alter flavor perception, particularly in beverages and dairy products (Orellana-Paucar, 2023).

Texture and Mouthfeel- Minimal bulk contribution affects texture in baked goods, frozen dessert, confectionary products. Additives like maltodextrins or fibers are required to restore texture. It leads to reduced viscosity particularly in liquid formulations (Karp et.al, 2016)

Nutritional Impact- Steviol glycoside is non-caloric, enabling the development of zero-calorie food products without affecting glycemic response. This makes them beneficial for individuals managing weight or diabetes. Steviol glycosides are not metabolized by the body, which may result in reduced impact on gut health compared to some other sugar alcohols (Stramarkou et.al, 2022).

Stability and shelf life- Steviol glycosides are highly stable under high-temperature conditions, making them suitable for baked and processed foods. They are stable across wide range of pH, making them ideal for acidic foods like fruit-based products and carbonated beverages. (Karp et.al, 2016).

Table 1 provides an overview of the processing effects of selected natural sweeteners, highlighting their stability under heat, pH conditions, and interactions with other food ingredients, which influence their suitability in different food formulations.

Table 1 : Processing Effects of Selected Natural Sweeteners

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Natural Sweetener** | **Stability in Heat Processing** | **pH Sensitivity** | **Interaction with Other Ingredients** | **Shelf-Life Impact** | **References** |
|  |  |  |  |  |  |
| **Steviol Glycosides** | Stable up to 200°C; minimal degradation at typical food processing temperatures. | Exceptionally stable across pH 2–10; minimal degradation in acidic conditions. | Does not interact with other food components; no browning reactions. | High stability; minimal impact on product shelf life. | González et al., 2014; Libik-Konieczny et al., 2021.; Prakash et al., 2012 |
|  |  |  |  |  |  |
| **Glycyrrhizin** | Moderate heat stability; degradation observed above 80°C over extended periods. | Stable across a wide pH range; slight instability in highly acidic conditions (pH <4). | Can stabilize emulsions; potential interactions with proteins and lipids. | Natural preservative properties may enhance shelf life. | Seki et al., 2018 |
|  |  |  |  |  |  |
| **Mogrosides (Monk Fruit Extract)** | High heat stability; retains sweetness during baking and pasteurization. | Stable across a broad pH range; suitable for various food and beverage applications. | Synergistic sweetness when combined with other sweeteners; minimal interaction with food matrices. | Antioxidant properties may contribute to extended shelf life. | Seki et al., 2018; Younes et al., 2019 |
|  |  |  |  |  |  |
| **Cinnamon (Cinnamaldehyde)** | Volatile compound; significant loss of flavour and efficacy at temperatures above 100°C. | Degradation observed in acidic conditions (pH <4); optimal stability at neutral pH. | Interacts with proteins and lipids; possesses antimicrobial properties beneficial for preservation. | Enhances shelf life due to antifungal and antibacterial activities. | Gharibzahedi, 2018; Gao et al., 2021 |
|  |  |  |  |  |  |
| **Agave Syrup** | Stable under moderate heat; caramelization occurs at high temperatures, affecting flavour and colour. | Stable in pH range 4–7; degradation may occur in highly acidic or alkaline conditions. | High fructose content may lead to increased browning reactions; interacts with other sugars and acids. | Hygroscopic nature can affect moisture content, potentially influencing shelf life. |  Maldonado-Guevara et al., 2018; Saraiva et.al, 2022 |
|  |  |  |  |  |  |
| **Thaumatin** | Heat-sensitive; denaturation occurs at temperatures above 80°C. | Stable between pH 3–8; instability in highly acidic or alkaline environments. | Enhances flavour profiles; potential interactions with other sweeteners and flavour compounds. | Used in low concentrations; minimal impact on overall product shelf life. | -Joseph et al., 2022; Kaneko & Kitabatake, 2001 |

1. **Glycyrrhizin**

Glycyrrhizin is a pentacyclic triterpenoid saponin glycoside derived from the roots and stolons of *Glycyrrhiza glabra* (liquorice) and related species such as G.*foetida* and G.*inflata*. Glycyrrhizin exists as potassium and calcium salts of glycyrrhizic acid and constitutes 6-14% of liquorice. It is known for its intense sweetness (50-100 times sweeter than sucrose) (Hongxun Hao, 2005), it is widely used as a natural sweetener and flavoring agent in food and pharmaceutical formulations. Ammoniated glycyrrhizin is particularly effective in masking the bitter taste of quinine (Kinghorn, 1987).

