



Agave syrup as a replacement for sucrose: An exploratory review

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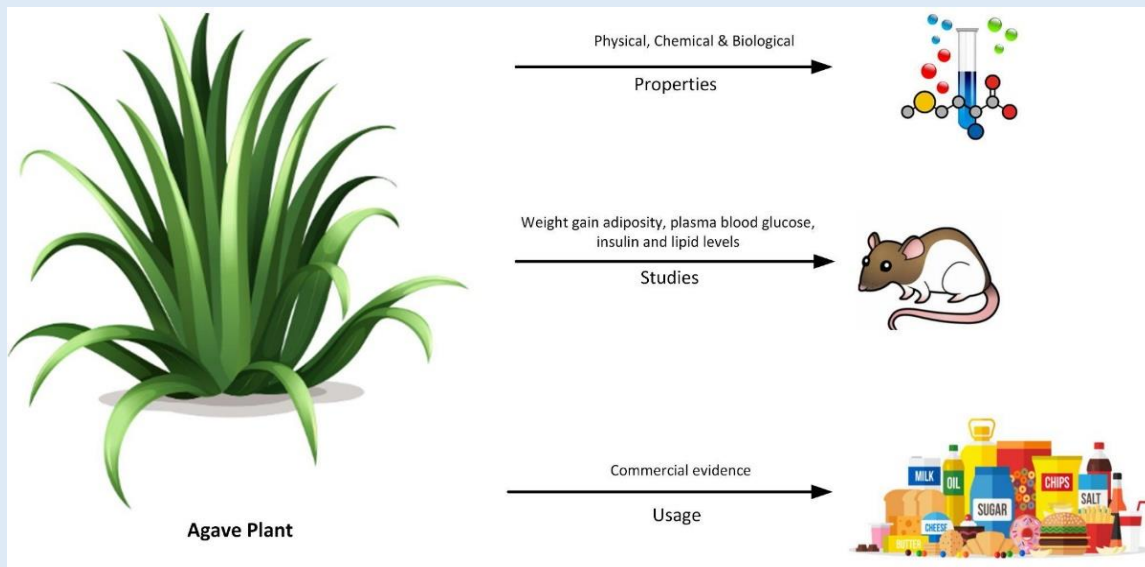
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ABSTRACT

Sucrose in its various forms has become an important part of our daily intake. Apart from sweetness, it also provides structure, and stability and plays important role in the appearance of the final product. Sucrose is widely used in the production of sweets, desserts, and beverages, however, the various effects of high consumption of sucrose, such as obesity, type 2 diabetes, and cardiometabolic disorders are of concern. Thus, in the present review, we have tried to summarize the usability of an alternative to sucrose. We explore the possibility of Agave, a native plant from Mexico, and its by-products (*Agumiel*, Agave syrup, etc) as a healthy alternative to sucrose in the food industry in this paper. This study uses Google scholar to review the history, properties, production, regulations, studies, and commercial adaptation of Agave in different food products. Chemical, physical, and biological properties are explored of the two most widely used varieties (*Agave Tequilana* & *Agave Salmiana*). The findings indicate that Agave has a long consumption history. Though the production is being regulated by the Mexican government, adulteration and fake labels are a concern. Recent animal studies have proved its safety, while long-term human benefits could be the scope of future studies. The authors conclude that Agave has good potential to replace sucrose shortly although long-term health benefits need acute exploration for it to be a suitable substitute for sucrose in order to reduce the risk of diet-related disorders.

Keywords: Agave; Natural sweeteners; Sucrose replacement; commercialization; New product development.



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INTRODUCTION

History: The term agave comes from a Greek word that means illustrious and admirable. The pre-Hispanics referred to it as *Metl* and Spaniards as *Maneuy*. Ethnic to Mexico, southern and western parts of the United States of America its dependability increased due to the shortage of other vegetation and harsh climatic conditions in this region. Archaeological reports stated its dietary importance to Indians of California with its consumption rate increased to 45 % of total food consumption during springtime when an acute shortage of other vegetables was common.

