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Natural Sweeteners : A Complete Review

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ABSTRACT

Two types of sweeteners are available: natural sweeteners of plant origin and artificial or synthetic sweeteners. Sweetening agents either evoke sweet taste or enhance the perception of sweet taste. Natural sweetening agents are preferred over synthetic sweetening agents since they do not have any adverse impact on health. Non-saccharide natural sweetening agents are low calorific, nontoxic and super sweet (100 to 10,000 times sweeter than sugar) in nature and can overcome the problems of sucrose and synthetic sweeteners. Natural sweeteners are useful sugar substitutes for diabetic patients. The active sweet principles stored in plants can be grouped under: terpenoids, steroidal saponins, dihydroisocoumarins, dihydrochalcones, proteins, polyols, volatile oils, etc. in nature. Common and scientific names of these sweeteners along with their properties, chemical structure of sweet principles, pharmaceutical uses have been presented in this paper.

Key words: Natural sweetening agents, Saccharide sweeteners, Non-saccharide sweeteners. Terpenoids, Polyols

INTRODUCTION

Preference for sweet taste at a range of intensities is characteristic of human species. In the fetus, taste buds are developed by the 16th week of gestation, and the new born infant is able to respond favorably to sweetened solutions. Sugar is a natural sweetener that provides 4 calories per gram. It is acknowledged that excess sugar ingestion amounts to increased energy intake which, in turn, can lead to weight gain and chronic diseases associated with obesity and dental caries. Therefore, there is need for sugar substitutes, which can help reduce caloric intake, particularly in overweight individuals [1] The demand for new alternative "low calorie" sweeteners for dietetic and diabetic purposes has increased worldwide. As of mid-2002, over 100 plant-derived sweet compounds of 20 major structural types had been reported, and were isolated from more than 25 different families of green plants. Several of these highly sweet natural products are marketed as sweeteners or flavouring agents in some countries as pure compounds, compound mixtures, or refined extracts [2].

Many synthetic sweeteners, which are widely used are proved to be carcinogenic and are non-nutritive. Hence demand greatly increased for natural sweetening agents, especially for non-sacchariferous sweetening agents, because they are highly potent, useful, safe and low-calorie sugar alternatives. Recently it was found that Himalayan forests are good sources of plants containing non-saccharide sweetening agents.

Ideal properties of sweetening agents

Sweetening agents should have the following ideal properties

1. They are required to be effective when used in small concentration.
2. They must be stable at a wide range of temperature to which the formulations are likely to be exposed.
3. Prolonged use of these agents containing preparations should not produce any carcinogenic effects
4. They should have very low or non-calorific value.
5. They should be compatible with other ingredients in formulations.
6. They should not show batch to batch variations.

They should be readily available and inexpensive.

Uses of Natural Sweetening agents

a. Pharmaceutical uses

1.In pharmaceutical industries these are used in liquid, oral preparations, lozenges, pills and tablets.
2.In liquid orals sugar is used to prepare syrup base, to maintain the consistency and viscosity of the preparation and to mask the bitter taste of the drug.
3.Sugar is also employed in the coating of pills and tablets
4.Honey plays an important role in Ayurvedic system of medicine. It is used as an important vehicle for many preparations

b. Food Industry

Sweetening agents are used to prepare jams, chocolates, sweets, ice-creams, cakes, candies, juices, soft-drinks, beverages, chewing-gums and many other food items.

Classification of Natural sweetening agents

The search for sugar substitutes from natural sources has led to the discovery of several substances that possess an intensely sweet taste or taste-modifying properties. About 150 plant materials have been found to taste sweet because they contain large amounts of sugars and/or Polyols or other sweet constituents [3]. A schematic representation of the types of sweeteners and their origin is given below.

