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A Comparative Analysis of Crystalline Sugar Substitutes for Better Food and Beverage Choices

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ABSTRACT

This research paper was set out to determine the best sugar substitute by comparing the sugar concentration of various prospective replacements. With five trials each of sugarcane, pandan, stevia, sugar beet, and jaggery, the study uses the Lane Eynon titration method. The findings show the substantial sugar concentrations in other sugar substitutes, particularly jaggery, and stevia's absence of sugar content. These findings have been validated through an ANOVA test. The experiment successfully matches with prior studies and provides a comprehensive data set, adding to the overall understanding of sugar content in a variety of substitutes. This study lays the foundation for people to make healthier dietary choices.

Introduction

Nearly all people are extremely susceptible to the appeal of sweet food, which often leaves us craving more. Despite our greatest efforts, reducing our sugar intake is a complex undertaking. Interestingly, Americans consume an average of 70 grams of sugar daily, far more than the 30 grams recommended (How Much Sugar Is Too Much?, n.d.). This poses the question of why we have such a strong affection for sugar. There are numerous causes, including biological, psychological, and chemical ideas. This study intends to explore the biological implications and offer solid solutions to this intriguing query. I have carried out an experiment using the Lane Eynon approach to accomplish this goal, which will be completely detailed and investigated later in this paper.

Monosaccharides, disaccharides, and polysaccharides are only a few of the several carbohydrate types that make up sugar, a staple of human meals. These different forms of carbohydrates appear in the form of glucose, fructose, sucrose, and lactose. Every cell in our bodies uses glucose, the most abundant and essential energy source, to survive. Having a Glycemic Index (GI) value of 100, glucose stimulates the release of leptin, ghrelin, and insulin, increasing hunger. The GI rating is a gauge of how foods high in carbohydrates affect blood sugar levels. Low GI foods make it easier to maintain a healthy weight; however, high GI foods may put people at risk for disease.

Because of its sweetness, fructose is often used as a sweetener in a variety of foods and beverages. Despite having a low GI score of 19 or so, a high level of fructose consumption can result in weight gain and an increased risk of obesity since it is converted to fat and stored in the body as triglycerides (Lustig, 2013). Given that it contains glucose, it may potentially contribute to cardiovascular disease and type 2 diabetes. With a GI rating of 65 and characteristics comparable to fructose, sucrose is a disaccharide made up of an equal amount of glucose and fructose (*Glycemic Index*, n.d.). The absorption of important minerals, including calcium, magnesium, and zinc, is aided by lactose, which is generally present in milk and is composed of glucose and galactose. Lactose has a GI value of 46 (*The Importance of Lactose in the Human Diet: Outcomes of a Mexican Consensus Meeting*, 2019). Notably, many gastrointestinal problems can result from lactose intolerance, a common ailment caused by the body's inability to generate the lactase enzymes needed to break down milk.

Food businesses increasingly use sugar alternatives to retain sweetness while reducing sugar content because of the rising obesity issues associated with excessive sugar consumption. As a sports enthusiast, I became aware of this tendency when I discovered that a sports drink had 0% sugar, despite its obvious sweetness. A closer inspection revealed that stevia had been used in place of sugar. This discovery motivated me to research the natural sugar replacements present in numerous plant species. Without evaluating artificial sweeteners made through chemical synthesis, the present paper will focus on sugar substitutes obtained from *stevia rebaudiana*, *pandanus amaryllifolius, saccharum officinarum*, *beta vulgaris*, and jaggery, excluding the evaluation of chemically synthesized artificial sweeteners.