A study on 359 coprolites dated between 7000 BC and 1500 AD compiled 25-60 % of the total study on agave. Archaeological study in the northern Tuscan basin inveterate cultivation of agave by discovering the existence of rock piles, terraces, and check dams. The Aztec civilization (1300 BC) used fermented sap (*Agumiel* or honey water) from the agave stems to produce a viscous beer called *Pulque*. The distilled process was introduced by Spaniards while colonializing the north-central Mexico region giving rise to the current

distillation which is used to make *Tequila*, *Miscal Bcanora*, and *Siscal* with higher alcohol content [1].

Agave was utilized as the bases of food, beverage, and fiber by civilizations for a long time. Evidence of agave cultivation includes the finding of tabular stone knives, rock piles, and roasting pits with agave phytolith residue indicating agave cultivation and consumption [2]. Both *Aguamiel* and *Pulque* were consumed for their perceived spiritual and healing powers during religious ceremonies [3]. Agave and its products went on to gain incredible social and economic importance within several Indigenous communities in Mesoamerica [4]. Even before the development of the agriculture of maize and beans took place, agave was considered a dietary staple [5]. The lack of domestic herbivores in the Mesoamerican diet also helped reinforce the importance of cultivating agave as a food source due to its energy and fibre-rich qualities [6]. Abundant archaeological evidence has been found to support the consumption of agave in these pre-Columbian times. Traces of agave, dating back to 7000 BC, have been found in the remains of roasting pits [7] Underground ovens all across Mexico, including several settlements of the Hohokam people along the Sonoran

desert as mentioned in the research by Cynthia Radding (2021) and the discovery of quid or fiber rejects from 7000 BC mentioned in the book by Howard Scott Gentry (2004) also supports the claim of consumption of agave by the Mesoamerican civilization. The soft meristem, floral peduncles, stems, and leaf bases of the agave plant were believed to have been used for consumption [8]. While the remaining hard parts of the plant were used to yield fiber. It is believed that the agave heads were baked in the fire pits and were either consumed directly or they were pressed and stored as flat disks that were easy to carry and could be consumed at a later time. The juice expressed from these agave heads was also further rendered down to produce a more stable syrup. Records also show that certain indigenous groups, such as the Tarhumara people, cultivated their species of agave that they used to bake in the roasting pits and then sun dry and ground into flour to prepare tortillas [7].

The arrival of the Spaniards in Mesoamerica in the 15th and 16th centuries caused the spread of the cultivation and consumption of the agave/maguey plant. The conquistadors took Mexican farmers who carried their maguey plants back with them to New Spain [8]. This introduced the agave plant as a food source to the Old World. The colonizers forced Indigenous communities, such as the Nahuatl people, to grow more agave plants, such as the *Agave salmiana*, to increase the production of *Aguamiel* and *Pulque* [9].

The Spanish also brought along Filipino workers who introduced the Aztecs to the process of distillation [8] widening the scope of agave as a food source and thereby leading to the creation of *Mescal* and *Tequila*. However, while the consumption of agave as a source of beverages increased, its role as a sweetener began to decline with the introduction of sugarcane in the early 17th century [8]. In the late 20th century, agave syrup re-emerged as a commodity when it was introduced at the Expo West in Modern America in 1995. The University of

Guadalajara had specially manufactured a batch at their pilot plant for this Expo [10].

Modern Production of Agave Syrup: In order to reach the appropriate maturity required for the production of agave syrup, the agave plant must be allowed to grow a minimum of 6 years before it is harvested by hand and used. To begin the processing, the heart or piña of the agave is first separated from the other parts of the plant and crushed into fibers. In this process, gravity is used by which juices are released from the fibers, which can then be filtered to remove any unwanted residue. The strained juices are then made to undergo natural hydrolysis, with the temperature gradually being increased to 80°C, over a period of time. After this, the juice is purified once again and then exposed to vacuum evaporation at around 90°C to eliminate all excess moisture and denature glycosidic actions, giving us the final product. Roughly 10% of harvested agave is used to produce agave syrup while the remaining is utilized for the making of fermented and alcoholic beverages, like *Pulque*, *Tequila*, and *Mescal*, which are mostly produced from the *Agave Tequilana* and *Agave Salmiana* varieties [11].