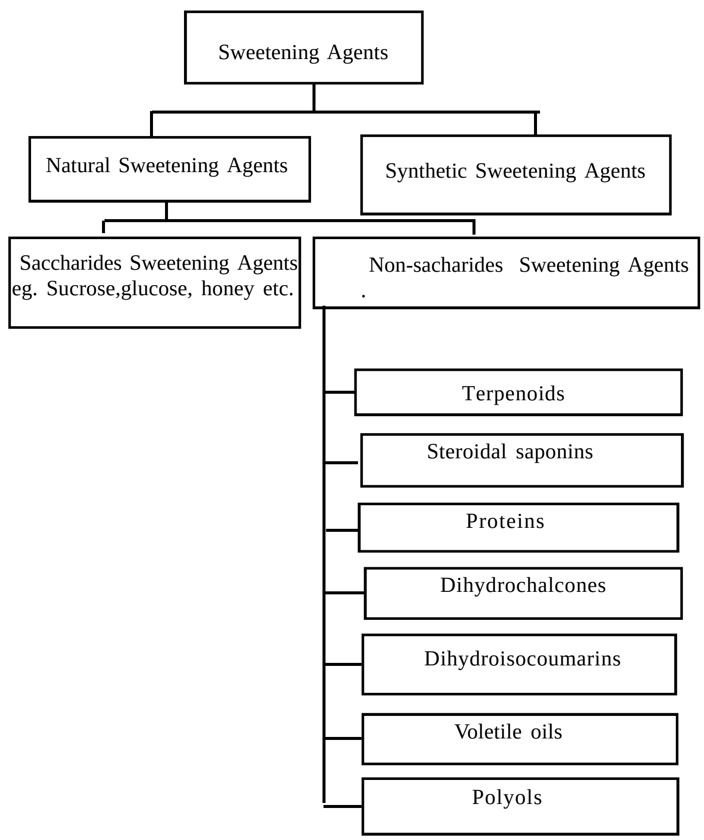

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Table 1. Various sources for different natural sweetening agents

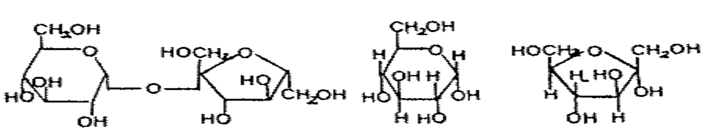
Plant	Family	Part	Sweetening Principle	Chemical Class	Times Sweeter than Sucrose
Abrus Precatoris	***Leguminosae***	***Leaves,roots***	***Abrusosides & glycyrrhizin***	***Triterpene glycosides***	***30-100***
Achras sapota	Sapotaceae	Latex and fruit	Glycyrrhizin	Triterpene glycosides	100
Baccharis gaudichaudiana		Aerial parts	Gaudichaudioside-A	Diterpene Glycosides	100
Beta vulgaris	Chenopodiaceae	Roots	Sucrose	Disaccharide	-
Cinnamomum osmophloeum	Lauraceae	Leaves	trans-Cinnamaldehyde	Aromatic aldehyde	50
Citrus aurantium	Rutaceae	Peels of the fruits	Neohesperidin dihydrochalcone	Dihydrochalcone	1000
Citrus limoni	Rutaceae	Peels of the fruits	Hesperidin dihydrochalcone	Dihydrochalcone	300
Citrus sinensis	Rutaceae	Peels of the fruits	Hesperidin dihydrochalcone	Dihydrochalcone	300
Citrus paradise	Rutaceae	Peels of the fruits	Naringin dihydrochalcone	Dihydrochalcone	1000
Cyclocarya palirus	-	Leaves	Cyclocaryoside	Steroidal saponins	250
Cynara scolymus	Asteraceae	Leaves & flowers	Cynarin	Protein	-
Dioscoreophyllum Cuminsii	Menispermaceae	Fruit pulp	Monellin	Protein	2500
Eremophila glutinosa	-	Entire plant	-	Dihydroflavonols	400
Foeniculum vulgare	Umbelliferae	Fresh aerial Parts	Trans-anethole	Phenylpropanoid	-
Glycyrrhiza glabra	Leguminosae	Roots and stolons	Glycyrrhizin	Triterpene glycosides	100
Hemsleya carnosiflora	-	Rhizomes	Carnosiflosides-V,VI	Triterpene glycosides	-
Hydrangea macrophylla	Saxifragaceae	-	Phyllodulcin	Dihydroisocoumarin	300-400
Illicium verum	Illiciceace	Dried fruits	Trans-anethole	Phenyl propanoid	-
Lippia dulcis	Verbenaceae	Herb	Hernandulcin	Sesquiterpene	1000-1500
Myrrhis odorata	Apiaceae	Fresh roots	trans-Anethole	Phenyl propanoid	-
Osmorhiza longistylis	Apiaceae	Fresh roots	trans-Anethole	Phenyl propanoid	-
Perilla frutescens	Labiatae	Leaves,seeds and flowering tops	Perillartine	Monoterpenoid	400-2000
Periandra dulcis	-	Roots	Periandrin V	Triterpene glycosides	100-200
Piper marginatum	Piperaceae	Dried leaves	trans-anethole	Phenyl propanoid	-
Polypodium glycyrrhiza	Polypodiaceae	Rhizomes	Polypodoside	Steroidal saponin glycosides	600
Polypodium vulgare	Polypodiaceae	Rhizomes	Osladin	Steroidal saponin glycosides	50-100
Pterocarya paliurus	-	Leaves and stem	Pterocaryoside A&B	Secodammaranoid saponin	50-100
Rubus suavissimus	Rosaceae	Leaves	Rubusoside & Sauvioside A	Diterpene glycosides	-
Saccharum officinarum	Poaceae	Canes	Sucrose	Disaccharide	-
Smilax glycyphylla	Liliaceae	All parts	Glycyphyllin	Dihydrochalcone glycosides	100-200
Staurogyne mergunsis	-	Leaves	Strigin	Steroidal saponin Glycosides	-
Stevia rebaudiana	Asteraceae	Leaves	Steviosides	Tricyclicditerpenoid Glycosides	200-300
Siraltia grosvenorii			Mogroside V	Triterpene glycosides	250
Symplococos paniculata	Symplocaceae	Leaves	Trilobatin	Dihydrochalcone Glycosides	400-1000
Synsepalum dulcifucum	Sapotaceae	Fruits	Miraculin	Protein	
Tessaria dodoneifolia		Aerial parts	Dihydroquercetin-3-*O*-acetate 4-(methyl ether)	Dihydroflavonol	
Thamatococcus	Marantaceae	Aril of the fruit	Thaumatin	Protein	3000

