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Review

Inclusive Overview of Sweeteners Trends: Nutritional Safety and Commercialization

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ABSTRACT: Food producers are scouring for substitute sweeteners in food products because of the change of consumer discernment on the absorption of sucrose. Due to the composite mixture of characteristics surviving within sucrose in terms of its taste and textural features, recreating it within a low calorie sweetener is frequently a demanding task. The gustatory system is the primary tool for evaluating sweet flavors, most desired by all categories of age, especially children. Consumer behavioral shifts toward vegan ingredients due to various reasons for global food shortfalls and awareness campaigns have diverted global health organizations' and food industrialists' attention toward vegan sweeteners to sweeten the tongue in a more natural manner with low or zero caloric products. Furthermore, recent advances in the phytoceutical attributes of food ingredients and higher yields with green approaches have gained importance, with a low loss of nutrients in waste.

KEYWORDS: *vegan sweeteners, safety and labeling, osladin, nonthermal extraction, membrane distillation, ohmic-assisted vacuum evaporation*

1. INTRODUCTION

According to estimates from the US Centers for Disease Control and Prevention, 39% of American adults as of 2017 were obese, and that number is expected to rise to 650 million by 2050. Numerous other health risks, including diabetes, cardiovascular disease, and stroke, are linked to obesity. Dietary recommendations for American people for the years 2015 to 2020 suggest consuming no more than 10% of their daily calories from sugar in order to avoid incurring the $2 trillion expense of treating diseases linked to obesity. The daily addition of 50 g of table sugar corresponds to the recommended 10% of sugar.[1] Many organizations today recommend limiting consumption of foods with added sugar, such as beverages, dairy desserts, bakery goods, and confectionery items, in order to avoid sugar intake. The Cambridge English Dictionary defines sweetness in this context as having a flavor like to sugar. Similar definitions of sweetness can be found in The Oxford Learner's Dictionary and The American Heritage Dictionary.[2] Artificial sweeteners have previously undergone substantial research and applications in food, but they had long-term inflammatory and mutagenesis effects, particularly when combined with alcoholic sugars.[3] Therefore, vegan-based sweeteners have recently caught the attention of researchers and international industrialists as a way to avoid such health issues. Based on SWOT and Porter's Five Forces models, Expert Market Research recently released a report named "Asia Pacific Natural Sweeteners Market Report and Forecast 2022−2027" via COMTEX. The sweetener market has been divided into low and high intensity sweeteners based on intensity, whereas it is based on a variety of natural sweeteners such as stevia, maple, Manuka honey, molasses, coconut sugars, and others, depending on type. The market for vegan sweeteners was projected to grow by 2.49% compound annual growth rate (CAGR) over the forecast period, reaching USD 85.92 billion in 2020 (2021−2026). Vegan sweeteners' promotion has been currently influenced by Incorporated, Archer Daniels Midland Company, Cargill, Tate & Lyle PLC, Stevia First Corp, Ingredion Incorporated, Pure Circle, Sudzucker, AB Sugar, SteviaPac Food Innovation, and Layn Corporate, among others. The main factor causing these business operators to experience a strong purchase in these markets is high brand loyalty for companies such as Cargill, Stevia First Corp, and Tate & Lyle in well-known nations.[4]

2. VEGAN SWEETENERS

Vegan sweeteners are not made from bacteria through biotechnology, but rather from natural plant sources. Plant-based sweeteners have positive effects on metabolism, prevent weight gain and blood sugar spikes, have low glycemic index and low fructose content, and can accommodate biomolecules with nutrition and health benefits, such as vitamins, phytoceuticals, and minerals.[5] Vegans consume primarily plant-based cuisine and fully avoid animal-based foods in their diets. For immediate health concerns, someone who has

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been considering going vegan or switching from animal- to plant-based products must be prepared to deal with several frequent difficulties. Date syrup is among the best plant-based sweeteners that vegans can utilize in their sweets and meals. Despite the fact that it is not really syrup, it is made by simply blending deseeded dates with warm water.[6] In international markets, there are many different kinds of vegan sweeteners that are easily accessible in powder or syrup form. The vegan sweeteners listed in Table 1 are both commercially accessible and currently being studied.

Table 1. Vegan Sweeteners Available in the Market as Syrups and Powders or Extracts[7−9]

Powder sweeteners	Syrup sweeteners
Osladin	Manuka Honey
Monk fruit extracts	Yacon root syrup
Miracle fruit extract	Maple syrup
Stevia extract	Brown rice syrup
Thaumatin extract	Date syrup
Licorice extract	Agave nectar
Coconut sugar	Corn syrup
	Palm syrup

When sweeteners are taken inside the mouth and interact with taste buds, they induce cephalic phase activity. Sweetness is detected by the tongue after binding of sweetener with the T1R2 and T1R3 taste receptors. Sweetness stimuli trigger the production of insulin, which in turn binds with glucose or sugar molecules and controls their fate in the blood. Insulin picks up sugar molecules from digested food and transfers them into fatty tissues and muscular portions of the body. Low caloric or non-nutritive sweeteners exert good effects on the liver (enhanced antioxidant effects with increased production of hepatic anti-diabetic enzymes to reduce diabetes-induced lipid peroxidation)[10] and boost probiotics (*Lactobacillus*, *Bifidobacterium* and *Escherichia coli*) proliferation inside the intestine (Figure 1). If imbalance happens in intestinal flora, then pathogens proliferate and dominate the intestinal flora, resulting in an unhealthy gut system and enhanced inflammation and giving rise to other pathogens such as *Clostridium* and *Campylobacter*.[11]

2.1. Extracts/Powders. *2.1.1. Osladin.* Osladin is natural sweetener extracted from the root portion (rhizome) of *Polypodium vulgare* that is 500 times sweeter than tabletop sugar. *P. vulgare* is a fern, found in rocky and shady habitats in North America, Europe and Asia, where it has been in use as shepherds' snacks and famine food. Osladin in extracted form was applied for treating kidney stones, renal colic, pyelonephritis and chronic nephritis as a diuretic and expectorant medicine. In Spain, its leaves are also used for curing parasitic diseases and jaundice. The chemical composition of Osladin is consisted of glycosylated bonds at the C-3 and C-26 positions which make it a powerful sweetener of bidesmosidic steroid saponins in nature.[12,13] Its sweetness is similar to glycyrrhizin and stevioside. In 2008, the European Medicines Agency (EMA) accepted *P. vulgare* rhizome to be used for relieving constipation and as an expectorant for colds and coughs. Screening studies revealed that polypody is rich in 3-O-caffeoylquinic acid, apicatechin, catechin and shikimic acid. Various phytochemicals are found in polypody extract such as flavonoids, triterpenoid alcohols, triterpenoid hydrocarbons, phytoecdysteroids and saponin glycosides.[14] However, owing to poor solubility in water, less availability and aftertaste similar to licorice have minimized the commercial potential of Osladin.[15]