Literature Review

Stevia rebaudiana

Stevia rebaudiana, a perennial herb grown all over the world for its naturally occurring sweetener, stevia, is rapidly gaining popularity as a sugar substitute in many industrial products. This is demonstrated by the well-known sports drink Gatorade Fit, which recently switched to stevia in favor of sugar and artificial sweeteners. Stevia does not obtain its sweetness from sucrose like the other sugar alternatives in this study, so it is different. It has both benefits and drawbacks. According to a 2009 study (*Effect of Stevia Extract Intervention on Lipid Profile*, n.d.), stevia could reduce low-density lipoprotein (LDL), or "bad cholesterol," while raising high-density lipoprotein (HDL), or "good cholesterol." Blood lipid cholesterol serves important physiological purposes but must be controlled to prevent coronary heart disease. According to "Cholesterol: Understanding Levels and Numbers," LDL cholesterol can cause plaque to form, which can cause heart attacks, whereas HDL cholesterol may help in the removal of extra cholesterol and prevent plaque from developing. Because stevia has a beneficial effect on cholesterol levels, it is a healthy sugar substitute. Stevia's flavor, which is not as sweet as white sugar and occasionally has a somewhat bitter aftertaste, is the only known downside.

The amaryllis-flowering pandanus

Because of its sweet aroma, the tropical herbaceous plant *pandanus amaryllifolius*, native to Southeast Asia, is frequently used as a powdered paste in sweet dishes. Many Asian recipes, such seri muka (coconut pandan layer cake), serabi kuah (Indonesian coconut pancakes), and pandan waffles, use its unique green hue and aroma (*11 Essential Sweet & Savoury Pandan Recipes*, 2022). Blood sugar stabilization, blood pressure lowering, digestive help, and immunological strengthening are only some of the health advantages of pandan. The Thai people have traditionally relied on pandan leaves as a natural medicine because of this. However, unlike stevia, pandan contains a lot of sugar, which could be harmful if ingested in large quantities. Consuming too much can result in diarrhea, which can have unpleasant side effects such as bloating, cramping, and vomiting (*Pandanus odoratissimus (Kewda): A Review on Ethnopharmacology, Phytochemistry, and Nutritional Aspects,* n.d.).

Saccharum officinarum

The perennial grass *saccharum officinarum*, frequently referred to as sugarcane, is grown for its sweet, sugar-rich juice. Since 8000 BCE (Rook), 2019, sugarcane has been the primary supplier of sweets for food and drink. This plant produces almost all the sugar needed in the culinary world via a straightforward boiling procedure. The main benefit of sugarcane as a natural sweetener is its high carbohydrate content, which offers the body a fast energy source. Additionally, it has vitamin C, an antioxidant that may lower the risk of conditions including coronary heart disease. However, sugarcane's high sugar content can drastically increase blood sugar levels, resulting in possible health issues like diabetes and obesity (Ajmera, 2019).

Beta vulgaris

Beta vulgaris, also referred to as beetroot, is a root vegetable that contains significant amounts of vitamins, carbohydrates, and water. Beetroot was first used commercially as a natural sweetener in 1870. Today, 52 countries farm sugar beets, which yield about 4.5 million tons of sugarcane (*History of Real Sugar: The Story of Sugar Beets | Sugar.org*, n.d.). Because of its high inorganic nitrate content, beetroot can decrease blood pressure and increase exercise capacity. On the other hand, beetroot contains toxic substances such as oxalates and FODMAPs that can cause kidney stones to develop and hinder the absorption of vital minerals. By harming the gut flora, which is essential for human immune and digestive processes, FODMAPs can also upset the digestive system (Bjarnadottir, 2023).

Jaggery

An unrefined sugar substitute, jaggery is mostly made in Asia and Africa. It includes more glucose and fructose than sucrose, in contrast to most white sugar replacements. India is the source of more than half of the world's jaggery, also known there as "gur." All jaggery varieties are used in traditional desserts and drinks like palm wine, though Indians tend to favor lighter-coated varieties because of their greater sucrose and lower glucose and fructose content. Because of its high iron and vitamin C content, jaggery strengthens the immune system, improves digestion, and provides extra iron. However, these benefits only materialize with large consumption, which raises the risk of sugar overload. Jaggery use in excess can, like other sugar alternatives, lead to obesity, heart disease, and type 2 diabetes (West, 2016).