**2.1 Chemical structure of Glycyrrhizin:**

Glycyrrhizin is a triterpene glycoside, also known as glycyrrhizic acid. It is a tribasic saponin composed of a triterpenoid aglycone, glycyrrhetic acid joined to a disaccharide of glucuronic acid. Glycyrrhizin is extracted from the roots of the liquorice plant, *Glycyrrhiza glabra* L. where it occurs naturally at levels of 2-15% of the dry matter as a mixture of potassium and calcium salts (Hartung, 1979). It is often converted to the ammonium form on extraction but is also added as a liquid, paste or spray-dried powder extract(Asl & Hosseinzadeh, 2008).

**2.2 Health benefits of Glycyrrhizin:**

Liver protection- Liquorice is rich in glycyrrhizin, helps protect the liver from toxins, drugs, alcohol and diseases like hepatitis (Kitagawa, 2002). Glycyrrhizin is widely used in traditional medicine and modern treatments in Japan and China to reduce liver inflammation and stabilize cells. Its metabolite, glycyrrhetinic acid (GA), has anti-inflammatory and anti-apoptotic properties, aiding liver repair and reducing fibrosis. Liquorice and its compounds show great potential as treatments for liver diseases, supporting detoxification and regeneration (Kokotou el.al, 2012)

Antimicrobial activity of Licorice- Antimicrobial resistance has led to a growing interest in exploring plant-based alternatives for combating microbial infections. Liquorice (*Glycyrrhiza glabra*) is a promising candidate due to its rich composition of bioactive compounds such as saponins, flavonoids, and glycosides, which have demonstrated significant antimicrobial properties. These compounds act against a range of microorganisms by disrupting cell membranes, inhibiting bacterial adhesion, and interfering with vital enzymatic pathways. Studies suggest liquorice extracts can effectively combat both Gram-positive and Gram-negative bacteria, as well as certain fungi. Its natural origin, coupled with its antimicrobial potential, positions liquorice as a valuable alternative to synthetic antimicrobial agents (Kumar et.al, 2015)

Studies on licorice extracts shows:

Leaves- Ethanolic extracts effectively inhibit Candida albicans and Gram-positive bacteria, suggesting potential as an alternative antimicrobial agent (Irani et.al, 2010)

Roots- Methanolic extracts of liquorice root demonstrates stronger activity against gram-positive bacteria and *Candida* species than gram-negative bacteria. The chemical composition and efficacy of these extracts are influenced by environmental factors (Gupta et al., 2008)

Prevention of dental caries - Dental caries is a widespread health issue caused by acid-producing bacteria like *Streptococcus mutans*, leading to tooth decay and enamel demineralization. Plaque buildup, high sugar intake and inadequate fluoride exposure are key risk factors (Valenzuela et.al, 2021)

**2.3 Effects of Glycyrrhizin on food product quality:**

Sweetness Profile and Flavor- Glycyrrhizin 50-100 times sweeter than sucrose Table 2 summarizes the primary sweetening compounds of selected natural sweeteners, their chemical structures, relative sweetness, and caloric content, providing a comparative understanding of their functional properties in food formulations. However, it has a distinct licorice-like flavor that may not suits all products. It can impart a lingering bitter or metallic aftertaste, which may require masking agents with other sweeteners (Venkata et.al, 2002).

Thermal Stability and Shelf life- Glycyrrhizin remains stable under moderate heat, making it suitable for processed foods. However, excessive heating slightly alters its flavor. It is stable across a wide range of pH, ideal for acidic beverages and fruit-based products. Its antimicrobial properties can enhance product shelf life by inhibiting microbial growth. (Kinghorn A. , 1987).

Table 2 : Chemical Composition & Sweetness Intensity of Natural Sweeteners

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Natural Sweetener** | **Primary Sweet Compound** | **Chemical Structure** | **Relative Sweetness (vs. Sucrose)** | **Caloric Content** | **References** |
| **Steviol Glycosides** | Stevioside, Rebaudioside A | Diterpene glycosides (stevioside, rebaudioside A-E, dulcoside A, steviolbioside). | 200-400 times sweeter | 0 kcal/g | Tavarini & Angelini, 2013; González et al., 2014; Prakash et al., 2012 |
| **Glycyrrhizin** | Glycyrrhizic Acid | Triterpene glycoside (glycyrrhizic acid) with a glycyrrhetic acid aglycone. | 50-100 times sweeter | 0 kcal/g | Kinghorn, 1987; Asl & Hosseinzadeh, 2008; Kokotou et al., 2012 |
| **Mogrosides** | Mogroside V | Triterpene glycosides (mogroside V is the primary sweetener). | 150-250 times sweeter | 0 kcal/g | Świąder et al., 2019; Guo et al., 2024; Pandey & Chauhan, 2019 |
| **Cinnamaldehyde** | Cinnamaldehyde | β-carbon formyl group with a styrene backbone (trans-cinnamaldehyde) | Not a sweetener (used for flavor and antimicrobial properties) | 4 kcal/g | Sheikh Shreaz et al., 2016; Zhu et al., 2017; Gao et al., 2021 |
| **Agave Syrup** | Fructans, Inulin | High fructose content (70-90%) with trace amounts of fructo-oligosaccharides (FOS). | 1.5 times sweeter | 3 kcal/g | Saraiva et al., 2022; Ozuna & Franco-Robles, 2022; Mejía-Barajas et al., 2018 |
| **Thaumatin** | Thaumatin I, II | Protein with 207 amino acid residues (thaumatin I and II). | 2000-3000 times sweeter (on a molar basis) | 4 kcal/g | Joseph et al., 2022; Kaneko & Kitabatake, 2001; Świąder et al., 2019 |