There are three processes that can be used for agave syrup production. The first is the age-old, traditional process wherein the agave sap is heated in pots over the fire until the carbohydrates hydrolyze and excess water is evaporated. The second, semi-industrial process makes use of the thermal hydrolysis of sap with a few adjustments, such as temperature and pH level, being controlled. The third process, i.e., the industrial one, is the most sophisticated production process. It involves using whole agave pines, either raw or semi-cooked, that are further processed under carefully controlled variables with the usage of highly refined technology for carbohydrate removal and hydrolysis. The industrial hydrolysis of the carbohydrates is done using the methods: of enzymatic, acid, or a combination of both [12].

Regulations for Production of Agave Syrup: The Mexican government has placed several legislations to regulate and control the process of producing agave syrup as well the quality of the product being produced. The main legislation that is in place is NOM-003-SAGARPA-2016, 2016. This legislation sets up parameters for the quality, authenticity, labeling, and conformity valuation of the agave syrup being produced. However, this legislation does not provide any restrictions on the variety of agave that can be used to produce syrup. The frequently selected agave species that are used for production include *Agave Tequilana*, *Agave Americana*, *Agave Potatorum*, *Agave Salmiana*, and *Agave Atrovirens* [12].

Despite the parameters established under this legislation, there is still a lot of range in the products that are sold under the same umbrella term as agave syrup as a result of the inconsistency of production methods, type of agave used, the growth area, and the portion of the plant used for production [12].

Moreover, fake agave sugars can also be produced by chemically manipulating the sugars that are obtained from cheaper plant sources. As a result, several processes to detect such adulteration and to carry out depth quality evaluation have also been established and highlighted under these legislations. One such process is the use of a

chromatographic outline of a few oligosaccharides so that the necessary signs from various sugar syrups in agave can be detected. Carbon 13 SNIF-NMR is another process that can help distinguish among sugars from CAM (Crassulacean Acid Metabolism) plants such as agave and C4 plants like cane and maize [13].

REVIEW METHODOLOGY

As a part of the methodology for this study three essential parameters were reviewed for agave syrup. Firstly, the properties including chemical, physical, and biological were observed for two popular and most frequently used agave varieties (*Agave Tequilana* & *Agave Salmiana*). Secondly, to find whether agave is safe for human consumption, a literature search was done to find any evidence studies done in past. Articles detailing previous clinical studies using Agave and its by-products were accessed for inclusion. At last, to check agave’s potential commercially, a literature search was done to find if agave was used as a substitute for sucrose and its effects. A snowballing search of the reference lists of included articles was conducted to identify further articles and patents in Google Patents that may have been missed in the Google Scholar search.