2.1.2. Monk Fruit Extract. Monk fruit (*Siraitia grosvenorii*), also known as Lo han guo or swingle fruit, is an herbaceous perennial plant, native to southern regions of China, where it is normally used as a low calorie natural sweetener. It carries 40

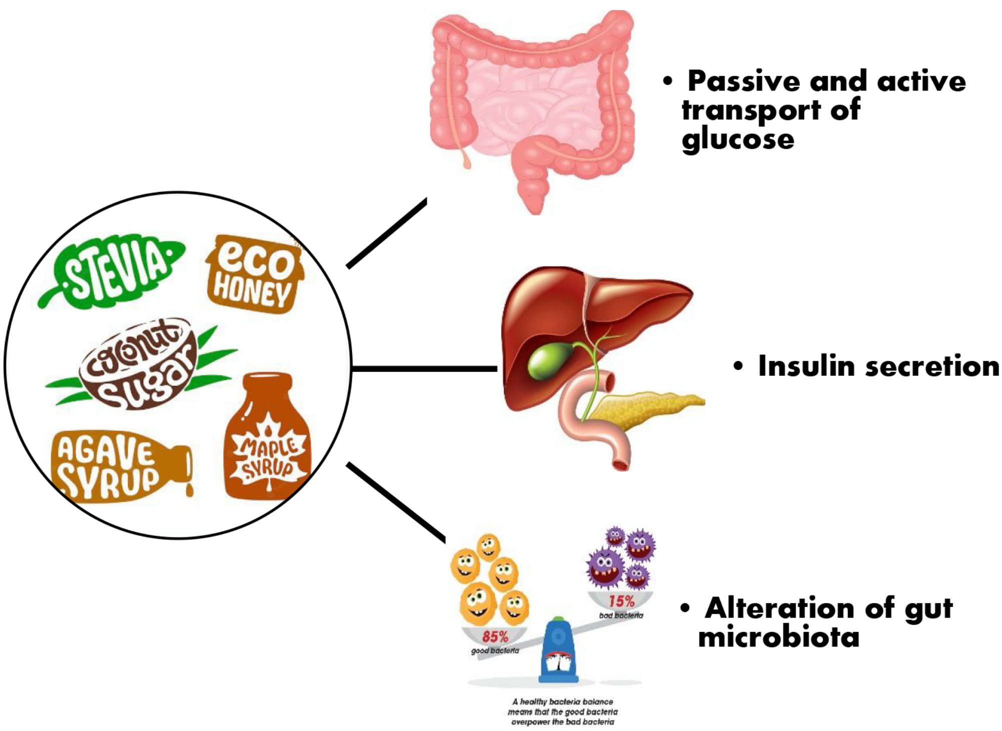

Figure 1. Potential metabolic effects involved in vegan sweeteners' digestion.

different cucurbitane-type triterpene glycosides known as mogrosides which in extract form are 250−300 times sweeter than sucrose and have been given the status of Generally Recognized as Safe (GRAS). However, its ADI (Acceptable Daily Intake) has not yet been specified by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). Despite its significant importance and worldwide demand, monk fruit has not yet been commercially cultivated outside of China due to missing clinical records for cultivation of this fruit plant.[16,17] The monetary part of the plant is the fruit, which comprises a sweet, fleshy and edible pulp, which had been used in conventional Chinese remedies for more than 300 years for cure of lung congestion, cold, cough and sore throats.[18] As international approaches promoting betterment of health and fitness, there is a massive need for herbal, excessive potency and occasional or zero-calorie sweeteners over traditional nutritional sweeteners in the food and beverage industries. However, this species are still not commonly cultivated because of the foremost reasons for constrained supply such as (1) less agronomic practices, (2) nonavailability of the best planting materials, (3) terrible adaptability to the environment, and (4) less clinical understanding.[19] Monk fruit sweetener is becoming more and more popular in beverage drinks, such as cocktails, beer, wine, liquor and coffee. It is used in popsicles, marshmallows, candy, chewing gum, chocolate, fruit jams, marmalades, spreadable creams, coffee drinks, juices, sodas, teas, smoothies, energy drinks, beer, rum, tequila, wine, cookies, cakes, bread, gelatin and cake.[17] The pharmaceutical benefits are very diverse in the case of monk fruit sweetener extract, which not only simply works as a natural sweetener but additionally exhibits anti-diabetic activity through improving blood glucose uptake. Mogrosides from *S. gosvernori* also exhibit bioactive potential against bacteria, allergy, inflammation and diabetes. Particularly, mogroside V is liable for the apoptosis and cell cycle arrest of pancreatic tumor cells[20] and is connected with free radical scavenging activity.[17] Mogrosides also persuade a hypoglycemic reaction by improving insulin secretion, impede lipid peroxidation, and reduce α-glucosidase activity.[21] Moreover, mogrosides beneficially impact blood glucose levels by enhancing postprandial insulin levels.[22] Commercially, monk fruit sweetener extract is available under the brand names of Nectress, Monk fruit in the Raw, and Purelo.[23]

2.1.3. Miracle Fruit Extract. Miracle fruit or berry (*Synsepalum dulcificum*) is normally regarded as an opportunity sweetener that changes bitter food taste into candy-like with the aid of affecting tongue taste receptors. The miracle fruit plant is native to tropical West Africa, especially Nigeria, Congo and Ghana, wherein it is used regionally to sweeten palm and different beverages. The fruit has been proposed as a treatment for flavor adjustments, experienced by some chemotherapy patients, requiring similar research in the flavoring industry. In the USA, a strike was promoted in 1970 to commercialize fruit extract low calorie or noncaloric sweetener, but it still has not been approved by the FDA or EFSA (European Foods Safety Authority).[24,25] Its sweetness is credited to the presence of glycoprotein "miraculin" that has specific binding properties with human tongue sweet receptors. Miraculin (combination of galactose, xylose, fucose, mannose and glucosamine sugars) is only 4.44% of total fruit weight but exhibits excellent flavoring, coloring and antioxidant properties. When induced by citric acid, miracle berry extract had 400,000 times sweeter than sucrose.[16] Fruit is rich in vitamin A, C, E and K, along with a reasonable quantity of essential and nonessential amino acids such as leucine, lycine, phenylalanine, isoleucine, threonine, glycine, tyrosine, serine and proline. The bright red color of fruit is representative of anthocyanins that have been proven excellent in chemo-protection and anticancer ability. Furthermore, 16 different types of phytochemicals (15.8% phenolics and 11.9% flavonoids in pulp, and 36.7% phenolics and 51.9% flavonoids in skin) are also identified in miracle fruit extract and minor elements such as Ca, Cr, Co, Zn and Fe. The methanolic extract of berry fruit has been screened and characterized for anthocyanins, phytoceuticals, bioactive compounds, luteins and tocopherols. The pharmaceutical advantages of miracle fruit include anti-diabetic, anticancer, anti-hyperuricaemic, anticonvulsant, anti-oxidant and anti-cholesterolemic properties.[26−29]