SACCHARIDE SWEETENING AGENTS

Sucrose

The sucrose, derived from Sanskrit word *Sarkara*, was being extracted from sugarcane in India, and has been identified about 6000-10,000 BC as mentioned in Rig and Atharva Vedas. It was introduced in non-Asiatic continents by Alexander the Great (c.325 BC) [4]. Sucrose is a Disaccharide sugar obtained mainly from the cane juice of *saccharum Officinarum* (Graminae) [5] and and from the roots of *Beta Vulgaris* (chenopodiaceae) [6]. Sucrose is most often prepared as a fine, white crystalline powder with a pleasing, sweet taste. It consists of two monosaccharides, α-glucose and fructose.

Sucrose melts and decomposes at 186ºC to form caramel, and when combusted produces carbon dioxide, and water [7]. Pharmaceutically sucrose is used for making syrups, lozenges. It gives viscosity and consistency to fluids. Sucrose is ubiquitous in food preparations due to both its sweetness and its functional properties; it is important in the structure of many foods including biscuits and cookies, candy canes, ice cream, and also assists in the preservation of foods. The structural and chemical formula is mentioned in Figure 1.



Sucrose α D-Glucose α D-Fructose

Figure 1. The structural and chemical formula of sucrose

Honey

Honey is a sugar secretion deposited in honeycombs by the bees Apis indica (Indian Bee), Apis mellifera, Apis dorsata (Rock Bee) and other species of Apis of family Apidae. Honey is the only sweetener obtained from animal source [8]. The typical composition of honey is: moisture, 17.7%; total sugars, 76.4%; ash, 0.18%; and total acid (as formic acid), 0.08%. Traditionally its use in food has been as sweetening agent several aspects of its use indicate that honey also functions as food preservative [9]. Honey also contains tiny amounts of several compounds thought to function as antioxidants, including chrysin, pinobanksin, Vitamin C, catalase, and pinocembrin [10]

Honey is essentially a solution of Leavulose (40-50%), dextrose (32-37%) and sucrose (0.2%) in water (13-20%). The properties of sugars vary with the floral source and on the activity of invertase normally present in honey. It is used as Demulcent, sweetening agents and good nutrient to infant and patients. It is antiseptic and applied to burns and wounds. It is a common ingredient in several cough mixtures, Cough drops and used in the preparation of creams, lotions, soft drinks and candies[11, 12].

Trehalose

Trehalose, also known as **mycose** or **tremalose**, is a natural alpha-linked disaccharide formed by an α,α-1,1-glucoside bond between two a-glucose units. First it was introduced by H.A.L. Wiggers in 1832. He discovered it in an ergot of rye. In 1859 Marcellin Berthelot isolated it from trehala manna, a substance made by weevils, and named it trehalose. Trehalose is also known as *Mycose*. It is synthesized by fungi, plants and invertebrate animals. Trehalose is mainly found in *Trehala manna*, a common constituent of fungi (Amantia muscaria)[13].

Trehalose has a solubility and osmotic profile similar to maltose. Above 80ºC tehalose becomes slightly soluble in water relative to other sugars. Compared to other sugars, trehalose is more stable to wide ranges of pH and heat, and does not easily interact with protienaceous molecules. Trehalose was shown to be homogenously distributed throughout all dietary formulations and was stable when stored for 7 days at 22ºC and for 6 weeks at 4ºC [14].

As an extension of its natural capability to protect biological structures, trehalose has been used for the preservation and protection of biologic materials. It stabilizes bioactive soluble proteins such as monoclonal antibodies and enzymes for medical use. It is used to preserve blood products for transfusion and greatly extends shelf life of platelets. It is used to preserve embryos during freeze-drying where it increases viability [15].*Maltose* ia also a disaccharide made by the action of the enzyme Maltase on starch, *Lactose* occurs in milk of all mammals and is prepared pure from cows milk.

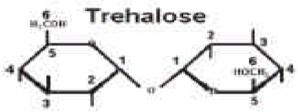
Saccharide sweetening agents have high calorific values (3600-4000 cal/gm). These saccharide sweeteners fulfill the most worldwide requirement. But regular use of sugar can increase prevalence of diseases like dental caries, cardiovascular diseases, obesity, diabetes mellitus and micronutrient deficiency. Hence demand is gradually decreasing for saccharide sweeteners.