1. **Mogrosides:**

Mogrosides are natural sweet compounds found in the fruit of *Siraitia grosvenorri* commonly known as monk fruit. This fruit originates from Southern China, where it has been used in traditional medicine and as a sweetener for centuries. Monk fruit has been valued not only for its sweetening properties but also for its sweetening properties but also for its medicinal benefits. Mogrosides are a group of triterpene glycosides, with mogroside 5 being most abundant and sweetest component, providing sweetness level 150-250 times than that of sugar but without calories. It is non-caloric with minimal impact on blood glucose. The antioxidant and anti-inflammatory benefits, contributes to immune health ( Świa̧der et.al, 2019).

* 1. **Chemical structure-**

Mogroside V is a triterpene glycoside and the primary sweetener in monk fruit (*Siraitia grosvenorii*), about 200-300 times sweeter than sucrose(Harshita K, 2023). Its structure consists of a cucurbitane aglycone (mogrol) attached to five glucose units. Calorie-free and heat-stable, it is ideal for low-calorie foods. Beyond sweetness, it offers antioxidant, anti-inflammatory and anti-diabetic benefits (Luo et al., 2020). MogrosideV, comprising 1-2% of dried monk fruit, is prized for its clean taste and functional health properties.

**3.2 Health benefits of Mogrosides:**

Antidiabetic and Antihyperglycemic properties- Monk fruit extract (MFE) improves diabetes-related markers. MFE-sweetened symbiotic yogurt enhanced liver lipid biomarkers, phospholipids and FAHFA profiles in type 2 diabetic rats, regulating fatty acid biosynthesis, bile secretion and metabolism. In Goto-Kakizaki rats, S.grosvenorri extract improved insulin response, pancreatic insulin levels, kidney function, and antioxidative properties in liver and plasma (Suzuki et.al, 2020) Studies confirm that monk fruit extract and mogrosides help regulate blood glucose and show antidiabetic potential in vitro and in vivo.

Anticarcinogenic Activity of Mogroside IV- Mogroside IV, a sweetener from monk fruit, demonstrated anticancer effects against colorectal and throat cancer in vitro and in vivo (Pandey, Chauhan, 2020). It inhibited HT29 and HEP-2 cancer cell proliferation by inducing apoptosis through upregulation of p53 and downregulation of p-ERK1/2 and MMP-9. Its dual role as a natural sweetener and anticancer agent makes it a promising dietary supplement with no side effects.

Anti-obesity Properties- Compared to the effects of S.grosvenorri extract (SG) and aspartame (ASM) on high-fat diet (HFD)- induced obese mice. SG-fed mice showed significantly lower body weight gain by week 10 compared to ASM and HFD-fed groups. At week 18, SG treatment resulted in lower weight gain (13.94±1.11) than ASM (18.84±3.21, P<0.05). Food intake was similar across groups, but ASM-fed mice had higher feed efficiency ratios (FER), suggesting more energy storage. These results highlight the potential of SG extract in managing obesity through reduced energy storage. (Wang et.al, 2025)

1. **Cinnamon: Cinnamaldehyde**

Cinnamon, derived from the inner bark of Cinnamomum species, notably C. cassia and C. verum, contains trans-cinnamaldehyde, a key antimicrobial compound. It effectively inhibits bacteria, molds, and yeasts and is GRAS-certified for food use by the FDA . Historically valued for its fragrance and preservation properties, trans-cinnamaldehyde is now used in antimicrobial food films and as a fungicide. Despite its broad-spectrum efficacy, its low water solubility, sensitivity to light and air, and enzymatic degradation in vivo limit its applications. Additionally, its allergenic properties restrict its use in cosmetics and foods. These challenges necessitate the development of cinnamaldehyde derivatives with improved stability, reduced toxicity, and enhanced antibacterial activity for safe and effective antimicrobial use. (Sheikh Shreaz , et.al, 2016)

* 1. **Chemical structure-**

Cinnamaldehyde is a phenylpropanoid compound characterized by a **substituted styrene structure** with a **β-carbon formyl group** (-CHO). It is the primary bioactive component of cinnamon oil and contributes to its characteristic aroma and flavor. The presence of the **α,β-unsaturated aldehyde** moiety makes cinnamaldehyde chemically reactive, allowing it to undergo oxidation, reduction, and condensation reactions. Its molecular formula is **C₉H₈O**, and it exists in the **trans (E)-configuration**, which is the most stable and naturally occurring form. The conjugated double bond system in cinnamaldehyde enhances its stability and reactivity, playing a crucial role in its antimicrobial, antioxidant, and bioactive properties.