2.1.4. Stevia Extract. Stevia is a plant local to part of northeastern Paraguay, and its taste comes from natural components from the leaves, called steviol glycosides. The leaves of the stevia plant contain different types of sweetening agents, namely, diterpene glycoside, steviosides, rebaudiosides A, B, C, D and E, and dulcoside A. Among all these sweetening compounds, rebaudioside A and stevioside contribute to the sucrose-like sweetness of stevia.[30] It is also referred to as candy leaf or honey herb due to its sweetening energy, which is up to 450 times that of sugar.[31] Stevia is a "noncaloric" sweetener because it contains less than 5 g of carbohydrates. It also helps in weight control, reducing the risk of pancreatic cancer, blood pressure, and allergies. Additionally, the Food and Drug Administration (FDA) has recognized purified Steviol glycosides as GRAS (E960) for consumption and recommended an ADI of 4−4.4 mg/kg body weight. The recent trends and approaches specify that consumers have been pleased to adopt natural sucrose substitutes.[28,9] Some high purity Steviol products have been sold in the global market under the brand names of HIP gastroplex, which prospered SUGARLESSe, Truvia, PureVia and Enliten. This economic product contains intense stevia and other plant-extracted sweeteners, often used in chocolates and marshmallows.[23,32] Stevia is often touted as a safe and healthful sugar substitute that can sweeten up meals without the poor fitness effects related to sophisticated sugar. *S. rebaudiana* also provides many health benefits such as reducing the calorie intake, lowering the blood glucose level and reducing the risk of cavities.[33] The pharmaceutical benefits include anti-diabetic, anti-inflammatory, anticancer, immunomodulatory, antioxidant, anti-hyperglycemic, reno-protective and antibacterial properties.[30]

2.1.5. Thaumatin Extract. Thaumatin, a vegan sweetener desired inside the global market nowadays, is derived from the fruit arils of a tropically grown plant referred to as *Thaumatococcus daniellii*. Thaumatins are a class of intensely sweet proteins found in the arils of *T. daniellii* fruits. Their current production method through aqueous extraction and the uncertainty of harvest from tropical rainforests limit their supply while the demand has been increasing.[34] Thaumatin sweetener has been extracted and sold globally by Tate and Lyle (UK) under the brand name of Talin.[35] Thaumatins are the first sweet-tasting proteins that have been found in nature with 2000−3000 times sweetness compared to sucrose and neither allergic nor mutagenic or teratogenic properties. The barks are fastened around the nuts which produce the jelly, that upon swelling to many folds of its weight, houses the Thaumatin. The arils which contain the Thaumatin constitute 4.8% of the fruit while the remaining fleshy part and seed

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account for 72.4% and 22.8%, respectively.[36] Thaumatin is currently used as a flavor modifier in food items such as ice creams, chewing gum, dairy, pet foods, and soft drinks and to mask undesirable flavor notes in food and pharmaceutical products.[34] Thaumatin is called a flavor modifier, which means it has the capacity to mask an unwanted after-taste, which paves the way for a better tasting plant protein powder or whey protein complement. Thaumatins supply fantastic tasting protein powders with low caloric content but that are nutrient-dense and relatively digestible. This sweetener is approved as GRAS in the US and approved as E957 in the European Union. JECFA and FEEDAP (Additives and Products or Substances used in Animal Feed) have recommended a Thaumatin ADI of 1−5 mg/kg body weight of the animal. It is usually safe, but some people may experience different side effects (especially if used in high quantities), such as nausea, headache, chest pain, flushing and fluttering heartbeats. However, being proteinaceous instead of a sugar, it cannot satisfy most cravings for sugar. Therefore, its use may lead to overeating in the case of satisfying sweet cravings.[37]

Apart from Thaumatin, until now, 8 different proteins have been discovered from natural plant sources, namely, mabinlin, monellin, lysozyme, pentadin, brazzein and miraculin. However, these sweet proteins are still under research and have not been completely exploited in food, nor are they commercially available.[37] Table 2 is given to summarize the basic attributes and natural derivation sources of sweet proteins.

Table 2. Natural Vegan Sourced Sweetening Proteins and Their Basic Characteristics

Sweetening protein	Amino acids	Relative sweetness (weight basis)	Vegan sources
Miraculin	191	N/A	*Richadella dulcifica*
Pentadin	54	500−2000	*Pentadiplandra brazzeana Baillon*
Mabinlin	33 (A chain), 72 (B chain)	100	*Capparis masaikai Levi*
Brazzein	54	2000	*Pentadiplandra brazzeana Baillon*
Monellin	45 (A chain), 50 (B chain)	3000	*Discoreophyllum cumminsii Diels*
Thaumatin	207	1600−3000	*Thaumatococcus danielii*
Curculin/ Neoculin	114	500	*Curculigo latifolia*

2.1.6. Licorice Extract. Licorice (UK) or licorice (US) is the commonplace term of *Glycyrrhiza glabra*, a flowering plant of the family Fabaceae, from the base of which a sweet, aromatic flavoring may be extracted. The licorice plant is an herbaceous perennial legume local to Western Asia, North Africa, and Southern Europe.[38] Botanically, it is not closely related to anise or fennels, which are assets of similar flavoring compounds. Licorice is 150 times sweeter than sucrose with a glycemic index of 78 and is used as flavoring and sweetening agents (glycyrrhizin) in sweets and tobacco, especially in a few European and West Asian nations.[39,40] To date, roughly 400 different chemical components have been identified in licorice, counting about 300 flavonoids, including chalcones, isoflavones, flavones, flavonols, and beyond 20 triterpenoids which got extensive interest due to their structural variety and important bioactivities.[41] Licorice contributes the lowering the blood cholesterol and enhancing the memory, acts as an antidepressant, and cures lung congestion, colds, and coughs.[42] For years, *G. Glabra* has been used for medicinal purposes including indigestion, belly inflammation, cough suppression, ulcer remedies, and laxatives. Roughly 90% of the utilization of licorice is in tobacco industry. The other 10% is utilized in meals and pharmaceuticals, at 5% of usage in each sector. Licorice extract is given GRAS status with an ADI of 0.015−0.2 mg per kg of body weight. It finds its application in many chocolates and sweets, some pills, alcoholic and nonalcoholic beverages such as root beer, chewing gum, tobacco merchandise such as snuff, soft and hard candy, herbs and seasonings, plant derived protein products, mineral and vitamin supplements, and toothpastes. It is very essential to screen the quantity of licorice in different products with the purpose of saving from toxicity because of many person to person elements of variation among men and women. In sensitive people, a maximum intake of about 100 mg of licorice per day can reduce troubles. This is equivalent to 50 g of chocolate added with licorice. But most people can eat as much as 400 mg before experiencing signs, which would be about 200 g of licorice sweets.[43,42,44,41]

