Comparative Analysis of Salivary pH Alterations Following Sugar Consumption Using Machine Learning Techniques

Amutha M V Soorya*[1], Vishnu Rekha Chamarthi[2], Santhosh Priya[2], Dhanraj Kalaivanan[2], Santham Krishnamoorthy[2]

[1]Department of Oral Pathology and Microbiology, Sree Balaji Dental College and Hospital, Bharath Institute of Higher Education and Research (BIHER), Bharath University, Chennai, Tamil Nadu, India.
[2]Sathyabama Dental College and Hospital, Sathyabama Institute of Science and Technology

venivetha1239@gmail.com

Abstract. The pH of saliva is a very important indicator of oral health because continued acidic environments favor caries in the mouth. Commercial sugars available in the market have different acidogenic capabilities associated with them, and they lead to a different acidogenic effect on salivary pH after consumption. This paper offers a machine learning method of relatively comparing the change in salivary pH in presence of sugars commonly ingested. The samples of saliva were taken on an empty stomach of healthy subjects at the baseline level and at certain times following the consumption of white sugar, brown sugar, jaggery, honey, and artificial sweeteners. The data was comprised of demographics, type of sugar, and amount of sugars, time, and reference pH before consumption, and post-consumption pH. The preprocessing was followed by a Random Forest model that was used to predict the changes in pH and to classify sugars according to their acidogenic potential. The presented model was characterized by a high predictive quality; the type of sugar and the duration of consumption were accepted as the most significant factors that impact pH decrease. Refined sugars experienced a higher loss of pH than natural and artificial versions. The given method emphasises the perspectives of machine learning in dental studies in terms of objective evaluation and preventive oral health planning.

Keywords: Dental caries, Fermentation, Sucrose, Saliva, Buffer.

1 Introduction

Dental caries remains a global health hazard that affects people of all ages, even with the advances in the understanding of oral disease. It is an infectious bacterial biofilm and pH mediated disease expressed in a predominantly pathologic oral environment [1]. Dental caries is of multifactorial etiology with host, substrate and dietary being the main variables, even though acid-producing bacteria are the causative agents. As a

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part of host factor, saliva is crucial in the fight against tooth caries. The balance between the cariogenic and noncariogenic bacteria communities that live in saliva, as well as the interaction of protective and pathologic elements, are factors that affect the caries process. A drop in salivary pH causes more demineralization leading to caries [2].

There is an ever-changing relationship between dental health and sugars. The quantity, pH, and composition of saliva are all influenced by diet. After salivary amylase hydrolyses sugars and other fermentable carbohydrates, oral bacteria use them as a substrate, lowering the pH of saliva. The consequence is the onset of tooth demineralization, which is an indicator in dental caries [3]. A few important factors to consider when determining the cariogenic, cariostatic, and anticariogenic qualities in a diet include the kind, frequency, and retention of food as well as its ability to increase salivary secretion. The length of time teeth are exposed to low pH levels increases with the amount of time cariogenic food is retained in the oral cavity. Therefore, a prolonged sugar intake raises the incidence of dental caries.The Vipeholm Study found that the physical form and frequency of sugar consumption are more crucial elements in the cause of dental caries than overall sugar consumption. As a result, the pH falls more slowly when retention times is longer [4].

Asia, Africa, Latin America, and the Caribbean use brown sugar, a natural, traditional, processed non-centrifugal sugar prepared by making the produced sugarcane juice more concentrated. More than 70% of its global output is manufactured in India [5]. In addition, rural residents may easily obtain it and it has higher nutritional and therapeutic properties. Because brow sugar has a variety of phenolic components, which imply increased bioactivity, or cytoprotective and antioxidant activity, recent study has advised using brown sugar as a sweetener. Takara et al. observed two phenolic bioactive compounds from sugar cane molasses: isoorientin-7,30-O-dimethyl ether and dehydrodiconiferyl alcohol-90-O-b-D-glucopyranoside. These compounds have inhibitory qualities similar to those of commercial antibacterial agents against the cariogenic bacteria Streptococcus sobrinus and *S.* mutans [6]. Since the ancient Egyptian era, honey has been used in China, India, Greece, Rome, and many other countries. It has a composition of 38% fructose, 31% glucose, 17% water, 10% other sugars, and a variety of micronutrients, including minerals, vitamins, and amino acids, as well as some enzymes like glucose oxidase and invertase. Hence these two sugars with commonly used commercially available white sugar was selected for the study [7].