NON-SACCHARIDE SWEETENING AGENTS

Non saccahride sweetening agents are those, which contain substances other than saccharides as sweet principles. They contain Terpenoids, proteins, dihydrochalcones, steroidal saponins, etc as sweet principles. The non-saccharide sweeteners posses some advantages over saccharide sweeteners. They are:

- Non-carcinogenic.
- Potent sweeteners (10,000 times sweeter than sucrose).
- They have very low calorific values, hence useful for diabetic persons.
- They do not have any effect on prevalence of diseases.

TERPENOIDSSteviosides



Steviosides

Stevia is the safest Natural Sweetener and it can substitute sucrose in various preparations and formulations.[16] Steviosides are obtained from leaves of small perennial herb *Stevia Rebaudiana* (compositae),a native of Paraguay, South Brazil and cultivated in Japan, southeast Asia, USA, etc. Stevioside was first isolated principle of this plant, which is 200-300 times sweeter principle than sucrose. In addition to stevioside several other sweet principles such as steviosides A and B, Steviobioside, RebaudiosideA, B, C, D, E and Dulcoside A were isolated from *Stevia rebaudiana* leaf. The major components of the leaf and their sweetness potency are shown in the table 2 [17].

Table2. Components of *Stevia rebaudiana* leaf

Component	Times sweeter than sucrose
Stevioside	250-300
Dulcoside	50-120
RebaudiosideB	300-350
RebaudiosideA	250-450
RebaudiosideC	50-150
RebaudiosideD	250-450
RebaudiosideE	150-300
Steiobioside	100-125

Stevioside is the major component (5-15% in the dried leaves) of sweet tasting leaf extract but has an unpleasant after taste, this problem is solved by blending it with other compounds or by its conversion into RebaudiosideA, which is normally present in the leaves in lower content (3-4%), does not have any after taste and has a sweetening power 1.2 to 1.6 times higher than steviosides.

Rebiana

Rebiana is the common name for highly-purity rebaudiosideA. It is sweeter and more delicious than stevioside [18]. It provides Zero calories and has a clean, sweet taste with no significant undesirable taste characteristics. It is also well suited for blending with other non-caloric or carbohydrate sweeteners. Rebaudioside is often 200-300 times sweeter than that of sucrose. As a dry powder rebiana is stable for at least 2 years at ambient temperature and under controlled humidity conditions. In solution, it is most stable between pH values 4-8 noticeably less stable below pH 2. Stability decreases with increase in temperature [19]. Typical rebiana concentrations used to sweeten various foods and beverages and pharmaceuticals are shown in the table 3. Marketed products are also available. There is no report on toxicity of Stevia glycosides. In Japan Stevia sweeteners are used in wide range, in liquid or solid foods, beverages as a substitute for conventional sugars or artificial diethetics, at present more than 10 food industries in Japan are undertaking the production of Stevia glycosides as food additives [20].

Table3.Concentrations of rebiana used in various products

Product	Range (mg/kg or mg/lit)
Carbonated soft drinks	50-600
Still beverages	50-600
Powdered soft drinks	200-200
Chewing gum	300-6000
Dairy products	150-1000
Edible gels	200-1000
Nutraceuticles	200-1000
Pharmaceuticals	50-1000

Glycyrrhizin

Glycyrrhizin is a pentacyclic triterpenoid saponins glycoside obtained from the root and stolons of the plant *Glycyrrhiza glabra* (Leguminosae) commonly known as *liquorice*. Other species of Glycyrrhiza like G.foetida, G.inflata also contain this sweet principle. Liquorice plant is native of Mediterranean region and China, cultivated in France, Italy, Spain, USSR, USA, England and Asia. In India it is found in Srinagar, Jammu, Dehradun, Baramulla, temperate Himalayan regions and south hilly districts. It is propagated through division of crown or rooted cuttings of underground stem.Glycyrrhizin is found in the form of potassium and calcium salt of glycyrrhizic acid (a trihydroxy acid, $C_{42}H_{62}O$; mp 205ºC quick decompose) in the roots and stolons of liquorice plant. Different varieties of liquorice contain varying amounts of glycyrrhizin (from 6-14%)[24]. Because of its sweet taste, glycyrrhizin is used worldwide as a natural sweetener and flavouring additive. It has been used as expectorant in cough mixtures and as flavouring agent in formulations of nauseous drugs like ammonium chloride, alkali iodides, quinine and cascara. Moreover,various pharmacological activities of glycyrrhizin, including anti-inflammatory, immunomodulatory, anti ulcer, and anti allergy activities have been reported. Glycyrrhizin also has anti viral activity against various DNA and RNA viruses, including HIV and severe acute respiratory syndrome (SARS) associated coronavirus. Therefore, a large amount of liquorice and its extracts are on the world market as sweetening agents and medicinal materials[21].Ammoniated glycyrrhizin, the fully ammoniated salt of glycyrrhizic acid, is commercially available and has been found to be 100 times sweeter than sucrose. It is one of the most efficient substances known for masking bitter taste of quinine. A Chinese Natural medicine prepared from the dried roots of various glycyrriza sp. is most frequently prescribed as an important ingredient in many preparations of traditional Chinese medicine(Kampou medicine) [45].