Lane and Eynon Method

The Lane and Eynon method is a popular technique for calculating the concentration of reducing sugars. This technique uses sodium potassium and world's finest copper sulfate, respectively, as components of Fehling's solutions A and B. The determination of sugar composition depends on the Fehling's solution factor, which is the amount of invert sugar necessary to totally diminish Fehling's solution. This is accomplished by a straightforward titration procedure in which samples of the sugar replacement react with Fehling's solution until a pinkish endpoint is reached. In this investigation, a lower total sugar composition in the evaluated sugar substitute correlates, and vice versa, with a longer titration period. I reviewed earlier assessments of various sugar kinds in each sugar replacement used in the present research before coming up with the hypothesis and starting the experiment. In general, it was discovered that stevia contains no sugar (Ogliore, 2019), pandan contains 2.38 mg of fructose and 1.77 mg of glucose per gram (*Free amino acid and reducing sugar composition of pandan (Pandanus amaryllifolius) leaves,* n.d.), sugarcane contains 12 to 21% sucrose (Brennan, 2021), sugar beet contains between 12 and 21% sucrose (Sugar beet, n.d.), and jaggery contains 75% sucrose, 12.5% of glucose and fructose (Marengo, 2021).

Hypothesis

Before stating the hypothesis, I have initially found all the true values for the sugar content inside in each sugar substitute. The real values were as follows; Stevia with 0 % of any sugar, pandan with about 0.4% of sucrose, sugarcane with 15% of sucrose, sugar beet with 12 to 21% of sucrose and jaggery with 75% sucrose. After consideration of these significant numerical values and each products' assets to refine humans' body from all kinds of severe diseases like obesity and diarrhea, the hypothesis would be as follows:
If Lane Eynon titration method is exploited to find out the experimental values of all sugar contents in each sugar substitutes, stevia will be assigned as the favorable sugar substitute due to its pureness created due to the exemption of any type of sugar and additionally, it can prevent numerous diseases as it is known to not contain any sugar, hence

no heart attack nor diarrhea nor obesity would likely to occur in humans' body when it is consumed. Thus, it is predicted that stevia would be the best substitute for sugar with zero or little sugar composition.

Variables

The independent variable in this experiment will be the type of sugar substitutes measured in this experiment as mentioned multiple times above. There are 5 different types with 1 sample of sucrose which would be the control variable. The dependent variable during the experiments will be the concentration of total sugar in each source for sugar mentioned and described previously. I will be using a titration method in order to determine this value. These concentrations of total sugar will be measured and calculated in percentages (%).

Materials

- 25g of *Stevia rebaudiana*
- 25g of *Pandanus amaryllifolius*
- 25g of *Saccharum officinarum*
- 25g of *Beta vulgaris*
- 25g of Jaggery
- 4L of Distilled water
- 300mL of Fehling's solution A
- 300mL of Fehling's solution B
- 1 Digital weight
- 20x Filter papers
- 6x 250mL Volumetric flask
- Hot plate
- 10mL of 1% Methylene blue
- 6x Magnetic stirrers
- 25g of Sucrose
- 100mL of 20% NaOH
- 100mL of 37% HCl
- 20mL of Phenolphthalein indicator
- 1x 500mL Volumetric flask
- 6x 100mL Volumetric flask

Procedure

1. Measure 5g of sucrose with a digital weight and prepare a 500mL volumetric flask and add 2.5mL of HCl, 5g of sucrose and 100mL of distilled water.
2. Wait for 3 days in room temperature and add enough distilled water to reach 500mL.
3. Transfer 62mL of this solution into a 250mL volumetric flask and add few drops of phenolphthalein indicator solution until solution is turned to pink.
4. Neutralize the solution with NaOH until pink color disappears and add enough distilled water to reach 250mL.
5. Measure 5g of the sugar substitute (one and at a time), add 150mL of 60 degrees distilled water with it and place it in a 250mL volumetric flask with addition of more distilled water until 250mL is reached.
6. Filter the sample with filter paper, remove the first 25mL of the solution and pipette 50mL of filtered solution into a 100mL volumetric flask and add 2.5mL of HCl.