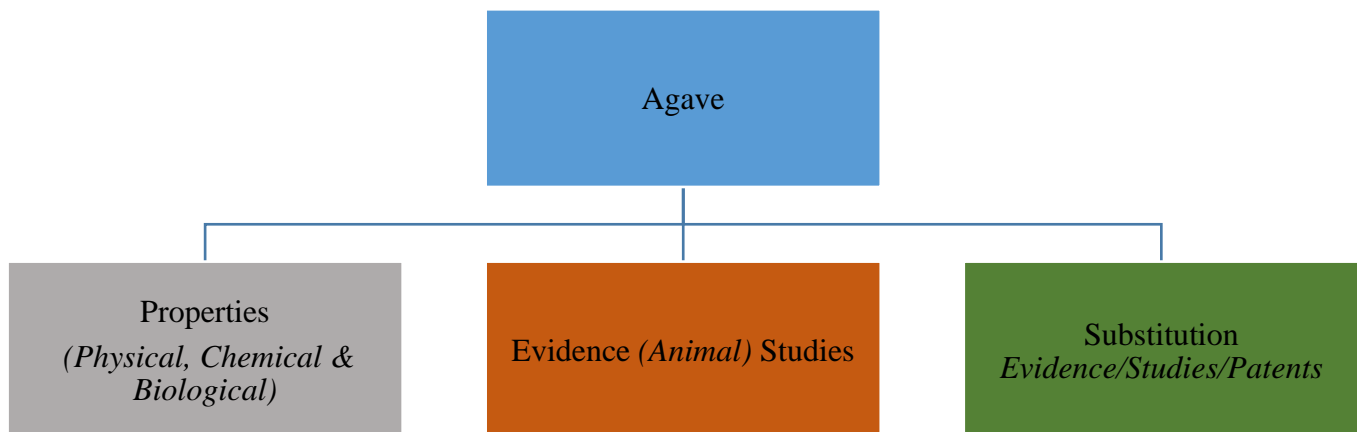


Figure 1. Parameters considered for the methodology of review study

PROPERTIES:**A) Chemical Properties****Table 1.** Chemical properties of agave species [14].

Agave Type	Fructose	Glucose	Sucrose	Inositol & Mannitol
<i>Agave Tequilana</i>	71% to 92%	4% to 15%	4%	0.31% to 0.43%
<i>Agave Salmiana</i>	>70%	>25%	>2%	0.02% to 2.54%

B) Physical Properties: Related range of color, density, and flavor as honey and maple syrup. Sweetness is relatively more than honey, corn syrup, and sugarcane syrup. Density: 1.49 g/ml, Surface tension of 45.3 dinas/cm, viscosity 212 mPa-s

C) Biological Properties:

- Demand is increasing due to low GI (Glycemic Index), antioxidant properties, and antibacterial characteristics.
- Numerous studies established their health advantages as reducers of plasma glucose and lipids
- The prebiotics improves the function of the colon
- The fructans reduce the glucose quantity and serum cholesterol, raising the level of calcium absorption in bones, however scientific studies on fructans from agave are inadequate.
- The saponins have anticancer, anti-inflammatory, ulcer-protective properties and are also capable of decreasing the acute glycemic response
- Antioxidant, mineral absorption, and anti-diabetic
- Also, when tried alongside, *Bacillus subtilis* and *E-coli* and presented inhibitory effects to these strains, the content of methyl glyoxal (pyruvaldehyde) is possibly accountable for this activity.

- Inhibitory actions against the cancer cell and develop antioxidant effects [14].
- The *Agumiel* or the agave sweet extract has a relatively good nutrient value; it also supplies the consumer with energy and is rich in amino acids. Hence, it is considered an important beverage [15].

Evidence studies: A study evaluating the metabolic effects of a diet based on agave nectar versus a diet based on sucrose was piloted for 34 days on young weanling mice. Parameters like weight gain adiposity, plasma blood glucose, insulin, and lipid levels were measured. Results supported better weight regulation, plasma glucose, and insulin homeostasis with an agave nectar-based diet.

Agave nectar is a natural sweetener in the liquid form obtained from the sap of either the *Agave Tequilana* or *Agave Salmiana* plant. This juice obtained from this sap is then treated with either heat or enzymatically to break down the complex carbohydrates into sugars and then it is reduced to a syrup. It has a high concentration of fructose and is therefore advertised as a low glycemic option [16].

Agave consists of highly branched fructans. These compounds are taken into account as prebiotic soluble dietary fiber. ADF (Agave Dietary fiber) and ADF-JC Jamaica Calyces (JC is extensively cultivated and used up as an infusion in many tropical regions) displayed favorable effects as functional ingredients for decreasing body weight gain when tested on rats. Although

efficiency and safety need confirmation for the usage of ADF and JC as a bioactive ingredient in humans [17].