2.1.7. Coconut Sugar. Coconut sugar is derived from the unopened flower bud of the coconut tree (*Cocos nucifera*), not particularly processed without additives, bleaching sellers, or any chemical substances. Commonly, the most effective processing that takes place is heating the coconut sap to evaporate its water content, which especially comes from the coconut tree. Mostly, coconut sugar is made and consumed in Southeast Asia, especially in Indonesia and Sri Lanka as an alternative for processed, delicate, and synthetic sweeteners.[45,46] The coconut sugar manufacturing process consists of six stages: (1) selection of a tree and mature inflorescence for tapping, (2) collection of coconut sap, (3) heating for evaporation of moisture at 115 °C for 3−4 h, (4) conversion of sap syrup to coconut sap sugar, (5) sieving and drying the coconut sap sugar, and (6) weighing and packaging.[47,48] The sweetening agents in coconut sap are sucrose (6.91%), fructose (3.48%) and glucose (2.53%) whereas coconut sugar contains 75% sucrose and less than 25% fructose with a glycemic index of 35−40. Coconut nectar has excessive mineral content, such as potassium, magnesium, zinc, calcium, manganese, copper, sodium and iron, and vitamins C, B1, B2, B3, B4 and B10. When compared to brown sugar, coconut sugar has twice the iron, four times the magnesium, and over 10 times the amount of zinc. Coconut sugar is unfiltered, unbleached and preservative unfastened.[48] Crystallized coconut sugar is used anywhere in place of delicate white or brown sugar. Liquid coconut sugar can be utilized in lieu of other syrups derived from corn, agave, and maple. This means coconut sugar is good in cakes and cookies, sprinkled on top of granola, blended into a parfait, used in sauces, and another method wherein ordinary sugar finds its manner into ingredients. To apply coconut sugars instead of white or brown sugar, without a doubt add it at a one-to-one ratio.[49] There are some doubtlessly risky side consequences to immoderate consumption of coconut sugar, which include issues with diabetes, cardiovascular headaches, and lowered metabolism. If an excessive amount of coconut sugar is eaten, the body will not be able to manage it all into usable energy, resulting in some of those carbohydrates (fructose) being stored as fats. This can cause more adipose fats deposition instead of bringing weight advantage.[50]

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2.2. Extraction Techniques of Sweeteners' Extract/Powder. Previously, extraction of powders or extracts was performed using the solvent extraction method using different solvents such as methanol, chloroform, hexane, ethanol, ether, etc. through the homogenization technique. The solvents used in extraction were very costly and posed hazards to food or the extracted material and provided less concentration of the extract.[51] But recently, homogenization has been replaced with novel green approaches which not only are environmentally friendly, as no solvent is used, but also provide greater quantity of the extract compared to the traditional extraction method. These green approaches include high pressure homogenization/processing, ultrasonication, ultrafast-microwave assisted heating, irradiation, ohmic heating, pulsed electric filed, and supercritical fluid (CO_2) extraction techniques.[52−55] The extraction rate is enhanced with novel nonthermal techniques depending upon the extraction parameters and the intrinsic properties of the raw material.[56]

Ultrasound assisted extraction operates on the principle of acoustics and the cavitation process that occurs due to an induced ultrasound force. The ultrasound waves move in the food matrix and produce compression and expansion of the medium, resulting in production of cavitation bubbles. The bubbles increase in size with repetition of the compression and expansion cycle and burst, which produces enough energy to break the cell wall of the food matrix, releasing cell content.[57] In high pressure liquid extraction, food material is subjected to a high pressure of 50−200 MPa whereas in the case of ultrahigh pressure homogenization, the pressure reaches above 400 MPa and in high pressure jet systems, the pressure goes up to 500−600 MPa. High pressure exerts forces upon food cells which bear the pressure up to certain limit and burst, releasing cell matrix completely; hence, the extraction rate enhanced.[58] Microwave assisted extraction is based upon the principle of the electromagnetic radiation energy of the microwave region, which is absorbed by the polar compounds of food, inducing bipolarity, rotation and migration of polar ions. Microwaves cause water vaporization and create pressure and heat inside cell structures that subsequently leads to cell bursting. In the case of supercritical CO_2 extraction, CO_2 is used as solvent, which is first converted into liquid through application of critical pressure limits (CP = 72.9 atm) at the critical temperature (CT = 31.3 °C). Supercritical CO_2 ($SCCO_2$) is not expensive, is nontoxic, and prevents oxidation of the extract. $SCCO_2$, being nonpolar, requires cosolvent (ethanol, alcohol, methanol, hexane, methane, etc.) for efficient extraction of compounds.[57] There is a small difference in the ohmic heating and pulsed electric field extraction techniques that is static and pulsed electricity application to food materials. In ohmic heating, a specific temperature is applied, depending upon the physical and chemical characteristics of the food. Electrons movement across the food matrix exerts repelling forces to molecules and ions of cell walls that are ionized, and bonds are broken (electroporation and permeabilization); subsequently, the cell wall integrity weakens, and cells are ruptured. A similar principle is followed in pulsed electricity with the difference of noncontinuous electricity application.[59,60] Green extraction techniques are more efficient for extraction of heat sensitive biomolecules and biomolecules of oxidative nature. Nonthermal techniques exert no negative effects such as toxicity or chemical or physical changes in molecules, and they provide the maximum yield of the subject compounds.