* 1. **Health benefits of Cinnamaldehyde:**

Antidiabetic properties- Recent studies suggests its potential in managing diabetes by modulating glucose and lipid metabolism. This review explores its glucolipid-lowering effects, pharmacokinetics, and safety based on multiple scientific databases. Cinnamaldehyde enhances glucose uptake, insulin sensitivity, glycogen synthesis, and pancreatic islet function while mitigating diabetic complications. Its mechanisms involve PPARs (Peroxisome Proliferator-Activated Receptors) , AMPK (AMP-Activated Protein Kinase), PI3k/IRS-1 (Phosphoinositide 3-Kinase / Insulin Receptor Substrate-1), RBP4-GLUT4 (Retinol Binding Protein 4 - Glucose Transporter 4), ERK/JNK/p38MAPK (Mitogen-Activated Protein Kinases), TRPA1-ghrelin, and Nrf2 (Nuclear Factor Erythroid 2–Related Factor 2) pathways, along with modulation of PTP1B (Protein Tyrosine Phosphatase 1B) and α-amylase activities. It metabolizes into cinnamyl alcohol, methyl cinnamate, and cinnamic acid in vivo. Despite its promising effects in diabetic animal models, potential toxicity raises safety concerns. While cinnamaldehyde presents a novel approach to diabetes management, further clinical trials are needed to confirm its efficacy and safety (Ruyuan Zhu, et.al, 2017).

Antimicrobial activity- TCA exhibits potent antimicrobial activity, inhibiting bacteria, molds, and yeasts while suppressing microbial toxin production. Its mechanism of action involves membrane disruption, leading to energy metabolism inhibition and ATP depletion. (Gill et al., 2004) suggest that TCA alters proton motive forces, causing ion leakage without ATP loss. (Helander et al., 1998) report changes in membrane fatty acids composition, enhancing TCA incorporation and compromising cell integrity, resulting in leakage of ions, DNA, and RNA. (Amalaradjou et al., 2011) associate TCA’s antibacterial effect on *Cronobacter sakazakii* with metabolic disruptions, impairing oxidative stress defenses and reducing virulence. Additionally, TCA induces reactive oxygen species (ROS) overload, leading to oxidative stress, mitochondrial dysfunction, and apoptosis via cytochrome c release and metacaspase activation. (Qu et al., 2019).

**5. Agave Syrup**

Agave syrup, derived from the sap of the agave plant, has gained popularity as a natural and vegan sweetener, primarily Agave tequilana and Agave americana. Agave syrup is not merely a sweetener; it also provides certain nutritional benefits (Saraiva et al., 2022). Agave syrup can be used in various culinary applications such as baked goods, sauces, and beverages. Agave syrup is widely being used as a replacement for sugar, honey, or corn syrup recipes (Ozuna et al., 2022). Agave Syrup has popularly gained interest in beverage industry particularly in the products which are marked as organic or health conscious. Agave syrup contains high fructose content around 70-90%. high concentration of fructose contributes to its exceptional sweetness, making it approximately 1.5 times sweeter than traditional table sugar (Ozuna et al., 2022).

**5.1 Chemical Structure of Agave Syrup:**

Agave syrup is composed of various sugars. Main component of sugar present in Agave syrup is Fructose followed by Glucose. High fructose content is responsible for the sweetness of Agave Syrup. It also contains trace amounts of fructo-oligosaccharides (FOS) which are important prebiotics important for health (Mejia-Barajas et al, 2018).

**5.2 Health Benefits of Agave Syrup:**

Lower Glycemic Index - Agave syrup's high fructose content contributes to its lower GI, which ranges between 15 to 30, making it a preferred sweetener for individuals managing blood sugar levels, such as those with diabetes (Saraiva et al., 2022).

Vitamins and Minerals - Agave syrup is a source of essential B vitamins, such as riboflavin (B2), pyridoxine (B6), and folate (B9). The presence of antioxidants in agave syrup helps combat oxidative stress, potentially lowering the risk of chronic diseases (Willems et al., 2012).

Prebiotic Effects - Agave syrup contains fructo-oligosaccharides (FOS) constituents like FOS can enhance gut microbiota diversity, which may lead to improved digestive health and better immune function (Saraiva et al., 2022).