While glucose tolerance was similar, lower glucose-induced hyperinsulinemia was witnessed with fructose. Lower insulin resistance compared to sucrose treatment and reduced hepatic IL-1B levels were observed with agave syrup. This shows that agave syrup might be a less injurious substitute for sucrose from the perspective of obesity. It is proposed that daily substitution of refined sucrose with natural sweeteners would generate low glycemic and insulinemic responses, translating into better metabolic health in the long term [18].

The Agave syrup extract is found to have anti-cancer properties also. For this particular reason, extraction processes or methods have been designed to gain extracts from agave syrup which contain various phytochemicals such as polyphenols, flavonoids, saponins, phytosterols, and other natural products, which have verified antioxidant characteristics. It is principally a method for using an agave syrup extract as an antioxidant and a food add-on. It could be also considered as an anti-neoplasia, anti-carcinogenic, or anti-tumoral preparation and hence could be used for the stoppage or reticence of cancer cells, such as tumors from the breast, prostate, or liver. Several Agave species from Mexico such as *Agave Salmiana*, *Agave Lehmanni*, and *Agave Atrovirens* have been found useful for inhibiting the growth of cancer cells as well as having an anti-oxidant effect [15].

COMMERCIALIZATION OF AGAVE SYRUP

Agave as a sweetener in chocolate: The new patented invention of a low moisture agave syrup allowed the chocolate industry to use agave syrup to produce a natural and organic, sugar-free chocolate that tasted good, retained its stability at room temperature, and had the desired snap, luster and taste that consumers demanded from chocolate [19].

The rheological properties, microstructural properties, and textural characteristics between chocolate prepared with saccharose and dark chocolates made with replacement extracted naturally (stevia and agave syrup) were analyzed. The study concluded that the chocolate sample with a high amount of fat and agave syrup replacement resulted in low sugar levels and the tinniest sugar crystal formation. It also showed that the sample with a low amount of fat depicted stress, and a higher level of viscosity, as the rheometer used could not measure higher levels. Agave syrup influences cocoa fat differently and instead of emulsifying with cocoa fat like in the usual case, it makes suspension [20].

Agave nectar in a nutritional supplement: Blue Agave nectar was used for creating a nutritional supplement. This nutritional supplement is created to provide a thermogenic effect and health benefits from Omega-3 and Omega-6 fatty acids [21].

Use of agave syrup as a sweetener in muffins: The usage of agave syrup in muffins produced a final product with a stable structure. The syrup was used to partially or replaces sucrose in muffins, cookies, cereal bars, and cakes with no gluten. While the results of using agave as the sweetener on the final product are known, the result of using syrup on the rheological, microstructural, and sensorial characteristics of the baked products are yet to be explored. However, a study did reveal that agave syrup can be used as an alternative for sucrose when preparing muffins and the results produced are best if the syrup is used in a mixture with the addition of xanthum gum and doubled quantities of leavening agents [22].

Use of Agave plant fructans (Agavins) for replacement of fat in dairy products: For this study yogurt samples with no fat and low fat were taken. Agavins from *Agave angustifolia* and *Agave potatorum* species were used to evaluate physiochemical, rheological, and sensory

properties. There was no change in the sensory properties and improvement was seen in the mouthfeel and texture of the samples. Significant differences were observed in viscosity, syneresis, and water retention capacity. All yogurt samples displayed strain thinning and weak viscoelastic gel properties [23].

Use of agave ingredients to prepare granola bars: A study sought to replace the use of honey and flour in granola bars with agave syrup and fructan sweeteners and agave fiber. The ground agave fiber was obtained as a by-product of producing agave syrup from the stem of *Agave Tequilana* plants. The researcher made use of ground fiber and agave fructans to manufacture a soluble agave dietary fiber that formed the body of the granola bar [24].