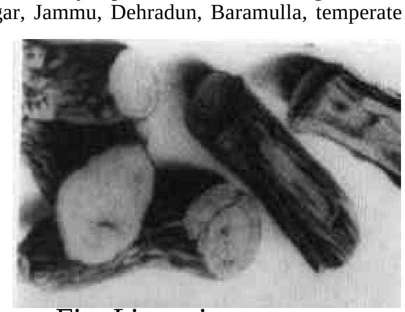


Fig. *Liquorice* root

Sapodilla (*Acharas sapota*)

Acharas sapota (sapotaceae) is another sweet plant, the latex fruits of which contain glycyrrhizin as sweet principle. Sapodilla is the medium-sized tree native to Central America, but it also grown elsewhere in the tropics. It is best known source of chicle gum (the coagulated latex) which is the basis for chewing gum manufacture [22]

Table 4.Glycyrrhizin content in various spices

Source	Glycyrrhizin content
Persian liquorice (*G.glabra* var violaceae)	7.5-13 %
Spanish liquorice (*G.glabra* var typical)	5-10%
Russian liquorice (*G.glabra* var glandulifera)	10%

Polypodium glycyrrhiza

Polypodoside A, a novel intensely sweet constituent of the rhizomes of polypodium glycyrrhiza. This compound was rated by human taste panel as exhibiting 600 times sweetness intensity of 6% w/v aqueous sucrose solution [23].

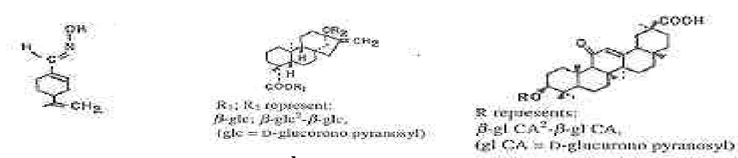
Abrusosides

These are Triterpene glycoside sweet principles present in the leaves of Indian liquorice plant *Abrus precatorius* (leguminosae). Like liquorice, roots of this plant also contain glycyrrhizin. Abrus precatorius is a climbing shrub, indigenously found throughout India. The plant is propagated through seeds. Leaves and roots of this plant contain sweet tasting Triterpene glycoside principles. Leaves taste sweeter than roots, seeds are poisonous and contain Abrin, a poisonous substance.

Leaves contain Triterpene glycosides Abrusosides, A, B, C, D and E. Roots contain the sweet oleanane type Triterpene glycoside glycyrrhizin. Hence this plant is used as substitute for liquorice. Abrusosides are non-toxic.Abrisosides A, B, C and D are found to be 30, 100, 50, 75 times sweeter than 2% w/v sucrose, respectively. Abrusoside E is marginally sweet but the monomethyl ester proved to be more potently sweet [24, 25]. Leaf extract (purified abrusosides A-D) is commercially used for sweetening foods, beverages and medicines. Leaves, roots and seed are used for medicinal purposes [26].

Table 5. The botanical name, chemical structure, potency of terpenoid sweeteners

Botanical name and family	Active sweet principle	Chemical structure	Sweetness compared to sucrose	Native place of plant species
Perrilla frutescens L (Labitae)	Monoterpenoid (Perillartine)	a	400-2000	India Sino-Japan Southeast Asia
Stevia rebaudiana Bertoni (compositae)	Diterpenoid (stevioside)	b	200-300	Paraguay and South Brazil
Glycyrrhiza glabra (Leguminosae)	Triterpenoid (Glycyrrhizin)	c	100	Mediterranean Countries & China
Abrus precatorius (Leguminosae)	Triterpenoid (Glycyrrhizin)	-do-		India
Achras sapota (Sapotaceae)	Triterpenoid (Glycyrrhizin)	-do-		S.America



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Perillartine

Perillartine is a monoterpene volatile oil obtained from the leaves, seeds and flowering tops of the plant perilla frutescens (Labitae).This plant is indigenous to India and found in Japan and Southeast Asia. Perllartine is 400-2000 times sweeter than sucrose on a unit weight basis, and 4-8 times sweeter than saccharine. The volatile oil provides flavours to sauces and confectionary as it contains the super sweet principle Perillartine [27].