**5.3 Effects of Processing on Agave Syrup:**

Chemical composition changes - Agave syrup is primarily composed of fructose (approximately 80%) and glucose, thermal treatment can change the concentrations of these sugars treatments often increasing sucrose levels while maintaining fructose and glucose concentrations largely unchanged (Márquez et al., 2015)

Nutritional Quality - Techniques such as thermal hydrolysis and vacuum evaporation are common in syrup production these methods can lead to the degradation of certain nutrients, such as vitamins, while also enhancing the syrup's sweetness and overall flavor profile. High fructose syrups may present improved sweetness while potentially sacrificing some nutritional benefits due to processing. (Carrascosa et al., 2022)

Viscosity Changes: Agave syrup's viscosity is an important attribute for its application in food products. Processing techniques, particularly heat treatment, can modify syrup viscosity, affecting its suitability for various uses. Heat can lead to the breakdown of some polysaccharides, resulting in a thinner product that may or may not meet commercial expectations for thickness and functionality in food applications. (Ozuna et al.,2022)

1. **Thaumatin –**

Thaumatin belongs to the family Marantaceae. It is naturally derived from the fruit arils of a tropically grown plant called *Thaumatococcus daniellii* (Benth) (Kant, 2005). The intense sweetness of thaumatin was first discovered by British surgeon W.F. Daniell in 1855 while studying the fruit of *Thaumatococcus daniellii*. It elicits a sweetness 2000-3000 times higher than that of sucrose on a molar basis, even at a low concentration of 50 nM. It is a caloric sweetener; however, it has a negligible impact at the level of concentration used within applications. It has a relative molecular mass of 22 kDa and consists of a single-chain of 207 amino acid residues (van der Wel & Loeve, 1972). Considering the health aspects related to thaumatin, it does not instigate any tooth decay and can be suitable for the diabetic, unlike artificial sweeteners (Kinghorn et al., 1998). several studies involving the safety aspects of thaumatin indicate that the sweetener does not cause any allergenicity or toxicity. It is mostly utilized as a flavour enhancer within a limit of 0.5 mg/L and 5 mg/kg respectively (Mortensen, 2006; Joseph, et al., 2019). There are at least five intensely sweet forms of thaumatin, with thaumatin I and thaumatin II being the most common, followed by thaumatin a, thaumatin b, and thaumatinc. The sweetness produced by Thaumatin lingers on tongue for a long duration of time. (Świąder, et al.,2019). Thaumatin is considered one of the sweetest and safest sweeteners. There is no specified Acceptable Daily Intake for it due to a lack of toxicity and ease of digestion.

**6.1 Chemical structure of Thaumatin:**

Thaumatin is a sweet-tasting protein derived from *Thaumatococcus daniellii*, a plant native to West Africa. It has a molecular formula of C19H29N3O3S and a molecular weight of 379.5 g/mol. Thaumatin is approximately 750–1,600 times sweeter than sucrose on a weight basis and 30,000–100,000 times sweeter on a molar basis. However, its sweetness is **thermolabile**, meaning it decreases upon heating, which limits its use in heat-processed foods (Kaneko & Kitabatake, 2001). There are two major isoforms of thaumatin, thaumatin I and thaumatin II, both are rich in hydrophilic amino acids and possessing significant structural variations. Thaumatin I comprices 207 amino acid residue while there are 206 amino acid residue linked together by polypeptide chain in thaumatin II. The difference in a single amino acid contributes to variations in sweetness intensity, with thaumatin I being sweeter than thaumatin II(IYENGAR et al., 1979) Structurally, thaumatin proteins have a single polypeptide chain with eight intramolecular disulfide bridges, which contribute to their stability. The unique folding of the protein plays a critical role in its intense sweetness and flavour-modifying properties. Thaumatin is widely used as a flavour enhancer in food products, particularly in sugar-free and low-calorie formulations (De Vos et al., 1985)

**6.2 Effect of processing on Thaumatin**

Thermal stability- It is considered that Thaumatin retains most of the sweetness even at a high temperature but prolonged heating can decrease the sweetness potency of Thaumatin. Prolonged heating can cause denaturation of protein (Pomon et al., 2023)

pH effect – The pH of the environment in which Thaumatin is processed plays an important role in the stability of the compound and also the sweetness potency. shows optimal stability at neutral to slightly acidic pH levels. Under extreme acidic or alkaline conditions Thaumatin can undergo conformational changes which can lead to changes in sweetening potency. The pH also effects on the solubility of Thaumatin (Younes et al., 2021)

Storage Conditions – Temperature and Humidity play an important role in the storage conditions of Thaumatin. If exposed to higher temperatures the protein can be broken down or denatured. Presence of oxygen can influence the degradation rates. Proper packaging and Storage conditions are required for the storage of Thaumatin (Joseph, et al., 2022).

**6.3 Health Benefits of Thaumatin**

Low Glycemic Index- The Glycemic Index of Thaumatin is Zero/0 which will not impact the blood glucose levels. The blood glucose spike will also will not occur. Thaumatin can be used in various food products and can be consumed without the fear of Diabetes.