Use of agave as a sweetener in a raspberry jam: Jams form an important part of the human diet and nutrition and are prepared by adding sweeteners, mainly sucrose, pectin, and acid to previously cooked fruits. A researcher carried out an investigation to determine and analyze the sensory differences that would result from substituting the sucrose in raspberry jams with other sweeteners, including agave syrup. The study revealed that using agave syrup and sorbitol was useful in the preparation of raspberry jam as it had superior hedonistic quality as compared to sucrose and other sweeteners [25].

Use of agave as a sweetener in Teriyaki sauce: Research conducted in Korea looked to examine how using low-calorie sweeteners, such as fructooligosaccharide, xylitol, erythritol, and agave syrup, in place of sugar in Teriyaki sauce would fulfill customers' health requirements. The moisture and viscosity of the sauce were measured after adding each of the sweeteners. The results indicated that

xylitol was a good ingredient for sauce considering taste and flavor [26].

Use of agave to replace sugar and fat in ice cream: A study to identify the effects of using agave fructans as a sugar and fat replacer in ice cream revealed that the use of agave in low-fat ice cream produced results with improved sensory, thermal, and textural properties, emphasizing the fact that agave is, in fact, a feasible fat and sugar replacer [27].

Use of agave fructans with spray dried pineapple and mango powder: Research conducted to study the effect of using native agave fructans (FT) on the physiochemical properties of spray dried pineapple and mango powder revealed that using a combination of the agave FT and maltodextrin (MD) as stabilizers produced positive effects in the physiochemical properties in the drying process of the powders. However, the study also noted that using high concentrations of the FTs produced changes in the physiochemical properties of the powders when stored at room temperature. It also caused accumulations and glueyness in the powders when stored in uncontrollable conditions. This resulted in higher water retention in the powders as a result of a surge in the hygroscopicity in the powders. A ratio of 7% MD and 3% FTs is recommended to be added to the powders to produce a synergistic effect, but further analysis is required to prove the same. The use of this technology can allow the production of mango and pineapple powders that have better physiochemical stability and quality [28].

Use of agave in tequila and tequila-based spirits: This study incorporates nectar derived from the agave plant and mixed in small discreet proportions with the produced tequila or tequila-like spirits. The present

invention improves the direct taste of tequila through the nectar addition [29].

Use of Agave sugar in Maqui berries gel: Maqui berries have a high concentration of antioxidants and exhibit anti-atherosclerotic effects. To take maximum advantage of these properties, agave sugar was used as a replacement instead of beet sugar in maqui berries gel. The research specifically studied the sensory, textural, and antioxidant properties of these gels. The study concluded that with the addition of citric acid at 0.5% concentration agave syrup is a better replacement than beet sugar in maximizing the antioxidant activity of gels [30].

Disadvantages of using Agave: While going through the literature review for our study the authors also came across a few disadvantages of using Agave which is summed up under the below subheadings:

Adulteration: Agave syrup being expensive is diluted and adulterated using comparatively cheaper corn syrup.

Labeling: It is heated up to 118°C and is a processed product and not raw as it is labeled.

High fructose consumption: Overconsumption of fructose appears to interfere with copper metabolism, increase uric acid, increase blood lactic acid, and so on [31].

DISCUSSION

Properties: Both species (*Agave Tequilana* & *Agave Salmiana*) contain high fructose content that is above 70%, with some samples of *Agave Tequilana* having 92% fructose. Relatively darker than honey and sweeter than sucrose its density- is 1.49 g/ml, the surface tension of 45.3 dinas/cm, viscosity 212 mPa-. Low GI (Glycemic Index), antioxidant properties, and antibacterial characteristics are some of the biological benefits of using Agave.