2.3. Syrups. *2.3.1. Manuka Honey.* Manuka honey is prepared in Australia and New Zealand by bees that pollinate the native *leptospermum scoparium* bush (also known as a tea tree). The common chemical composition consists of 60−85% carbohydrates, 12−23% water, minerals, vitamins, proteins, organic and amino acids, enzymes and several bioactive materials, e.g., phenols and flavonoids.[61] Once the honeybees start their pollen and nectar gathering event, the whole colony will live until the nectar resources would have been used up, assisting to get the maximum out of the vegetation they pollinate with. Honeybees have a second stomach to save the gathered nectar, which provides an opportunity for it to be mixed with enzymes that allow for long-time storage.[62] The foraging regions around a beehive can spread to miles, and people are made aware of which areas have plentiful supply of essentials for making manuka honey. Timing is vital for the process too, as manuka bushes most effectively bloom for 2−6 weeks.[63] When it comes to superfoods, raw honey is associated with superb health benefits. Manuka is not a raw honey, but it is produced by special tradition culturing techniques, having excellent antibacterial qualities, which means that bacteria would not be able to build up tolerance against its antibacterial effects. Manuka honey is effective for treating many health issues from a sore throat to clearing up blemishes on your skin. The main medical use for Manuka honey is for wound and burn healing, which is available under the brand name of MediHoney (95% Manuka honey and 5% Na-alginate), approved by the FDA in 2007, for medical sterilization of wounds. Similarly, honey and honey-like products are also given the status of GRAS with a glycemic index (GI) of 54−59, as to be used in food in suggested doses.[64−66] It is generally used for treating minor wounds and burns. Research shows Manuka honey to be effective in treating other conditions, including skin problems such as eczema and dermatitis, soothing a cough or sore throat, and digestive health. The honey is used to treat wounds as a dressing, in the form of medical-grade honey prepared by sterilization. Its side effects may include allergic reaction, especially in people who are allergic to bees, rise in blood sugar if consumed in huge quantity, and negative interaction with certain chemotherapy drugs and various other medicines. Its safety dose, specified by the Ministry of Health, Labour and Welfare, Japan, has been established according to 0.3 mg/kg of maximum residual levels (MRLs) of tetracycline in Manuka honey. There are also various other types of honey (Table 3), cultivated in the wild and made commercially available in the market.[67−70]

2.3.2. Yacon Root Syrup. Yacon root, or *Smallanthus sonchifolius*, comes from the Andean mountains of the south and north of Colombia and the south of Argentina. *S. sonchifolius* has been cultivated in South America for hundreds of years. Yacon is sometimes called strawberry jicama, as the 2 root veggies are comparable. Yacon root syrup is dominantly comprised of fructooligosaccharides (FOSs) and inulin, around ~70% of their dry mass.[71] FOSs are used as low calorie sweeteners since human digestive enzymes do not decompose them. Therefore, they are not absorbed in the gastrointestinal tract and, hence, have a low glycemic index (40 ± 4) and are approved GRAS by the FDA.[66,72] Its health benefits include its goodness for weight loss in preliminary research, acting as a healthier sugar substitute of low caloric content for coffee, promoting bowel regularity, and improving cellular and humoral immunity with no associated effect on appetite and no cravings of more eating.[73,72] Furthermore, Yacon root

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Table 3. Different Types of Honeys, Their Nectar Sources and Sugar Content

Honey types	Nectar sources	Honey bees	Total sugar content (%)	Sucrose (%)
Sourwood honey	*Oxydendrum arboretum*	*Apis mellifera*	55.33	3.17
Rubber tree honey	*Hevea brasliensis*	*Apis mellifera*	62.27	1.66
Gelam honey	*Melaleuca cajuputi*	*Apis dorsata*	64.93	2.77
Longan honey	*Dimocarpus longan*	*Apis mellifera*	56.67	1.89
Heather	*Erica arborea* L., *Erica scoparia* L.	*Apis mellifera* L.	Fructose = 34−37	0.26
			Glucose = 28−33	
Lavender	*Lavendula pedunculata, Lavendula stoechas* L.	*Apis mellifera*	Fructose = 40−42	1.5
			Glucose = 26−29	
Orange blossom	*Citrus sinensis*	*Apis mellifera*	Fructose = 40.18	3.3−4.45
			Glucose = 27.11	

carries compounds that function as prebiotics inside the gastrointestinal tract (GIT), enhancing digestive fitness and treating positive kinds of colitis. Those prebiotic properties have an effect on the development of microflora in the GIT, leading to progressed gastrointestinal fermentation. The syrup contained in Yacon root is associated with weight reduction in human beings, which was supported by human studies in April 2009, namely medical nutrition. Obese ladies were administered to eat 0.14 to 0.29 g per kg body weight of Yacon syrup over the course of 120 days and noticed a reduction in weight, body mass index and waist circumference.[66,74]

2.3.3. Maple Syrup. Maple sap is a rich nutrient matrix, gathered from Acer timber to produce numerous food products (i.e., sap, water, extract, syrup, and sugar), of which syrup is the most well-known inside the food industry for its wonderful flavor. Maple syrup is collected from the sap of numerous species (*Acer saccharum, A. nigrum, and A. rubrum*) of maple and converted into fine syrup through thermal evaporation (pan evaporation) or membrane separation. Recently, ultrahigh membrane concentration is preferred before evaporation, to cut-down the energy cost during the intense and lengthy evaporation duration. Worldwide marketing of maple syrup reached $393 USD in 2019, in top seller countries such as Canada, USA, Netherland, Germany and Denmark.[75,76] Its chemical composition is chiefly comprised of sucrose (60−65%), xylose, ribose, arabinose, glucose, maltotriose, and a furcosyl oligosaccharide, namely, blastose. Various organic acids such as succinic, acetic, gluconic and lactic acids are also reported in maple syrup.[77] Moreover, some amino acids are also present in syrup such as proline, leucine, histidine, arginine and threonine, and minerals such as Na, Mg, Al, K, Ca, Fe and Zn. Being rich in 25 phenolic compounds majorly including gallic acid 3,5-dimethoxy-4-hydroxy-(2-hydroxy) acetophenone, p-coumaric acid, vanillic acid, syringic acid, dihydroxybenzoic acid and hydroxyphenylacetic acid makes maple syrup potentially suitable for functional beverages. Additionally, lignans and phytohormones (abscisic acid, dihydrophaseic acid, phaseic acid, abscisic acid glucose ester, *trans*-ABA and 7-hydroxyabscisic acid) also contribute to maple syrup's functional and phytoceutical properties.[78,76,79,80] The production steps at the commercial level involve (1) drilling a tap hole right into a maple tree, (2) insertion of a spout leading to a massive collection tank at the sugar house to transfer the raw syrup, (3) evaporating the syrup takes in the vicinity, (4) halting the evaporation when the thermometer of the pan reaches 219 levels and the syrup shows 60−70°Brix, (5) product filtering and adjusting for density, and (6) grading for flavor and coloration.[75]