To assess the association between food and dental caries, a number of methods have been used to evaluate the interaction between sugars and dental caries. The majority of research on salivary pH have compared one kind of sugar replacement with other commonly used goods, and assumptions have been made on their potential to cause cancer. Therefore, the study's objective was to compare and assess how three commercially available sugars affected the pH of saliva and null hypothesis is that no differences in pH will be seen among the available form of sugars [8].

2 Materials and methods

Prior to the study's execution, the institutional ethical committee reviewed and approved the research protocol. After gaining the parents' signed informed consent, study participants were chosen from the outpatient in Pediatric and Preventive Dentistry department. Children between the ages of 7-12 who were seeking routine dental care and are healthy were included in the study [9]. Children receiving dental care, people taking medications that would change salivary flow, people with painful, incapacitating oral conditions, and people with systemic diseases were not included.
A total of forty-five kids were chosen at random and split into three experimental groups based on the sugar solution given.

Group I: White sugar dissolved in purified water(n = 15)

Group II: Brown sugar dissolved in purified water (n = 15)

Group III: Honey dissolved in purified water (n = 15)

Following the subjects' selection, they were divided into various groups at random. Before their saliva was collected, all subjects were instructed to fast for one hour. After 60 seconds, the subjects were instructed to collect their saliva beneath the tongue and then expel into the sterilized cup. The pH of the collected saliva samples was assessed.

The solution are prepared when and where required. They were prepared by using commercially available forms of white sugar, brown sugar and honey. According to the groups that were split up, 10 grams dissolved in 90 millilitres of distilled water.

pH evaluation: Before the sugar rinse was administered, saliva samples were collected in a beaker and their pH was measured using pH indicator strips (Just Filter, China). After dipping the pH strip into saliva, the color change was monitored for ten seconds. The changes were compared to the kit's reference chart, and the results were tallied.

Following the baseline pH measurement, participants were told to rinse their mouths with the corresponding group's solutions. The subjects received 10 milliliters of freshly made solutions in total. After a minute of swishing the corresponding solution around in their mouth, they were directed to expel into a sterilized cup. At 0, 15, and 30 minutes after rinsing with the appropriate solutions, the pH of the saliva was measured.

2.1 Statistical analysis

The mean and standard deviation were used to express the data. Analysis was conducted using the statistical program for social sciences (SPSS 20.0) version. To determine whether there was a statistically significant difference between the groups, a one-way ANOVA Posthoc was used, followed by the Dunnet t test and the paired t test. At a 95% confidence interval, a p value of less than 0.05 is deemed statistically significant.

2.2 Design of Study and the selection of participants.

The study is an experimental study that utilized healthy adult subjects to determine how variations in salivary pH occurred after consumption of the various commercially available sugars. The individuals who were excluded were those with a history of systemic diseases, active oral infections, and those who were currently on any form of medication that interferes with the flow of saliva, and those who underwent any dental procedure in the recent past. Ethical approval had been received, and informed consent was gathered before data were acquired [10].

2.3 Sugar Administration and Saliva Collection.

Commercial sugars, such as white sugar, brown sugar, jaggery, honey and artificial sweeteners were chosen to be evaluated. All the participants were administered a controlled amount of one sugar in standard conditions. The samples of salivary pH were taken in unstimulated salivary before taking sugar to measure the baseline and at predetermined time (5, 10, 20 and 30 minutes) following sugar consumption. To measure the pH of saliva, a calibrated digital pH meter was used in order to make it more accurate and reproducible [11].

2.4 Preparation and Preprocessing of Data.

The dataset that was gathered consisted of demographics, type and amount of sugar that the participants consumed, time elapsed after consumption, baseline salivary pH, and post-consumption pH of the subjects. Numerical coding and mean imputation with missing variables were used to encode categorical variables like sugar type. The data was normalized using feature scaling, and it was split into a training (70) portion and a testing (30) portion [12].