7. Add a few drops of phenolphthalein indicator solution until the solution is turned to pink.
8. Neutralize the solution with NaOH until the pink color disappears and add enough distilled water to reach 100mL.
9. Prepare 5mL of Fehling's solution A and B each and add 30mL of distilled water with a magnetic stirrer (for the sucrose sample)
10. Place the flask with this solution on a hot plate, place a burette and fill it with the working solution prepared in step 1 and 2.
11. When the solution inside the flask starts to boil, initially note the burette reading and add 4 drops of methylene blue in the flask and turn on the magnetic stirrer.
12. Drop the working solution from the burette until bright orange appears and not the final burette reading.
13. Prepare 5mL of fehling's solution A and B each and add sample solutions with sugars substitutes depending on their true concentration of sugar (Above 80% of total sugar: add 4mL, 50~80%: add 5~7mL, 30~49%: add 10mL, 11~29%: add 17mL, below 10%: add 25mL), then dilute up to 50mL and place it on a hot plate with a magnetic stirrer.
14. Prepare the burette with the working solution and when the solution inside the flask starts to boil, add 4 drops of methylene blue and note the initial reading.
15. Start dropping the working solution inside the flask until the solution reaches a bright orange color and note the final reading of the burette.

Overview of all samples prepared for the experiment

Figure 1. All the samples gathered with all the materials used and required for titration.

Data

Table 1. First trial of titration for all 5 sugar substitutes.

Sugar source	**Sucrose sample**	**Sugarcane**	**Pandan**	**Stevia**	**Sugar beet**	**Jaggery**
Initial reading (mL)	34	20.0	26.3	0.0	32.3	6.0
Final reading (mL)	59.5	40.8	51.6	80.2	53.6	15.7
Final reading - Initial reading (mL)	25.5	20.8	25.3	80.2	21.3	9.7

Table 2. Second trial of titration for all 5 sugar substitutes.

Sugar source	**Sucrose sample**	**Sugarcane**	**Pandan**	**Stevia**	**Sugar beet**	**Jaggery**
Initial reading (mL)	11.0	4.0	21.9	1.0	31.0	38.0
Final reading (mL)	36.7	24.7	47.3	75.9	52.2	47.1
Final reading - Initial reading (mL)	25.7	20.7	25.4	74.9	21.2	9.1

Table 3. Third trial of titration for all 5 sugar substitutes.

Sugar source	**Sucrose sample**	**Sugarcane**	**Pandan**	**Stevia**	**Sugar beet**	**Jaggery**
Initial reading (mL)	6.0	31.5	7.2	0.0	29.9	26.1
Final reading (mL)	32.2	52.6	33.3	76.5	51.3	36.1
Final reading - Initial reading (mL)	26.2	21.1	26.1	76.5	21.4	10.0

Table 4. Fourth trial of titration for all 5 sugar substitutes.

Sugar source	**Sucrose sample**	**Sugarcane**	**Pandan**	**Stevia**	**Sugar beet**	**Jaggery**
Initial reading (mL)	7.4	7.8	13.4	0.0	22.7	7.7
Final reading (mL)	31.9	26.4	37.7	82.7	41.5	17.1
Final reading - Initial reading (mL)	24.5	19.6	24.3	82.7	18.8	9.4

Table 5. Fifth trial of titration for all 5 sugar substitutes.

Sugar source	**Sucrose sample**	**Sugarcane**	**Pandan**	**Stevia**	**Sugarbeet**	**Jaggery**
Initial reading (mL)	4.0	25.2	9.4	0.0	14.5	28.2
Final reading (mL)	25.2	42.6	29.7	74.5	32.2	35.1
Final reading - Initial reading (mL)	21.2	17.4	20.3	74.5	17.7	6.9

Table 1,2,3,4 and 5 deduce all the data for five trials done for each sugar substitute in the titration.