Maple syrup has been used as an ingredient in baking, and its diverse artificial imitations are widely used as toppings for pancakes, waffles, and French toast in North America. Syrup can also be used to flavor a variety of foods, such as fritters, ice cream, ice sherbets, warm cereal, fresh fruit and sausages. It is also used as a sweetener for granola, applesauce, baked beans, oatmeal, porridge and candied sweet potatoes.[81,13,82,83] In Canada, the packing of maple syrup ought to comply with the "Packing" conditions stated in the Maple products guidelines or make use of the equal Canadian or imported grading machine. As said within the Maple merchandise rules, Canadian maple syrup may be categorized as "Canadian grade A" or "Canadian Processing grade". Any maple syrup container underneath these classifications ought to be stuffed to at the least 90% of the bottle size while still containing the net quantity of syrup product as said on the label.[84]

2.3.4. Brown Rice Syrup. Brown rice syrup is a sweetener derived from brown rice (*Oryza glutinosa Lour.*; *O. sativa* var.) through enzymatic breakdown of starches into smaller sugars, followed by filtering out the impurities. The result is a thick, sugary syrup comprised of maltotriose, maltose, and glucose in 52%, 45%, and 3%, respectively, with a moderate glycemic index value of 41−60.[85,86] Maltose is just two glucose molecules, while maltotriose is three glucose molecules; therefore, brown rice syrup acts like 100% glucose inside the human body. Brown rice syrup may be considered better than normal sugars, due to the absence of fructose. Vegans must consult their nutritionist or a certified dietitian about which sweetener is the best for them, or for their particular health condition, and then make the right pick.[87] Brown rice is exceptionally high in manganese, vital for many important processes in the body including bone development, wound healing, muscle contraction metabolism, nerve function and blood sugar regulation. A deficiency in manganese has been linked to a higher risk of developing metabolic syndrome, bone demineralization, impaired growth and low fertility. Just one cup of rice fulfills nearly all your daily requirement for this important nutrient. Aside from being an excellent source of vitamins and minerals, brown rice provides powerful phytocompounds as well.[88] Brown rice syrup is prepared through a fermentation process, following the given process: (1) rice flour is heated to 45 °C for gelatinization and slurry preparation, (2) it is mixed with amyloglucosidase and α-amylase enzymes, (2) continuous stirring is performed, (3) the mixture is allowed to rest for a specific duration to allow enzyme reaction at a specific incubation temperature, (5) filtration or centrifugation is performed to separate the liquefied and saccharified syrup, and (6) evaporation is carried out to give the syrup in its final form.[89] Hard candies, jelly and gum candies, panned candies and confectionary coatings are a few of the top examples of rice syrup applications. It helps in controlling sugar blooms and moderating stickiness, it is a good choice for its processing viscosity, clean flavor, and use as

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a barrier coating, and it provides shine to the finished product. Baked goods such as cakes, cookies and muffins are the best examples of rice syrup applications that help stabilize moisture, moderate texture, and exhibit excellent freezing stability.[90]

2.3.5. Date Syrup. Date syrup, recognized as a dark brown material, is the main acquired product from dates, particular fruit trees (*Phoenix dactylifera L.*) in the Middle East and North Africa region. It is chiefly grown in Iran (20%), Egypt (17%), Iraq (15%) and Saudi Arabia (14%).[91,92] In early ages, dates were consider necessary for human nutrition and food production in the desert ranges. There were approximately 8 million tons of dates reaped in 2017.[93] Date syrup is dense in various nutrients such as sugar entities (70%; glucose, fructose and sucrose) with a glycemic index of ∼70, organic acids (acetic, citric, fumaric, lactic, malic, oxalic and succinic acids), protein and minerals (Cu, Mn, Fe, Ca, K, Na, Se and Mg). Some other nutritionally vital constituents are found in date syrup, including dietary fiber, vitamins C and B-complex, and antioxidants such as polyphenols, flavonoids, and carotenoids.[94−96] Its health benefits are diverse in its effects on body metabolism, such as antimicrobial, antimutagenic, immunostimulant, hepatoprotective, nephroprotective, gastroprotective and anti-hyperlipidemic properties.[97] At the research level and commercial level, date syrup has been fortified and added in various food products such as functional yogurt, dough and bread, fermented milk drinks, processed cheese, rabri milk drink, probiotic dairy desserts and different backed goods and drizzled over ice cream, oatmeal, yogurt, French toast, pancakes, or even savory bites, such as a grilled cheese sandwich.[98−102] In Arabic countries, date syrup in an essential cooking ingredients in various native dishes and added to improve the flavor of poultry, meat, fish, vegetables, pasta and rice. It is also drizzled over cheesecakes, cream cakes, toast, croissants, bagels, pancakes, sorbets, crepes and shakes.[103] Date syrup production is very simple, and it can be prepared at home following the given steps: (1) soak dates for at least 2 h in warm water (60 °C), (2) mash with a masher, (3) strain the liquid through a nut bag or a thin muslin cloth by squeezing, rehydrate pulp again and extract juice once more, (4) transfer strained liquid in pan and boil on medium heat with continuous stirring to prevent burning, (5) boil mixture until it turns thick (70°Brix) and (6) cool syrup and transfer to an airtight glass jar.[104]

2.3.6. Agave Nectar. Agave syrup, also known as "maguey syrup" or "agave nectar", is a sweetener, commercially produced from the fluid of several species of agave, including *Agave tequilana* (blue agave) and *Agave salmiana*, which is the same plant used to make tequila. Blue-agave syrup contains 56% fructose which provides sweetening properties. Agave nectar is actually a syrup whereas nectar is just a marketing term. Blue Agave is a desert succulent not a cactus, a specie native to Mexico.[105] Agave is naturally fortified with inulin that is naturally occurring oligosaccharides, namely fructans, in many types of plants. Inulin is used by some plants as a means of storing energy and typically is found in roots or rhizomes.[106] Polyphenolic compounds are also richly present in agave syrup, including saponins, flavonoids, quinones, glucosides, cardiac glucosides, terpenoids and coumarins.[107] Fructans present in agave nectar are excellent in boosting the metabolic system through glucose digestion, reduction in weight and obesity, enhanced mineral absorption, brain protection, and chemoprotective and immunomodulatory effects. Food applications of agave syrup are its inclusion as a sugar alternative in cheese, cookies, bread, fruit preserves, coating microspheres, cereal bar snacks, dehydrated snacks, chocolate, guava purees, gummy bears, ice cream, microcapsules, sports drinks, and yogurt.[108,109] In a 100 g recommended quantity, blue-agave syrup contributes 310 kcal of energy and is an ordinary source of vitamin C and several B vitamins. It is a concentrated liquid of 76% carbohydrates, 23% water, 0.4% fat, and protein.[110] Agave nectar is made by the following the steps: (1) fluid is first extracted from the plant, (2) juice filtered, (3) filtered juice is heated to break down its components into a simple fructose sugar, and (4) finally, the sugar is concentrated into a syrup at 65°Brix.[111]