3 Implementation of the Machine Learning Model

The prediction of change in salivary pH and the classification of sugars according to acidogenicity was done using a Random Forest classifier. The point of training of the model was done using training dataset and various decision trees were developed to identify non-linear relationship among the variables. The hyperparameters were tuned to enhance the performance of Classification and minimize overfitting. Model Evaluation Accuracy, precision, recall, F1-score and the confusion matrix were used to evaluate the performance of the model. The scores of feature importance were determined in order to determine the most significant factors influencing changes of salivary pH. The comparative evaluation of the cariogenic potential of the selected sugars was done using the results obtained by the machine learning model.

4 Design of the Study and Sampling

This was experimental research done on healthy adult people to measure the variations in salivary pH when various commercially available sugars were consumed. Individuals who have systemic diseases, dental infections which are in progress, continuously under medication that affects the amount of salivary flow, and individuals who have undergone dental treatment within the last 3 months were excluded. Informed consent was gathered and the ethical approval received before data acquisition. Collection of Saliva and Sugar Administration. The selection of commercial sugars to get evaluated was done on white sugar, brown sugar, jaggery, honey, and artificial sweeteners. Controlled conditions were maintained in terms of the amount of one sugar that was taken by each participant. The unstimulated salivary samples were taken at a baseline before the sugar consumption was done to take the baseline salivary pH and at set points (5, 10, 20, and 30 minutes) following consumption. A digital pH meter was calibrated with HCl to measure Salivary pH producing high accuracy and reproducibility.

5 Preprocessing Dataset Preparation

The data gathered consisted of the participant demographics, type of sugar, amount excluding, time elapsed after consumption, initial salivary level pH and post consumption levels of pH. Numerical encoding was done to categorical variables like sugar type with missing values being taken care of by imputation of means. The data was normalized using feature scaling and the data was split into training (70%), and testing (30%) subsets. Utilization of the Machine Learning Model. To predict the changes in salivary pH and classify sugars according to their acidogenicity, a Random Forest classifier was used. The training dataset was used to train the model and several decision trees were built to represent non-linear relationships between variables. To maximize the achievements of classification and decrease overfitting, the hyperparameters were optimized. Model Evaluation Accuracy, precision, recall, F1-score, and the analysis of confusion matrix were used to determine the performance of the model. The analysis of the importance scores of the features was done to identify the most significant aspects that influence the change of salivary pH. The cariogenic potential of the chosen sugars was comparatively evaluated using the results obtained by the machine learning model.

6 Results

Comparison of mean pre-rinse pH values between the three groups shows no significant difference, signifying normal distribution of the prerinse pH. Fig.1. shows the Comparison of mean rise of pH at 0 minutes between the groups When comparing the groups' mean pH rise at 0 minutes, group I had the largest decrease in pH, followed by groups II and III. There was also a significant difference between groups II and I as well as between groups III and I and II which is given in Table 1. Fig.2. shows the Comparison of mean rise of pH at 5 minutes between the groups. Table 2 shows the comparison of the groups' mean pH rise at 15 minutes and it revealed that group I had a significantly lower pH than the other two, which is not statistically significant. Fig.3. shows the Comparison of mean rise of pH at 30 minutes between the groups. Table 3 shows the comparison of mean rise of pH at 30 minutes between groups I and II, the mean rise in pH at 30 minutes revealed a significant difference with group III. Fig.4 shows the Comparison of rise in pH at different time period of group-I. Table 4 shows the comparison of rise in pH at different time period of group-I showed all the time period was statistically significant only when compared pre-rinse pH, owed with no significance with other time period in group I Fig.5. shows the Comparison of rise in pH at different time period of group-II. Table 5 shows the Comparison of rise in pH at different time period of group-II. group II's pH increased throughout various time periods, it was statistically significant after 15 minutes compared to pre-rinse and 0 minutes, but not at any other time. Fig.6. shows the Comparison of rise in pH at different time period of group-III. Table 6 shows the comparison of rise in pH at different time period of group-III showed no statistical difference with any time period suggesting that the pH remained almost the same with respect to all three-time period.