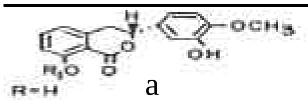
DIHYDRO ISOCOUMARINS

Phyllodulcin

Phyllodulcin is obtained from the plant *Hydrangea macrophylla* (Saxifragaceae) commonly known as amacha. This plant is Indigenous to Japan, china and is found in North and south America, an d temperate hills of India particularly Assam and in Himalayas. The sweet principle, is 300-400 times sweeter than sucrose, is shown in table 6. [4]

Table 6. Source, family, chemical structure active principles of Phyllodulcin

Botanical name And family	Active sweet principle	Chemical structure	Sweetness compared to sucrose	Native place of plant species
Hydrangea macrophylla (Saxifragaceae)	Dihydro Isocoumarin (phyllodulcin)	a	300-400	Japan, china, North & South America and India



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PROTEIN SWEETENERS

Thaumatin

The Thaumatins are a family of very sweet proteins present in the fruits of the tropical plant *Thaumatococcus danielli* (marantaceae) a bushy plant that grows in west Africa[28] All the forms of a Thaumatin are intensely sweet, and have 207 amino acids. The two predominant forms, Thaumatin I and II differ by 5 amino acids.Thaumatin elicits a very sweet taste that is rated to be 2000 to 10000 times sweeter than sucrose, depending on purity and concentration. Thaumatin I and II are soluble in water and dilute alcohol [29]. Their solubility is maximal at pH 2.7-3. The sweetening power does not disappear on heating. The sweetness of Thaumatin disappeared on heating at pH above 7 for 15 min, but the sweetness remained even after heating at 80ºC for 4 hr at pH 2. This indicated that the protein Thaumatin is more thermoresistent under acid conditions than under neutral or alkaline conditions [30] Thaumatin is effective at masking bitter notes often associated with pharmaceuticals or vitamins. Used at 20-400 ppm in pills and tablets, its long lasting effect covers strongly bitter aftertastes and leaves a pleasant feeling in the mouth. Thaumatin can also be useful for masking astringency and off-flavors [31]

Miraculin

The taste- modifying protein, miraculin has the unusual property of being able to modify a sour taste into a sweet taste [32]. *Richardella dulcifica* (sapotaceae), a shrub native to tropical West Africa, produces red berries that have an active ingredient, glycoprotein molecule with some trailing carbohydrate chains called, miraculin, a taste modifying protein that cause citric acid, ascorbic acid, and acetic acid, which are normally sour, to perceived as sweet after the berry has been held in the mouth[32] The maximum sweetness after exposure to 0.4 µm miraculin induced by 0.02M citric acid was estimated to be around 400000 times that of sucrose on a molar basis [32, 33] The taste modifying effect lasts for usually 1-2 hr. Miracle fruit is available as freeze dried granules or in tablets – this form has a longer shelf life than fresh fruit. Tablets are made from compressed freeze dried fruit which causes the texture to be clearly visible even in tablet form [34].

Curculin

Curculin isolated from *curculigo latifolia*, aplant grown in Malaysia, has an intriguing property of modifying sour taste into sweet taste. In addition to this taste modifying activity, curculin itself elicits a sweet taste [28] Curculin has a unique property to exhibit both taste modifying activities. Although curculin was originally reported to be a homodermic protein, sweet taste of this protein is actually expressed by its heterodermic isoform (also termed neoculin) composed of two homologous subunits designated as curculi1, curculin2, which share 77% identity in the amino acid sequences. The underlying mechanism for the sweet tasting and taste modifying dual capability of curculin remains largely a mystery [35].

Monellin

Monellin is present in red berries of West African plant *Dioscoreophyllum cumminsii* Diels. This protein is about 3000 times sweeter than sucrose on a weight basis. Unlike the single chain thaumatin, monellin consists of two polypeptides of 45 and 50 amino acid residues, respectively that are associated through non-covalent interactions. Monellin has been shown to lose its sweetness when heated above 50ºC under acidic pH [28].

Mabinlin

Mabilin the sweet tasting polypeptide exists in the fruits of Chinese plant *capparis masaki*. This protein is comprised of two polypeptide chains, of 33 and 72 amino acids respectively, which are tightly associated through non-covalent interactions. It is about 100 times sweeter than sucrose on a weight basis [28].

Pentadin

Fruits of the plant *penta diplandra brazzeana* Ballion, a climbing shrub found in some countries of tropical Africa(such as Gabon), contain 12-kDa sweet-tasting protein, first isolated by van der Wel et al (1989). Electrophoretic studies in the presence and absence of 2-mercaptoethanol suggested that the mature protein consists of subunits coupled by disulfide bonds. The sweetness intensity was estimated to be around 500 times that of sucrose on a weight basis.No further work has been reported towards characterization of this sweet-tasting protein [36]

Brazzein

Brazzein is also contained in the fruit of *P.brazzeana* Ballion. It was first isolated by Mind and Hellekant(1994). The molecular mass of Brazzein is 6473, and its three dimensional structure has been solved, like thaumatin, brazzein is a single chain protein (54 amino acids). Its sweetness profile remains even after incubation at 353 K for 4 hrs, probably because of its compact structure afforded by its four disulfide bridges [28]. Comparision of thaumatin, monellin, mabinlin, pentadin, brazzein, curculin and miraculin are shown in the table 7.