Anti Inflammatory Properties- *H.* pyloriproteins induce an increased release of pro-inflammatory interleukin 17A in the test cells.

Low Calorie Sweetener – As Thaumatin is nearly 2000 times sweeter than sucrose, small quantity of Thaumatin is enough to provide the required sweetness. Quantity of Thaumatin used is less therefore calories provided in the food product are also less. It also helps in weight management (Chakraborty, 2016).

Safety- Thaumatin (E 957) is approved as a food additive within the European Union, and extensive evaluations have confirmed its safety for consumption. There is no significant health risk associated with Thaumatin even high dosage do not produce toxic effect. Thaumatin is a digestible protein. (EFSA Panel on Food Additives and Flavourings (FAF), (Younes et al., 2021).

**Conclusion**

The increasing demand for natural sweeteners as healthier alternatives to sugar and artificial sweeteners has driven significant research into their chemical composition, health benefits, and processing application. Steviol glycosides, glycyrrhizin, mogrosides, cinnamaldehyde, agave syrup, and thaumatin each offer unique sweetness profiles, metabolic effects, and functional properties, making them suitable for diverse food formulations. However, sensory challenges, thermal instability, regulatory concerns, and large-scale production limitations remain key obstacles to their widespread adoption. Future research should focus on enhancing the stability and taste profile of these compounds through enzymatic modifications, nanoencapsulation, and biotechnological advancements. In addition, long-term human studies are required to better understand their effects on gut microbiota, metabolism, and chronic disease prevention. Interdisciplinary collaborations between food scientists, biochemists, and nutritionists will be essential to optimize formulation strategies, improve consumer acceptability, and address regulatory barriers. With the growing shift toward clean-label and sustainable ingredients, natural sweeteners are poised to play a crucial role in sugar reduction strategies However, bridging the gap between scientific innovation, industrial feasibility, and consumer expectations will be essential for their successful commercialization in the food and beverage industry

# **References**

Amalaradjou, M. A. R., Narayanan, A., & Venkitanarayanan, K. (2011). Trans-cinnamaldehyde decreases attachment and invasion of uropathogenic Escherichia coli in urinary tract epithelial cells by modulating virulence gene expression. *The Journal of urology*, *185*(4), 1526-1531.

Asl, M. N., & Hosseinzadeh, H. (2008). Review of pharmacological effects of Glycyrrhiza sp. and its bioactive compounds. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, *22*(6), 709-724..

Das, A., & Chakraborty, R. (2018). An introduction to sweeteners. *Sweeteners: Pharmacology, Biotechnology, and Applications*, *1*, 1-13.

Fry, J. C. (2012, June). STEVIA-A NON-CALORIC SWEETENER OF NATURAL ORIGIN AS REPLACEMENT FOR ADDED SUGAR IN FRUIT JUICE BEVERAGES. In *X International Symposium on Vaccinium and Other Superfruits 1017* (pp. 455-460).

Bai, G. & Wen, X. & Niu, L.. (2016). Recent Developments in Amorphous Alloy Catalysts for Hydrogenation. 10.1016/B978-0-12-409547-2.11034-0.

Gao, Y., Liu, Q., Wang, Z., Zhuansun, X., Chen, J., Zhang, Z., Feng, J., & Jafari, S. M. (2021). Cinnamaldehyde nanoemulsions; physical stability, antibacterial properties/mechanisms, and biosafety. *Journal of Food Measurement and Characterization*, *15*(6), 5326–5336.

Giahi, L., Mohammadmoradi, S., Javidan, A., & Sadeghi, M. R. (2016). Nutritional modifications in male infertility: a systematic review covering 2 decades. *Nutrition reviews*, *74*(2), 118-130.

Gill, A. O., & Holley, R. A. (2004). Mechanisms of bactericidal action of cinnamaldehyde against Listeria monocytogenes and of eugenol against L. monocytogenes and Lactobacillus sakei. *Applied and environmental microbiology*, *70*(10), 5750-5755.

González, C., Tapia, M., Pérez, E., Pallet, D., & Dornier, M. (2014). Main properties of steviol glycosides and their potential in the food industry: A review. In *Fruits* (Vol. 69, Issue 2, pp. 127–141).

Gupta, V. K., Fatima, A., Faridi, U., Negi, A. S., Shanker, K., Kumar, J. K., ... & Khanuja, S. P. (2008). Antimicrobial potential of Glycyrrhiza glabra roots. *Journal of ethnopharmacology*, *116*(2), 377-380.

Guo, Y., Chen, X., Gong, P., Long, H., Wang, J., Yang, W., & Yao, W. (2024). Siraitia grosvenorii as a homologue of food and medicine: a review of biological activity, mechanisms of action, synthetic biology, and applications in future food. *Journal of Agricultural and Food Chemistry*, *72*(13), 6850-6870.