Table 1. Comparison of mean rise of pH at 0 minutes between the groups

Groups	**Rise pH at 0 minute (MEAN±SD)**
Group-I	5.73±0.38
Group-II	6.18±0.42*

Group-III	6.16±0.38*,#

(*p<0.05 significant compared group-I with other groups, #p<0.05 significant compared group-II with other groups)

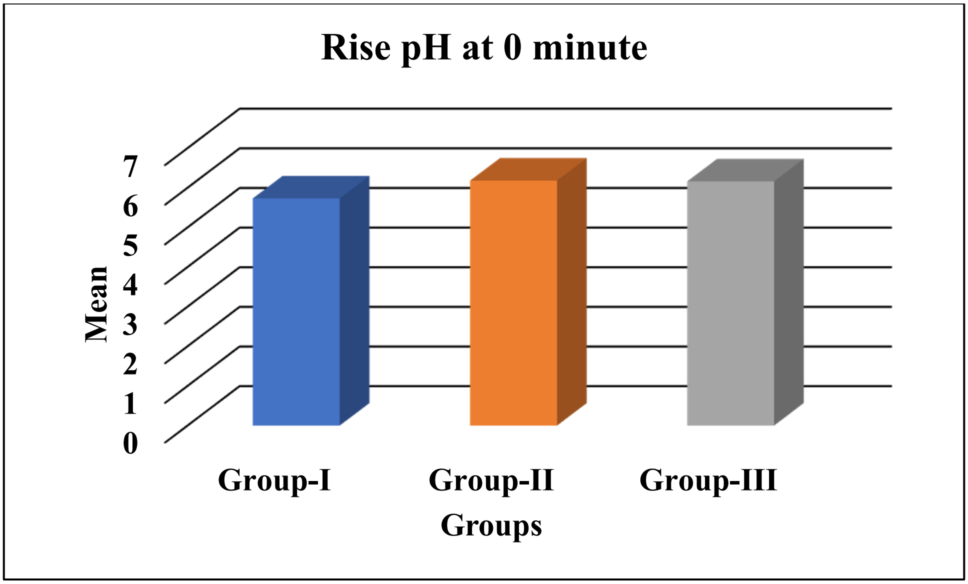

Fig. 1. Comparison of mean rise of pH at 0 minutes between the groups

Table 2. Comparison of mean rise of pH at 15 minutes between the groups

Groups	**Rise pH at 15 minutes (MEAN±SD)**
Group-I	5.60±0.42
Group-II	5.86±0.31
Group-III	6.45±0.39

(*p<0.05 significant compared group-I with other groups, #p<0.05 significant compared group-II with other groups)

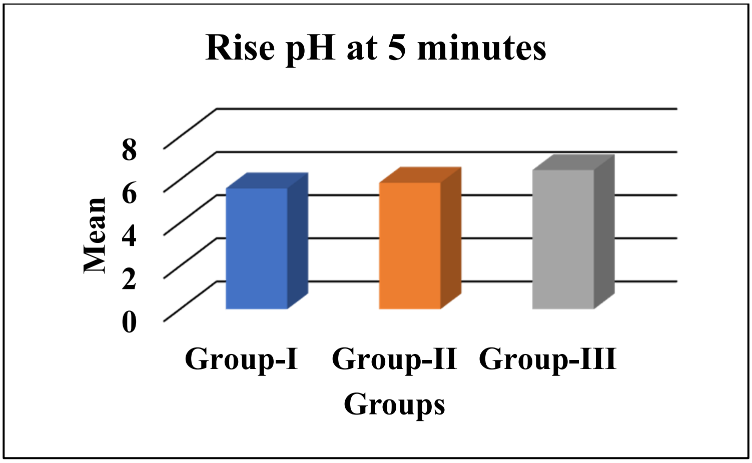

Fig. 2. Comparison of mean rise of pH at 5 minutes between the groups

Table 3. Comparison of mean rise of pH at 30 minutes between the groups

Groups	**Rise pH at 30 minutes (MEAN±SD)**
Group-I	5.88±0.45
Group-II	6.11±0.31
Group-III	6.68±0.22*,#