2.3.7. High Fructose Corn Syrup/Corn Syrup. Corn syrup is a viscous sweet syrup produced by breaking down (hydrolyzing) cornstarch, either by heating it with a dilute acid or by combining it with enzymes. Cornstarch is a product of corn. Corn syrup is different from high fructose corn syrup (HFCS), as 100% glucose is present in corn syrup whereas 90% fructose and 10% glucose in HFCS, having a moderate glycemic index of 55−65.[112] HFCS is commonly produced by following 3 major biochemical conversion steps: (1) liquefaction, (2) fractionation, and (3) isomerization. Corn syrup production starts with the mechanical processing of corn through brewing to soften it; following wet grinding to separate the cornstarch, enzymatic breakdown takes place with addition of α-amylase, glucose isomerase and amyloglucosidase. Subsequently, enzymatic conversion reduces starch to simpler units of glucose and fructose and produces a mixture of 90% fructose and 10% glucose that is termed commercially as HFCS-90. HFCS-90 is further mixed with glucose syrup to produce HFCS-55 and HFCS-42, comprising 55% and 42% fructose concentration, respectively.[113] Owing to the high concentration of fructose in HFCS, it presents a moderate glycemic index. However, adverse health effects have been reported in various human and animal trials including insulin resistance, obesity, dyslipidemia, hyperuricemia, gout, hyperinsulimia, excessive visceral fat, and hypertension.[114−116] HFCS is applied in different food products as an ingredient or sugar alternative, including cookies, crackers, catsups, cereals, flavored yogurts, ice cream, preserved meats, soups, beers, buns, breads, doughnuts and rolls, flavored milk, canned fruits and vegetables, ketchups, fruit preserves, jams, jellies, and spice mixes.[115,117]

HFCS has been given the status of GRAS by the FDA. As far as HFCS's safety is concerned, European countries have applied rigid rules to control the use of bulk sweeteners by Common Agricultural Policy, according to which only HFCS-42 can be utilized in the EU. In the United Kingdom, only 2% of HFCS is utilized in food products while the remaining are other sugars. However, in USA, HFCS-55 is added in soft drinks and other products as a direct sugar replacer. Studies have reported that a moderate quantity of HFCS, to be utilized in food products, is advisable to avoid adverse health hazards.[66,115]

2.3.8. Blackstrap Molasses. Molasses, black treacle (British English) or black honey (Egypt) is a viscous substance resulting from the refining process of sugar cane (*Saccharum officinarum*) or sugar beet (*Beta vulgaris*) juice into sugar. The molasses composition varies in the amount of sugar depending upon the method of extraction and the age of the plant. This syrup is called molasses or blackstrap molasses and is mostly used in livestock feed and as substrate for ethanol production.[9] Molasses is composed of 22% water, 75% carbohydrates and

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Table 4. Plant-Derived "Vegan" Sweeteners and Their General Characteristics and Safety Aspects

Sweetener	Source	Sweetening compound	Sweetness intensity	Glycemic index	GRAS status	ADI
Extracts						
Osladin	*Polypodium vulgare*	Glycosylated bonds at C-3 and C-26, Bidesmosidic steroid saponins	500	0	N/A	N/A
Monk fruit	*Siraitia grosvenorii*	Mogrosides (IV, V and VI), 11-oxo-mogroside V and siamenoside I	250–300	0	Approved	JECFA approved 25 mg/kg body weight for monk fruit juice concentrate
Miracle fruit	*Synsepalum dulcificum*	glycoprotein "miraculin" (galactose, xylose, fucose, mannose and glucosamine sugars)	400,000 times induced by citric acid	N/A	not approved by FDA or EFSA	ADI not defined
Stevia	*Stevia rebaudiana*	steviol glycosides, diterpene glycoside, steviosides, rebaudiosides A, B, C, D and E, and dulcoside A	450 times	0	Steviol glycosides as GRAS (E960)	4–4.4 by JECFA
Thaumatin	*Thaumatococcus daniellii*	Proteins (207 amino acids in single chain)	1600–3000	0	GRAS in the US and approved as E957 in EU	1–5 mg/kg by FEEDAP[a] and JECFA
Licorice	*Glycyrrhiza glabra*	Glycyrrhizin	150	78	Approved by FDA	0.015–0.2 mg/kg by JECFA
Coconut sugar	*Cocos nucifera*	75% sucrose and <25% fructose	N/A	35–40	N/A	ADI not defined
Syrups						
Manuka Honey	*leptospermum scoparium*	60–85% sugars (mainly glucose, and fructose, 1–15% sucrose)	N/A	54–59	approved GRAS,	ADI not defined, 0.3 mg/kg of MRL[b] of tetracycline by Ministry of Health, Labour and Welfare, Japan
Yacon root	*Smallanthus sonchifolius*	~70% of fructo-oligosaccharides and inulin	N/A	40 ± 4	Approved GRAS	ADI not defined
Maple syrup	*Acer saccharum, Acer nigrum, and Acer rubrum*	sucrose (60–65%), xylose, ribose, arabinose, glucose and maltotriose, and furcosyl oligosaccharide namely, blastose	N/A	54–65	Approved GRAS	ADI not defined
Brown rice syrup	*Oryza glutinosa Lour and Oryza sativa*	52% maltotriose, 45% maltose and 3% glucose	N/A	41–60	Not approved	ADI not defined
Date syrup	*Phoenix dactylifera L.*	70% of glucose, fructose and sucrose	N/A	~70	GRAS approved	ADI not defined
Agave nectar	*Agave tequilana*	56% fructose	N/A	N/A	N/A	ADI not defined
High fructose corn syrup	*Zeya maize*	HFCS-90 with 90 fructose; HFCS-55 with 55% fructose; HFCS-42 with 42% fructose	N/A	55–65	GRAS approved	ADI not defined
Blackstrap molasses	Sugar cane (*Saccharum officinarum*); Sugar beets (*Beta vulgaris*)	75% sugars	N/A	55	GRAS approved	ADI not defined

[a]FEEDAP (Additives and Products or Substances used in Animal Feed). [b]Maximum residual levels.