Calculations

- Sugar working standard concentration = $0.0025 \frac{g}{mol}$
- Weight of all the sucrose replacements = 5.0g
- Volume of final sample solution used during titration = 5mL

Volume of working standard for blank titration

1. 59.5mL - 34.0mL = 25.5mL
2. 36.7mL - 11.0mL = 25.7mL
3. 32.2mL - 6.0mL = 26.2mL
4. 31.9mL - 7.4mL = 24.5mL
5. 25.2mL - 4.0mL = 21.2mL

Average: $\frac{(25.5 + 25.7 + 26.2 + 24.5 + 21.2)}{5}$ = 24.62mL

Volume of working standard for *saccharum officinarum* titration

1. 40.8mL - 20mL = 20.8mL
2. 24.7mL - 4.0mL = 20.7mL
3. 52.6mL - 31.5mL = 21.1mL
4. 26.4mL - 7.8mL = 19.6mL
5. 42.6mL - 25.2mL = 17.4mL

Average: $\frac{(20.8 + 20.7 + 21.1 + 19.6 + 17.4)}{5}$ = 19.92mL

Standard Deviation: 1.5189

Volume of working standard for *pandanus amaryllifolius* titration

1. 51.6mL - 26.3mL = 25.3mL
2. 47.3mL - 21.9mL = 25.4mL
3. 33.3mL - 7.2mL = 26.1mL
4. 37.7mL - 13.4mL = 24.3mL
5. 29.7mL - 9.4mL = 20.3mL

Average: $\frac{(25.3 + 25.4 + 26.1 + 24.3 + 20.3)}{5}$ = 24.28mL

Standard Deviation: 2.3156

Volume of working standard for *stevia rebaudiana* titration

1. 80.2mL - 0.0mL = 80.2mL
2. 74.9mL - 0.0mL = 74.9mL
3. 76.5mL - 0.0mL = 76.5mL
4. 82.7mL - 0.0mL = 82.7mL
5. 74.5mL - 0.0mL = 74.5mL

Average: $\frac{(80.2 + 74.9 + 76.5 + 82.7 + 74.5)}{5}$ = 77.76mL

Standard Deviation: 3.562

Volume of working standard for *beta vulgaris* titration

1. 53.6mL - 32.3mL = 21.3mL
2. 52.2mL - 31.0mL = 21.2mL
3. 51.3mL - 29.9mL = 21.4mL
4. 41.5mL - 22.7mL = 18.8mL
5. 32.2mL - 14.5mL = 17.7mL

Average: $\frac{(21.3 + 21.2 + 21.4 + 18.8 + 17.7)}{5}$ = 20.08mL

Standard Deviation: 1.7167

Volume of working standard for jaggery titration

1. 15.7mL - 6.0mL = 9.7mL
2. 47.1mL - 38.0mL = 9.1mL
3. 36.1mL - 26.1mL = 10.0mL
4. 17.1mL - 7.7mL = 9.4mL
5. 35.1mL - 28.2mL = 6.9mL

