Monday 2-5

Effect Of Sugar Concentration in Soaking Liquid on Tapioca Pearl (Boba) Texture

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Abstract

Does sugar concentration influence the texture of boba pearls? Boba pearl is a key component in boba tea, where its chewiness is highly valued. Boba tea is a product with a significant economic value worldwide. Boba pearls' texture toughens after soaking due to a process called starch retrogradation. In previous works, it is hypothesized that higher sugar content in soaking liquid slows down the process of retrogradation. This study used texture analyzer to collect data on boba pearl texture after soaking in solutions of various sugar concentrations over the span of 4 hours. The hardness slope is statistically significantly upward at 0%, 20%, 40% and 50%. The concentration slope is statistically significantly upward at 20%, 40% and 50%. All cohesiveness slopes are statistically significantly downward. This matches the theory that higher sucrose concentration yields tougher, chewier boba pearls.

Keywords: boba tea, tapioca pearls, starch retrogradation, sugar, texture

1. Introduction

Boba tea (bubble tea) is a popular drink from Asia that has also gained popularity in America and the Western world. The global boba tea market is projected to grow from $2.29 billion in 2022 to $3.78 billion by 2029 [1]. Boba tea comes in wide varieties. The most common type is the boba milk tea - concentrated tea combined with milk, sweetener, and boba pearls, which are balls made of starch extracted from tapioca, a root vegetable, water, and sugar. In a cup of boba tea, the boba pearls provide a chewy texture, which is the leading quality that drinkers find attractive [2].

The texture of boba pearls is affected by their cooking and storage method. Pearls are cooked in water and stored in sugar syrup. While boba manufacturing and cooking has been well studied—all boba commercially available comes with cooking instructions—the same cannot be said about boba storage.

There is little academic literature on the best method to preserve boba pearls. There is one patent for storage of boba pearls [3], but the boba pearls must be stored in oil, which might cause complications for vendors. Shedding light on how sugar syrup concentration affects chewiness can increase the quality of boba as well as reduce cost and waste for vendors.

This paper shows how various sugar concentration affects boba texture over 4 hours of soaking period. To get this data, 160 pearls were boiled according to package instructions and soaked in sugar water of concentrations from 0% to 50% in 10% increments. The force feedback properties of the pearls are then measured on the Stable Micro System TA.XT Plus Texture Analyzer over the span of 4 hours. The force feedback data are then used to calculate a pearl's chewiness, hardness, and cohesiveness. Then, a linear fit of texture over time for each sugar concentration is performed. Using the slopes of these fit lines, we find a relationship between the sugar concentration and the rate at which the textures change. The data is verified by checking for statistical significance using its 95% confidence interval. Furthermore, this paper discusses the possible mechanism underlying the change in texture.

2. Gelatinization and Retrogradation of Tapioca Starch

Tapioca pearls are made primarily from tapioca starch. In a process called gelatinization, a three-dimensional matrix of starch molecules is formed with water trapped in this matrix [4]. This gives boba pearls a chewy texture. The rest of this background section briefly summarizes the material properties of starch, the gelatinization process, and the retrogradation process which hardens boba after it is cooked.

2.1 Properties of Starch

Starch is a carbohydrate that is made of simple sugars such as glucose. The glucose modules are lined up into larger macromolecules in two possible formations: amylose and amylopectin. The formation and concentration of amylose and amylopectin vary across different starch sources and conditions. Starches have different properties partly due to the variance in the amount of amylose and amylopectin. This paper focuses on tapioca starch. Tapioca starch is made from the roots of the cassava plant, which is grown in tropical areas [5]. Tapioca starch is special compared to other starches for its low amylose content of 17-20% [4]. Below we will see how amylose and amylopectin lead to gelatinization, which are the direct causes of the tapioca pearl's chewy texture and subsequent hardening.

2.2 Gelatinization

At high concentration of starch, when starch granules are heated in water, they become hydrated and swell [6]. This process is called gelatinization. If the starch granules are heated above a certain temperature determined by the starch and any additives, the starch granules disintegrate and form a paste. This is due to the melting of crystallites, unwinding of the double helices that make up the starch molecules, and the breaking of the hydrogen bonds [6]. The temperature at which tapioca starch undergoes gelatinization is 67-70 C° [7], which can be reached by boiling the tapioca pearls in water. After starch undergoes gelatinization and is cooled, it becomes more elastic with more solid-like characteristics [4]. In tapioca, this contributes to the signature chewy texture of tapioca pearls after boiling.

2.3 Retrogradation

The gelatinized starch is an unstable system. When the gel is cooled, the disrupted amylose and amylopectin chains tend to realign themselves due to the strong association to hydrogen bonding [4]. This realignment of starch granules is called retrogradation. This retrogradation comes with changes in physical properties of the starch mixture. The starch mixture will increase in viscosity and hardness [6]. The process also expels water from the starch mixture.