Harshita, K. (2023). Monk fruit *(Siraitia grosvenorii): A comprehensive review of its sweetness, health benefits, and applications as a natural sweetener*. The Pharma Innovation Journal, 12(6), 3007-3012

Hao, H. X., Hou, B. H., Wang, J. K., & Zhang, M. J. (2005). Solubility of erythritol in different solvents. *Journal of Chemical & Engineering Data*, *50*(4), 1454-1456.

Helander, I. M., Alakomi, H. L., Latva-Kala, K., Mattila-Sandholm, T., Pol, I., Smid, E. J., ... & von Wright, A. (1998). Characterization of the action of selected essential oil components on Gram-negative bacteria. *Journal of agricultural and food chemistry*, *46*(9), 3590-3595.

Irani, M., Sarmadi, M., Bernard, F., & Bazarnov, H. S. (2010). Leaves antimicrobial activity of Glycyrrhiza glabra L. *Iranian journal of pharmaceutical research: IJPR*, *9*(4), 425.

Joseph JA, Akkermans S, Van Impe JFM. Effects of Temperature and pH on Recombinant Thaumatin II Production by *Pichia pastoris*. Foods. 2022 May 16;11(10):1438.

Kaneko, R., & Kitabatake, N. (2001). Structure–sweetness relationship in thaumatin: importance of lysine residues. *Chemical senses*, *26*(2), 167-177.

Karp, S., Wyrwisz, J., Kurek, M., & Wierzbicka, A. (2016). Physical properties of muffins sweetened with steviol glycosides as the sucrose replacement. *Food science and biotechnology*, *25*, 1591-1596.Kinghorn. (1987).

Kinghorn, A. D. (1987). Biologically active compounds from plants with reputed medicinal and sweetening properties. *Journal of Natural Products*, *50*(6), 1009-1024.

Kitagawa, I. (2002). Licorice root. A natural sweetener and an important ingredient in Chinese medicine. *Pure and applied chemistry*, *74*(7), 1189-1198.Kokotou el.al. (2012). Food Analysis by HPLC .

Kokotou, M. G., et al. (2012). Food Analysis by HPLC. \*Journal of Agricultural and Food Chemistry\*, 60(4), 924-930.

Kumar, A. A., Narayanan, B. S., & Sandiya Ravi, S. R. (2015). Stevia the ideal sweetener: a review.

Libik-Konieczny, M., Capecka, E., Tuleja, M., & Konieczny, R. (n.d.). *Synthesis and production of steviol glycosides: recent research trends and perspectives*

Luo, Y., Gong, C., Wei, M., Chen, Y., Song, T., Wu, C., Mo, L., & Zhang, J. (2020). Evaluation of Mogroside V as a promising carrier in drug delivery: Improving the bioavailability and liver distribution of silybin. *AAPS PharmSciTech, 21*(4), 123

Maldonado-Guevara, B. I., Martín del Campo, S. T., & Cardador-Martínez, A. (2018). Production process effect on Mexican agave syrups quality: A preliminary study. *Food Res*, *7*, 50-57.

Matsui, M., Matsui, K., Kawasaki, Y., Oda, Y., Noguchi, T., Kitagawa, Y., ... & Sofuni, T. (1996). Evaluation of the genotoxicity of stevioside and steviol using six in vitro and one in vivo mutagenicity assays. *Mutagenesis*, *11*(6), 573-579.

Mejía-Barajas, J. A., Alvarez-Navarrete, M., Saavedra-Molina, A., Campos-García, J., Valenzuela-Vázquez, U., Amaya-Delgado, L., & Arellano-Plaza, M. (2018). Second-generation bioethanol production through a simultaneous saccharification-fermentation process using kluyveromyces marxianus thermotolerant yeast. In *Special Topics in Renewable Energy Systems*. IntechOpen.

Mubarak, M., Hussain, A., Jan, I., & Alam, S. (2020). Phytochemical investigations and antimicrobial activities of glycyrrhiza glabra (LINN.). *Fresenius Environ. Bull*, *29*, 251-259.

Muñiz-Márquez, D. B., Contreras, J. C., Rodríguez, R., Mussatto, S. I., Wong-Paz, J. E., Teixeira, J. A., & Aguilar, C. N. (2015). Influence of thermal effect on sugars composition of Mexican Agave syrup. *CyTA-Journal of Food*, *13*(4), 607-612.

Oikonomopoulou, V., Stramarkou, M., Plakida, A., & Krokida, M. (2022). Optimization of encapsulation of stevia glycosides through electrospraying and spray drying. *Food hydrocolloids*, *131*, 107854.

Ozuna, C., & Franco-Robles, E. (2022). Agave syrup: An alternative to conventional sweeteners? A review of its current technological applications and health effects. *Lwt*, *162*, 113434.