Table 2. Included reporting on animal studies related to Agave and its byproducts

Authors	Study	Type of study	Aim of study	Results
Hooshmand S, Holloway B, Nemoseck T, et al. 2014.	Study on young weanling mice for 34 days	A diet based on agave nectar versus a diet based on sucrose	Weight gain adiposity, plasma blood glucose, insulin, and lipid levels were measured	Better weight regulation, plasma glucose, and insulin homeostasis with an agave nectar-based diet.
Sáyago-Ayerdi SG, Mateos R, Ortiz-Basurto RI, et al. 2014	Study on hypercholesterolemic rats	ADF (Agave Dietary fiber) and ADF-JC Jamaica Calyces	Body weight gain and redox status	Displayed favorable effects as functional ingredients to decreasing body weight gain
Valle M, St-Pierre P, Pilon G, Murette A. 2020	Rat Model of Diet-Induced Obesity	Differential Effects of Chronic Ingestion of Refined Sugars versus Natural Sweeteners	Insulin Resistance and Hepatic Steatosis	Glucose tolerance was similar, lower glucose induced hyperinsulinemia was witnessed with fructose. Lower insulin resistance compared to sucrose treatment and reduced hepatic IL-1B levels were observed with agave syrup

Table 3. Included evidence, studies, and patents related to the commercialization of Agave and its byproducts.

Product	Substitute	Result
Chocolate	Low moisture agave syrup	Sugar-free chocolate that tasted good, retained its stability at room temperature and had the desired snap, luster, and taste that consumers demanded from chocolate
Nutritional supplement	Blue agave nectar	Nutritional Supplement had thermogenic effect and health benefits from Omega-3 and Omega-6 fatty acids
Muffins	Agave Syrup	Muffins were best when the syrup is used in a mixture with the addition of xanthum gum and doubled quantities of leavening agents
Dairy Products- Yoghurt	Agavins from <i>Agave angustifolia</i> and <i>Agave potatorum</i> species	All yogurt samples displayed strain thinning and weak viscoelastic gel properties, but an improvement was seen in the mouthfeel and texture of the samples.
Granola Bars	Agave syrup and fructans sweeteners and agave fiber from stem of <i>Agave Tequilana</i>	Oat-based granola bars containing agave are feasible, sensory acceptable, and exhibit a low predicted glycemic load.
Raspberry jam	Agave syrup	The study revealed that using agave syrup and sorbitol was useful in the preparation of raspberry jam as it had superior hedonistic quality as compared to sucrose and other sweeteners
Teriyaki sauce	Fructooligosaccharide, xylitol, erythritol, and agave syrup	The results indicated that xylitol was a good ingredient for sauce considering taste and flavor
Ice cream	agave fructans	Low-fat ice cream produced results with improved sensory, thermal, and textural properties.
pineapple and mango powder	Agave FT and maltodextrin (MD)	Produced positive effects in the physiochemical properties in the drying process of the powders
tequila and tequila-based spirits	Nectar from agave syrup	The present invention improves the direct taste of tequila through the nectar addition
Maqui berries gel	Agave syrup	With the addition of citric acid at 0.5%, concentration agave syrup is a better replacement than beet sugar in maximizing the antioxidant activity of gels.

CONCLUSION

Agave has a vast history of usage and dependability; this was due to various factors like shortage of vegetation and harsh climate, especially in southern and western US and Mexico. Its social and economic status made it a dietary staple among several Indigenous communities in the past. Though presently the majority of its production is controlled and regulated by the Mexican government, there are still concerns regarding adulteration and fake products. Since agave syrup has a low glycemic index, it opens opportunities for its usage in products that depend heavily on sucrose. Looking at its recent studies and commercial substitution it is wise to assume that it has good potential to replace sucrose in the near future although long-term health benefits and its status as functional food need acute exploration.

List of Abbreviations: BC, Before Christ; AD, After Death; CAM, Crassulacean Acid Metabolism; GI, Glycemic Index; ADF, Agave Dietary Fibre; ADF-JC, Agave Dietary Fibre Jamaica Calyces; FT, Fructans; MD, Maltodextrin.

Authors' contribution: Rizwan Yargatti conceptualized the work and prepared the successive drafts. Arti Muley reviewed and approved the final draft.

Competing interest: The authors declare no conflict of interest.

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