(*p<0.05 significant compared group-I with other groups, #p<0.05 significant compared group-II with other groups)

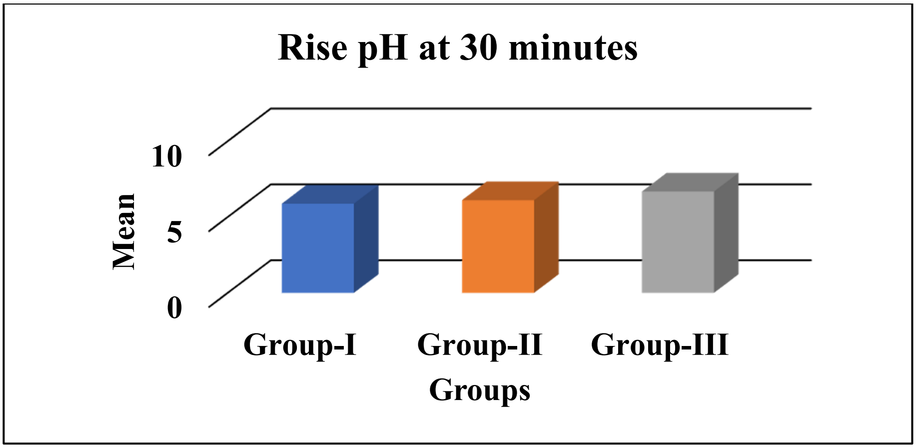

Fig. 3. Comparison of mean rise of pH at 30 minutes between the groups

Table 4. Comparison of rise in pH at different time period of group-I

Time	Group-I (MEAN±SD)
Pre rinse pH	6.58±0.27
Rise pH at 0 minute	5.73±0.38*
Rise pH at 15 minutes	5.65±0.42*
Rise pH at 30 minutes	5.88±0.45*

(*p<0.05 significant compared pre rinse pH with others, #p<0.05 significant compared rise pH at 0 minute to others, $p<0.05 significant compared rise pH at 15 minutes with others)

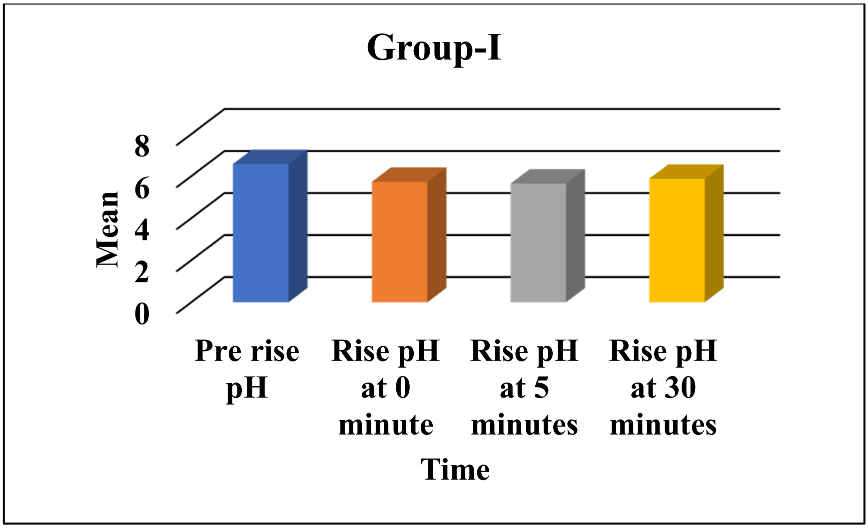

Fig. 4. Comparison of rise in pH at different time period of group-I

Table 5. Comparison of rise in pH at different time period of group-II

Time	Group-II (MEAN±SD)
Pre rinse pH	6.50±0.35
Rise pH at 0 minute	6.18±0.42
Rise pH at 15 minutes	5.86±0.31*,#
Rise pH at 30 minutes	6.11±0.31$

(*p<0.05 significant compared pre rinse pH with others, #p<0.05 significant compared rise pH at 0 minute to others, $p<0.05 significant compared rise pH at 15 minutes with others)