Table 7. Composition of protein sweeteners

Protein Sweetenes	Source	Geographic Distribution	Sweetness factor (Weight Basis)	Amino acids
Thaumatin	*Thaumatococcus danielli Benth*	West Africa	3,000	207
Monellin	*Dioscoreophyllum Cumminsii Diels*	West Africa	3,000	45(A chain) 50(B chain)
Mabinlin	*Capparis masaki*	China	100	33(A chain) 72(B chain)
Pentadin	*Pentadiplandra brazzeana*	West Africa	500	
Brazzein	*Pentadiplandra brazzeana*	West Africa	2000	54
Curculin	*Curculingo latifolia*	Malaysia	550	114
Miraculin	*Richadella dulcifica*	West Africa	-	191

DIHYDROCHALCONES

Glycyphyllin

The sweet principle glycyphyllin is present in almost all parts of the plant *smilax glycyphylla* (liliaceae). Commonly, it is known as barichob-chini. It is Indigenous to India and found in Himalayas. It is mainly propagated through Rhizomes and tuberous roots. The sweet principle is a dihydrochalcone glucoside, 100-200 times sweeter than sucrose. The extract of shoot or almost all parts provide sweetening agent [4].

Trilobatin

Trilobatin is obtained from the plants *Symplococos paniculata* (simplocaceae) commonly known as sweet leaf, sapphire berry, ludh. This plant is found in India and is being cultivated on large scale. It is 400-1000 times sweeter than sucrose. A water soluble fraction from the bark has been reported to exhibit antioxidative activity. Seeds contain oil. Leaves are used as fodder. Further studies are required on quantity and distribution of sweet principles in different parts of plant [4].

Neohesperidin Dihydrochalcone

Neohesperidin is obtained from the peels of the fruits of plant *citrus aurantium* (Rutaceae), commonly known as Seville orange.The flavonoid compound neohesperidine is itself bitter but dilute alkali extract gives a sweet compound called Neohesperidin dihydrochalcone, which is about 1000 times sweeter than sucrose and has a slow onset and persists for some time.The sweetener is relatively inert to the action of carcinogenic bacteria and is approved in Belgium for use as a sugar substitute in beverages and chewing gum [37].

Naringin Dihydrochalcone

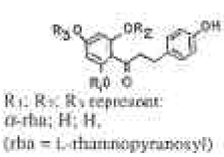
The sweet principle, Naringin is a type of dihydrochalcone. The flavonoid parent compound naringin is bitter present in the peels of fruit of the plant *Citrus paradisi* (Rutaceae) commonly known as grape fruit. However, the naringin extract in dilute alkali gives a sweet principle, naringin dihydrochalcone, which is nearly 1000 times sweeter than sucrose. The plant is indigenous to West Indies and is cultivated in India. Naringin can be commercialized and could be used to prepare neohesperidin.

Hesperitin Dihydrochalcone

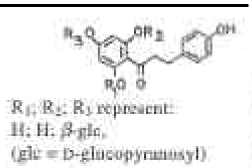
The parent compound Hesperitin is isolated from the peels of the plant *Citrus sinensis* and *citrus limoni* (Rutaceae). The reduction of hesperidin in dilute alkali yields hesperidin dihydrochalcone. Partial hydrolysis of this compound, either by acid or by dissolved or immobilized enzyme, gives rise to sweet hesperetin dihydrochalcone. This is 300 times sweeter than sucrose [37, 38].*Citrus sinensis* is commonly known as betavian, sweet orange. It is native of India and China and cultivated widely in subtropical regions as most valued commercial citrus of the world. *Citrus limoni* is commonly known as lemon and jambira. Wild stock of this plant is native of Northwest region of India. Both plants are widely cultivated in India [24] The botanical name, chemical structure, sweetness potency of dihydrochalcone sweeteners are given in the table 8.