Average: $\frac{(9.7 + 9.1 + 10.0 + 9.4 + 6.9)}{5}$ = 9.02mL

Standard Deviation: 1.2317

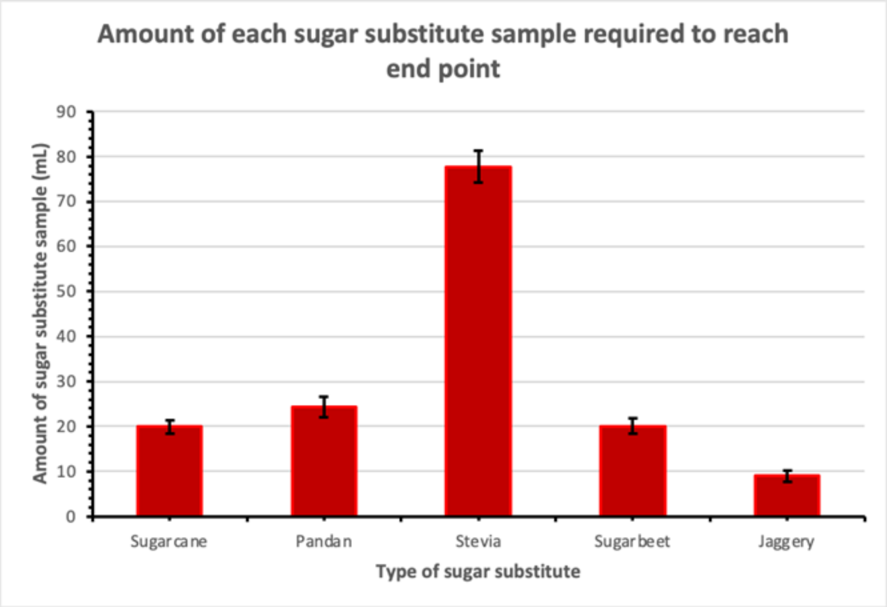

Figure 2. Graph with each sugar substitutes' amount required to end titration (indication of amount of sugar, higher the value, less total sugar) with standard deviation.

Equation 1: Example of an equation that will be used to determine the percentage of sugar:

$$\text{\% Reducing Sugars in the sample} = \frac{0.0025 \times V_1 \times V_2 \times 100}{V_3 \times W}$$

V_1 = Amount of sugar substitute sample
V_2 = Dilution volume for the sample
V_3 = Volume of clarified sample solution required for Fehling's reaction
W = Weight of sugar substitute sample

(Unit 7, n.d.)

1. Total sugar percentage of sugarcane: $\frac{0.0025 \times (24.62-19.92) \times 25{,}000 \times 100}{25 \times 50}$ = 23.5%
2. Total sugar percentage of pandan: $\frac{0.0025 \times (24.62-24.28) \times 25{,}000 \times 100}{25 \times 50}$ = 1.7%
3. Total sugar percentage of stevia: $\frac{0.0025 \times (24.62-24.85) \times 25{,}000 \times 100}{25 \times 50}$ = -1.15%
4. Total sugar percentage of sugarbeet: $\frac{0.0025 \times (24.62-20.08) \times 25{,}000 \times 100}{25 \times 50}$ = 22.7%
5. Total sugar percentage of jaggery: $\frac{0.0025 \times (24.62-9.02) \times 25{,}000 \times 100}{25 \times 50}$ = 78%

Sample of a solution that has reached the end point.

Figure 3. The color of the solution should look like above when the end point has been reached.

Result

The results of Lane Eynon Fehling's approach after five rounds produced the following sugar concentrations: sugarcane at 23.5%, pandan at 1.7%, stevia at -1.15% (effectively 0%), sugar beet at 22.7%, and jaggery with a notable high sugar content of 78%. Stevia had the least amount of sugar in the sugar content hierarchy, which was followed by pandan, sugar beet, sugarcane, and jaggery, which had the highest concentration. The experiment successfully demonstrated that stevia contains no sugar, supported by earlier studies, and that the sugar content of other substitutions was substantially comparable. The experiment may have been improved upon even though it was mostly successful.

Analysis

The exploration for the source of stevia to the experiment's endpoint was noticeably longer than expected in the search for the ultimate sugar substitute. Data collection was difficult, necessitating more trial iterations before stevia was determined to be the endpoint. Despite running numerous titration tests for stevia, getting a predictable outcome remained challenging. Stevia specifically showed a negative proportion of total sugar content, which defied logic. The stevia sample took longer than expected to reach the endpoint, which produced this negative number. The experiment, therefore, clearly shows that stevia does not contain sugar. Additionally, every alternative sugar substitute that was tried produced accurate results. The percentage mistakes in sugar content for each alternative were as follows when compared to data from earlier studies:

1. *Saccharum officinarum*: $\left|\frac{23.5-15.0}{15.0}\right| = 56.7\%$

2. *Pandanus amaryllifolius*: $|\frac{1.7-0.4}{0.4}| = 3.25\%$

3. *Stevia rebaudiana*: $|\frac{0.0-0.0}{0.0}| = 0\%$

4. *Beta vulgaris*: $|\frac{22.7-21.0}{21.0}| = 8.1\%$

5. Jaggery: $|\frac{78.5-75.0}{75.0}| = 4\%$

The percentage error was less than 10% throughout, except for sugarcane, indicating that the experimental results were highly accurate and precise. However, sugarcane showed a substantial percentage inaccuracy greater than 50%. This discrepancy could be related to possible titration processes interruptions, such as modest changes in the concentration of the sucrose sample or slight fluctuations in the quantities of Fehling's solutions and sugar substitute samples utilized. An ANOVA test was run on the data sets to ensure that the results were consistent with the predicted values. A p-value of less than 0.00001 indicated statistical significance. Except for stevia, all findings from the four independent variables were statistically significant. This was primarily because, in comparison to the other alternatives, the stevia solution needed a much larger volume to reach the goal. The majority of the information for the other sugar alternatives, however, was significant.

Evaluation

Despite noteworthy outcomes that closely match those of other studies, there is always room for improvement. The sugarcane results were alarming given the low sample size of the other sugar replacements. This discrepancy might be brought about by irregular laboratory visit intervals, which might have had an impact on the sugar substitutes' quality. Every sugar substitute has an expiration date that could change how sugary it is. Additional tests might have increased the accuracy of the results. Five trials offer a trustworthy dataset, but doing more trials might produce even more accurate results.

Conclusion

After carefully examining the entire experimental process and evaluating its findings, it can be concluded that stevia and pandan stand out as the best sugar substitutes for culinary applications. This is mostly because of their extremely low sugar contents—0% and 1.7%, respectively—which makes them great sugar substitutes. Given that it is currently a substitute in the commercial food and beverage industries, stevia in particular seems to be a desirable option for individuals looking for a sugar-free substitute. However, when examining the subtle differences between these sugar alternatives, pandan may have an advantage over stevia. Stevia is a common choice among consumers despite the undeniable fact that it contains no sugar. Instead, it is sweeter than regular sugar. Because of the existence of steviol glycosidic molecules, which are discovered to be "250-300 times sweeter than regular sugar" (Shoemaker, 2019).

However, this feature of stevia could result in a negative effect. Studies show that steviol glycosides cannot be broken down by the human body since neither gastric juice nor digestive enzymes can do so (Orellana, n.d.). Comparisons to disorders like lactose intolerance, in which some people are unable to digest lactose, a type of sugar present in milk products, may be made in light of this. Compared to the other sugar alternatives tested in this trial, which are mostly based on sucrose or glucose, stevia is difficult to digest. The human body can easily process these carbohydrates. Meanwhile, steviol glycosides are challenging for our small intestines to digest and absorb because of their complicated structure and large molecular weight. This might make people more likely to become obese.

It is important to note that steviol glycosides can be "degraded by bacterial intestinal flora, transforming it into free steviol," which can subsequently be assimilated by the human body (Geuns et al., 2003, 1600). However, this procedure promotes the growth of gut bacteria, which could have its own negative effects.

Therefore, moderate sugar intake is essential despite the risks connected to high sugar intakes, such as numerous ailments like diarrhea, obesity, and heart disease. Numerous health benefits could come from choosing sugar replacements with favorable nutritional characteristics. Pandan, for example, has been discovered to increase the effectiveness of antibiotics in human bodies, preventing bacterial infections (*Sugar administration is an effective adjunctive therapy in the treatment oit'seudomonas aeruginosa pneumonia*, n.d.). Thus, with a relatively low risk of obesity, consuming little amounts of sugar has the potential to improve a number of health-related factors, including the effectiveness of antibiotics.

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