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0.1% fat with a glycemic index of approximately 55. In a reference amount of 100 g, molasses is a rich source of vitamin B6 (20% of Daily Value) and several dietary minerals, including manganese, magnesium, iron, potassium and calcium. The sugars in molasses are sucrose (29%), glucose (12%) and fructose (13%). By the evaporation of sugar cane juice, three types of molasses are obtained by triple effect evaporation, namely molasses A, B and C type. Grades A and B are usually recycled to enhance sugar production while C grade is taken as such to generate molasses. Molasses is densely comprised of 13 polyphenols such as chlorogenic acid, caffeic acid, syringic acid, vanillin, homoorientin, orientin, sinapic acid, vitexin, swertisin, diosmon, apigenin, tricin and diosmetin. Moreover, according to a recent research report, 3 tricin-*O*-glycosides, 3 methoxyluteolin-C-glycosides and 7 epigenin-C-glycosides were identified in blackstrap molasses.[118−121] The antiaging antioxidants selenium, manganese, and zinc in blackstrap molasses work from the inside out to soften hair and reduce hair loss and graying hair. The anti-inflammatory properties help in easing the discomfort and symptoms of arthritis by reducing swelling, joint inflammation, and pain. Its rich supply of calcium supports healing and improves bone and connective tissue health. The calcium, magnesium, and B vitamins in molasses fight fatigue, anxiety, and stress while enhancing brain function, improving mood, and focus.[120] Molasses is used in yogurts, Jaggery, dark rye breads or other whole grain breads, cookies, pies, gingerbread (particularly in the Americas), barbecue sauces, and beer styles such as stouts and porters. Furthermore, commercial uses may include stabilization of emulsifiers in homemade vinaigrette, reconstitution of brown sugar by combining it with white sugar, and a source for yeast production.[122,123]

2.4. Concentration Techniques for Syrups. Syrups are required to be concentrated and made free of microbes via different techniques during processing. Traditional techniques of concentration were based upon heating at high temperature through injection of hot air which used to cause various physicochemical and sensory changes, Millard reaction, and oxidation of liquid compounds. Traditional techniques have recently been substituted with novel nonthermal concentration methods via the application of reverse osmosis, forward osmosis/evaporation (FO), nanofiltration (NF), membrane distillation (MD), osmotic distillation (OD), pervaporation, ultrasound assisted membrane technology (UAMT) and ohmic-assisted vacuum evaporation (OAVE).[124−127] All these concentration techniques are physical methods of concentration that operate without application of heat. However, pressure is applied or a pressure gradient is created to move the ions from high gradient to low gradient or for passing of small molecules across membranes.[127] Ultrasound assisted membrane technology works on the principle of ultrasound waves which remove a layer of deposits from a membrane surface as a result of the membrane shaking with the progression of waves. Moreover, ultrasound reduces the fouling; hence, a more efficient time duration can be created with sound waves application.[124] In membrane techniques, two basic principles are followed: (1) cross-flow and (2) dead-end. Cross-flow is comparatively more efficient, as it produces a very low quantity of filter cake. Reverse osmosis is a hydraulic-pressure driven process where the TMP (trans-membrane pressure) is kept higher than the osmotic pressure of the syrup solution in order to permeate the water flow from a high concentration gradient to a low gradient.[128] Contrarily, in forward osmosis, the TMP is kept lower than the osmotic pressure of syrups, which moves water from the feed solution to draw solution through a selective permeable membrane.[126] In a membrane distillation process, temperature gradients are applied on both sides of a porous hydrophobic membrane. Temperature differences on both sides of the membrane induce a vapor pressure gradient on the cold and hot sides which causes movement of vapors from the hot side (higher vapor pressure gradient) to the cold side (lower vapor pressure gradient).[125] In the case of syrups, concentration is the basic stage where more energy is consumed; hence, it increases process costs. Utilization of physical techniques is a better solution to cut-down the energy costs as well as prevent oxidation and sensory changes in food solutions and syrups with minimal physicochemical changes and maximum microbial load rejections.

2.5. Labeling and Sale Regulations/User Guidelines. In 1958, under the amendments of the Federal Food, Drug and Cosmetics Act, safety evaluation of non-nutritive sweeteners (NNSs) was given under the authority of the Food and Drug Administration (FDA) in the USA. There are various agencies and international bodies working for safety evaluation of nutritive and non-nutritive sweeteners, such as the Bureau of Chemical Safety in Canada, World Health Organization (WHO), Codex Alimentarius Commission (CAC) and Joint Expert Committee on Food Additives (JECFA) in the USA. In the GRAS list, some sweeteners are given the status of GRAS (Table 4), stated as "the reasonable certainty of no harm". Redbook 2000 published by the FDA has included the guidelines for the safety of foods, based on toxicological studies of NNSs and harmonization of technical requirements for registration of pharmaceuticals for safe consumption in humans.[129,130] Moreover, it is a requirement to mention a statement of "intense sweetener" on a food product label, as per the code and instructions of the Food Standard Australia New Zealand (FSANZ). Sweeteners added in food products must comply with the specified Accepted Daily Intake (ADI), developed by the Food and Agricultural Organization (FAO).[131] Complying with the regulation (EU No. 1169/2011) laid out in the European parliament, it was made necessary to mention twice the name of alternate sweeteners and European No. (EU) on the label of foods containing sweeteners.[130]

3. CONCLUSION

Society is becoming increasingly aware of the utmost importance of eating a balanced diet to maintain and promote health. Excessive sugar consumption is now a cross-cutting concern, but this habit is not an easy one to break. Recently, sugar-free and/or low sugar foods and drinks are in great demand, depending upon the organoleptic properties, structure, texture, and the amount of value they add to different products. Today, the food industry applies bulk and intense sweeteners which are mainly synthetic in origin, to substitute sucrose. Consumers have become more eager to eat products, added with natural ingredients and cleanly labeled, preferably with other functional properties along with no compromise in taste. The food industries are inspecting more sweetening substitutes to meet consumer insistence, an approach that has been extended to bakery products, beverages and dairy products (mainly yoghurt), in spite of fermentation processes. Especially, the current market movements denote the demand for improving minimally processed foods. Labeling

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and complying with FDA requirements for use of intense vegan sweeteners have become prominent needs of the recent food market and industries. The food industry needs to face the challenges of developing new products with natural functional sweeteners to continue innovating and satisfying consumers.

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Notes

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