Table 8. Different dihydrochalcone sweeteners

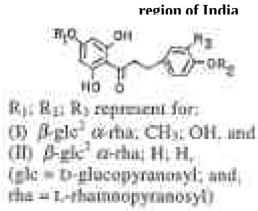
Botanical name and family	Active sweet principle	Chemical structure	Sweeteness compared to sucrose	Native place of plant species
Smilax Glycyphylla (liliaceae)	Dihydro Chalcone Glycoside (glycyphyllin)	a	100-200	Temperate hills of India
Simplococos paniculata (simplocaceae)	Dihydro Chalcone Glycoside (trilobatin)	b	400-1000	India
Citrus aurantium (Rutaceae)	Dihydro Chalcone Glycoside (Neohesperidin)	c	1000	India
Citrus paradisi (Rutaceae)	DihydroChalcone Glycoside(Narigin)	-do-	>1000	West Indies
Citrus sinensis (Rutaceae)	Hesperetin		300	India and china
Citrus limoni	-do-	-do-	-do-	North west region of India



a



b



c

Above reduced hesperidin skeleton with 4' β-D-glucoside

STEROIDAL SAPONINS

Polypodoside A

The sweet principle polypodoside A is obtained from the rhizomes of the North American plant *Polypodium glycyrrhiza* (polipodiaceae), commonly known as liquorice fern, initially, the sweet taste of the rhizomes was attributed to the presence of a sweet glycoside glycyrrhizin. Later it was found that a novel intensely sweet compound, polypodosideA, which is 600 times sweeter than 6% w/v aqueous sucrose solution. This steroidal saponin glycoside on enzymatic hydrolysis with hesperindinase yields D-glucose, L-rhamnose and aglycone polypodogenin [39].

Osladin

European polypody fern**.** *Polypodium vulgare* (polypodiaceae) rhizomes contain the glycoside Osladin as sweet principle. It is 300-3000 times sweeter than sucrose [40].

Pterocaryosides A and B

Two novel, potentially sweet 3-4 secodammaranoid saponins, pterocaryoside Aand B are isolated from the leaves and stems of Chinese tree *pterocarya paliurus.* These pterocaryosides are proved as nontoxic, safe and potent sweetening agents. Pterocaryoside A and B are 50and100 times sweeter than 2% sucrose, respectively.

Strogin

It is isolated from water extract of the leaves of *staurogyne mergunsis*. This is a new compound isolated. On the basis of spectral analysis the structure of this compound was elucidated as 3-O-ß-d-xylopyranosyl-(1or2)-ß-D-glucurono pyranosyl-3ß, 21ß, 22ß, 23, 29-pentahydroxy olean-12-ene-21-a-(2,3,4-O-triacetyl)-L-rhamnoside.

Cyclocaryoside

Three intensely sweet cyclocaryosides I, II and III are obtained from the leaves of *cyclocarya paliurus,* the structure of cyclocaryoside is elucidated as 20, 24 epoxy- dammaran-(3ß, 12ß, 20S, 24R)-12-ß-D-quinovo pyranosyl-25-hydroxy-3-O-a-L arabino furanoside. It is the main sweet principle of the plant, possessing about250 times more than the sweetness intensity of sucrose [24].

POLYOL SWEETENERS

Xylitol

Xylitol is apolyol, with a sweetening power similar to sucrose, found in fruits and vegetables. It has many advantages as a food ingredient. It does not undergo a Millard reaction, responsible for both darkening and reduction in the nutritional value of proteins. When continuously supplied in the diet, it limits the tendency to obesity, and the incorporation of xylitol in food formulations improves the colour and taste of preparations without causing undesired changes in properties during storage. A number of studies have shown the beneficial effects of xylitol as a sweetener when used alone or formulated in combination with other sugars, provides texture, colour, taste, stable for longer periods than those of products formulated with conventional sugars such as sucrose [41].With fructose, xylitol is the sugar recommended for diabetic patients. Because of its negative heat of dissolution, xylitol produces a feeling of vaporization in the oral and nasal cavities and is used as a part of the coating of confectionary or pharmaceutical products such as vitamins or expectorants, and in formulation or dietary complements such as amino-acids, vitamins, trace elements and non-reducing sugars. Used in combination with alcohols, sugars and aminoaacids, xylitol has been used as stabilizing agent for proteins during their extraction from natural membranes thus avoiding denaturation [42].

Erythritol

Erythritol is 1,2,3,4-butanetetrol.It is a white crystalline powder that is odorless, with a clean sweet taste that is similar to sucrose. It is approximately 70% as sweet as sucrose as flows easily because of its non hygroscopic character. Erythritol is a good tasting bulk sweetener that is suitable for a variety of reduced-calorie and sugar free foods. Since 1990 erythritol has been commercially produced and added to foods and beverages to provide sweetness as well as to enhance their taste and texture. Erythritol has a high digestive tolerance, is safe for people with diabetes, and does not promote tooth decay [43].

CONCLUSIONS

The desire for sweet taste is inborn. Since the ingestion of sugar increases caloric intake and can lead to obesity, a risk factor for some chronic diseases, this common sweetener has been restricted in the diet of diabetics. The availability of natural sweeteners has made it possible to offer consumers sweet taste without the calories that a diet high in sucrose implies.

In India 13 species of plants that accumulate nonsaccharides as the active sweet principle have been identified. For fast multiplication of these plants, developments of suitable techniques are required not only to save them from becoming extinct but also to enable their large scale cultivation. Furthermore, simple techniques for the extraction of these principles are required which could be adapted at small-scale level.

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