Pandey, A. K., & Chauhan, O. P. (2019). Monk fruit (Siraitia grosvenorii)-health aspects and food applications.

Pomon, B., Zhao, Y., Lai, A. L., Lin, T., Freed, J. H., & Abbaspourrad, A. (2023). Thermal degradation of thaumatin at low pH and its prevention using alkyl gallates. *Food hydrocolloids*, *139*, 108544.

Prakash, I., Clos, J. F., & Chaturvedula, V. S. P. (2012). Stability of rebaudioside A under acidic conditions and its degradation products. *Food Research International*, *48*(1), 65–75.

Priya, K., Gupta, V. R. M., & Srikanth, K. (2011). Natural sweeteners: A complete review. *Journal of Pharmacy Research*, *4*(7), 2034-2039.

Qu, S., Yang, K., Chen, L., Liu, M., Geng, Q., He, X., ... & Tian, J. (2019). Cinnamaldehyde, a promising natural preservative against Aspergillus flavus. Frontiers in microbiology, 10, 2895.

Samuel, P., Ayoob, K. T., Magnuson, B. A., Wölwer-Rieck, U., Jeppesen, P. B., Rogers, P. J., ... & Mathews, R. (2018). Stevia leaf to stevia sweetener: exploring its science, benefits, and future potential. *The Journal of nutrition*, *148*(7), 1186S-1205S.

Saraiva, A., Carrascosa, C., Ramos, F., Raheem, D., & Raposo, A. (2022). Agave syrup: chemical analysis and nutritional profile, applications in the food industry and health impacts. *International journal of environmental research and public health*, *19*(12), 7022.

Seki, H., Tamura, K., & Muranaka, T. (2018). Plant-derived isoprenoid sweeteners: Recent progress in biosynthetic gene discovery and perspectives on microbial production. *Bioscience, Biotechnology and Biochemistry*, *82*(6), 927–934.

Shreaz, S., Wani, W. A., Behbehani, J. M., Raja, V., Irshad, M., Karched, M., ... & Hun, L. T. (2016). Cinnamaldehyde and its derivatives, a novel class of antifungal agents. *Fitoterapia*, *112*, 116-131.

Shreaz, S., Wani, W. A., Behbehani, J. M., Raja, V., Irshad, M., Karched, M., ... & Hun, L. T. (2016). Cinnamaldehyde and its derivatives, a novel class of antifungal agents. *Fitoterapia*, *112*, 116-131.

Soni, N., Sharma, E. K., Singh, N., & Kapoor, A. (2020). Artificial intelligence in business: from research and innovation to market deployment. *Procedia Computer Science*, *167*, 2200-2210.

Świąder, K., Wegner, K., Piotrowska, A., Tan, F. J., & Sadowska, A. (2019). Plants as a source of natural high-intensity sweeteners: a review. *Journal of Applied Botany & Food Quality*, *92*.

Tavarini, S., & Angelini, L. G. (2013). Stevia rebaudiana Bertoni as a source of bioactive compounds: the effect of harvest time, experimental site and crop age on steviol glycoside content and antioxidant properties. Journal of the Science of Food and Agriculture, 93(9), 2121-2129.

Valenzuela, M. J., Waterhouse, B., Aggarwal, V. R., Bloor, K., & Doran, T. (2021). Effect of sugar-sweetened beverages on oral health: a systematic review and meta-analysis. *European journal of public health*, *31*(1), 122-129.

Van der Wel, H., & Loeve, K. (1972). Isolation and characterization of thaumatin I and II, the sweet‐tasting proteins from Thaumatococcus daniellii Benth. *European Journal of Biochemistry*, *31*(2), 221-225.

Venkata, S. D., Srisilam, K., & Veeresham, C. (2002). Natural sweetening agents from plants.

Wang, Y., Sun, K., Hu, Y., Lin, Y., Li, J., Ban, Q., & Liu, F. (2025). Gels stability by improving the hydrophobic region of casein: Effect of the mogrosides on the structure, microstructure, and antioxidant activities in vitro digestive of the casein acid-induced gel. *Food Hydrocolloids*, *163*, 111070.

Younes, M., Aquilina, G., Engel, K. H., Fowler, P., Frutos Fernandez, M. J., Fürst, P., Gürtler, R., Gundert-Remy, U., Husøy, T., Mennes, W., Moldeus, P., Oskarsson, A., Shah, R., Waalkens-Berendsen, I., Wölfle, D., Degen, G., Herman, L., Gott, D., Leblanc, J. C., … Castle, L. (2019). Safety of use of Monk fruit extract as a food additive in different food categories

Zhu, R., Liu, H., Liu, C., Wang, L., Ma, R., Chen, B., ... & Gao, S. (2017). Cinnamaldehyde in diabetes: A review of pharmacology, pharmacokinetics and safety. *Pharmacological research*, *122*, 78-89.