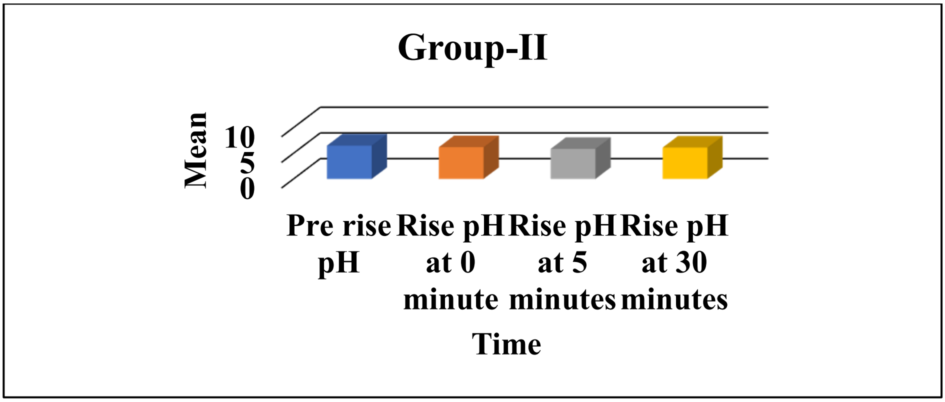

Fig. 5. Comparison of rise in pH at different time period of group-II

Table 6. Comparison of rise in pH at different time period of group-III

Time	**Group-III (MEAN±SD)**
Pre rinse pH	6.68±0.24
Rise pH at 0 minute	6.16±0.38
Rise pH at 15 minutes	6.45±0.39
Rise pH at 30 minutes	6.68±0.22

(*p<0.05 significant compared pre rinse pH with others, #p<0.05 significant compared rise pH at 0 minute to others, $p<0.05 significant compared rise pH at 15 minutes with others)

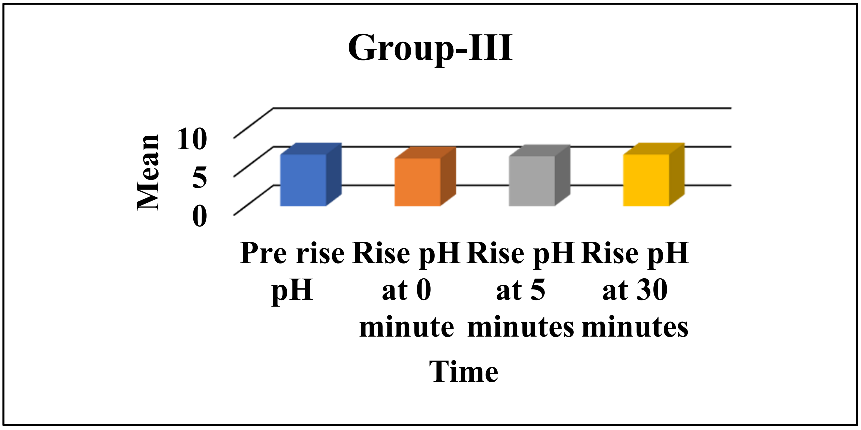

Fig. 6. Comparison of rise in pH at different time period of group-III

7 Conclusion

This research paper has proven that machine learning is effective in a comparative analysis of a change in salivary pH after the use of commercially available sugars. The model that was built on the use of the Random Forest was able to not only predict the change in salivary pH but also classify sugars based on their acidogenicity with a high degree of precision. The results showed that refined sugars had more and longer lasting decrease in salivary pH as compared to natural sugars and artificial sweeteners which had a relatively lower effect. The analysis of the importance of the features revealed that the time after consumption and sugar type were the most important factors affecting salivary pH changes. Combined with machine learning integration, the approach offered a predictive and objective model that is independent of traditional statistical analysis and allows a better evaluation of cariogenic risk regarding the level of dietary sugars. This methodology can facilitate the evidence-based dietary counseling and preventive measures in the dental practice. Development of intelligent decision support systems in oral healthcare Future research on larger and more diverse populations will be able to further improve the generalizability of the model as well as contribute to the development of intelligent oral healthcare decision support systems.

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