2.4 Effect of Sugar and Retrogradation

A prior study [8] showed that adding sugars into starch mixtures can slow down starch retrogradation. There are mixed results for what kind of sugar is optimal for slowing down starch retrogradation. Some studies [6,8] have shown that disaccharides are more effective than monosaccharides at inhibiting starch retrogradation, but at least one study [9] showed that sucrose (a disaccharide) increase the rate of starch retrogradation. The mechanism behind how sugar can slow down retrogradation is explained as competition for water between starch and the other carbohydrates [6].

Other studies measured the retrogradation rates of various starches (including tapioca starch) under the presence of sucrose, but in these studies, the starch is presented in powder form and never in a spherical shape. These studies also did not investigate the effect of geometry of the starch food items on their retrogradation rate. My study specifically looks at tapioca pearls, which are spherical. My results will be helpful for boba tea vendors, since boba pearls might behave differently then these previously studies predict due to its spherical shape.

3. Experimental Design

At a high level, the experiment setup can be described as the following steps: the boba pearls were cooked according to package instructions and soaked in solutions with varying concentration of sucrose. The pearls were then placed on the texture analyzer for data collection.

The following sections describe the experimental design in more detail.

3.1 Apparatus and Testing Procedure

A Stable Micro System TA. XT Plus Texture Analyzer with the 1.5" diameter acrylic compression probe (TA-4) was used for this experiment. The general layout of the texture analyzer can be seen in Figure 1. The machine is run by the accompanied software on a laptop, and the test is setup with parameters described in Table 1.

Figure 1: Experiment setup. A pearl is placed in a petri dish and measured on the Stable Micro System TA. XT Plus Texture Analyzer with the 1.5" diameter acrylic compression probe (TA-4).

Table 1: Configuration of the Texture Analyzer used in this setup.

Caption	Value	Units
Pre-Test Speed	5.00	mm / sec

Test Speed	10.00	mm / sec
Post-Test Speed	10.00	mm / sec
Target Mode	Distance	
Distance	7.000	mm
Time	3.00	sec
Trigger Type	Auto (Force)	
Trigger Force	0.49	N
Advanced Options	Off	

Data collection took a span of 4 hours. The test is set up in such a way that each pearl took about a minute to measure. The pearls were continuously fed into the machine for measurement. Runs cycled from 0 to 50 percent 4 times. The cylinder is wiped down after every press since the pearls leave a sticky residue. After measuring, the pearls were discarded.

3.2 Sample Preparation

Dry boba pearls were purchased online. Before cooking them, the weights of 28 pearls were measured to test their homogeneity, and they were quite different. The weights of the dry boba pearls are shown in Figure 2.

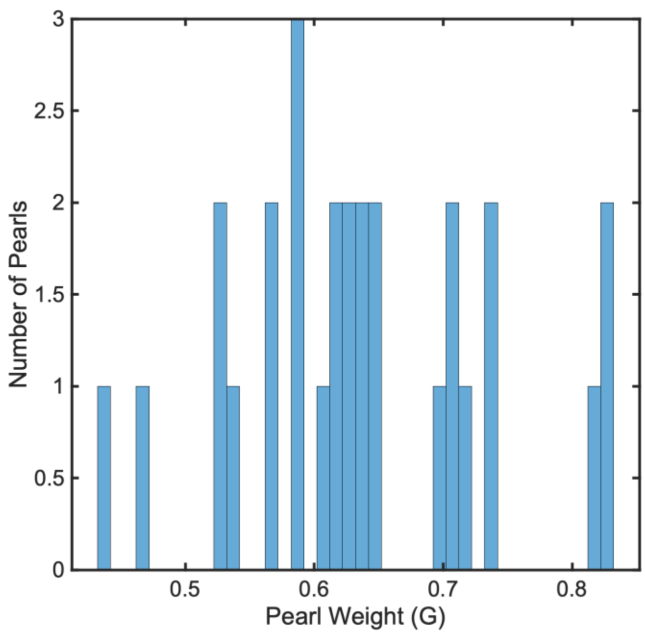

Figure 2: Histogram of the weight of dry boba pearls. 28 pearls were measured on a scale. The weights ranged from 0.42 g to 0.83 g.

This variance could lead to high variance in the results. The pearls are cooked according to package instructions. Then, sugar (sucrose) water solution of 0 – 50 % by volume is prepared in

10 increments. Around 25 cooked pearls are placed in each cup and removed one by one for measuring. The pearls were placed on a small petri dish with tweezers, and the petri dish was placed on the texture analyzer.

3.3 Macro-data Calculation

The texture metrics used in paper models after industry standards defined by The Centre for Industrial Rheology [10]. Hardness and cohesiveness are computed according to the methodologies described in [10], whereas chewiness is defined similarly to [10] but modified to calculate area under the two peaks instead. These modified calculation methods correlate better to the concepts of impulse and work. Figure 3 shows the raw data and Table 2 shows how each macro-data is calculated. The data from the texture analyzer comes in two peaks. It presses the pearl, lifts, then presses again. This two-peak method allows us to calculate some complex textures, which will be referred to as macro-data from now on.

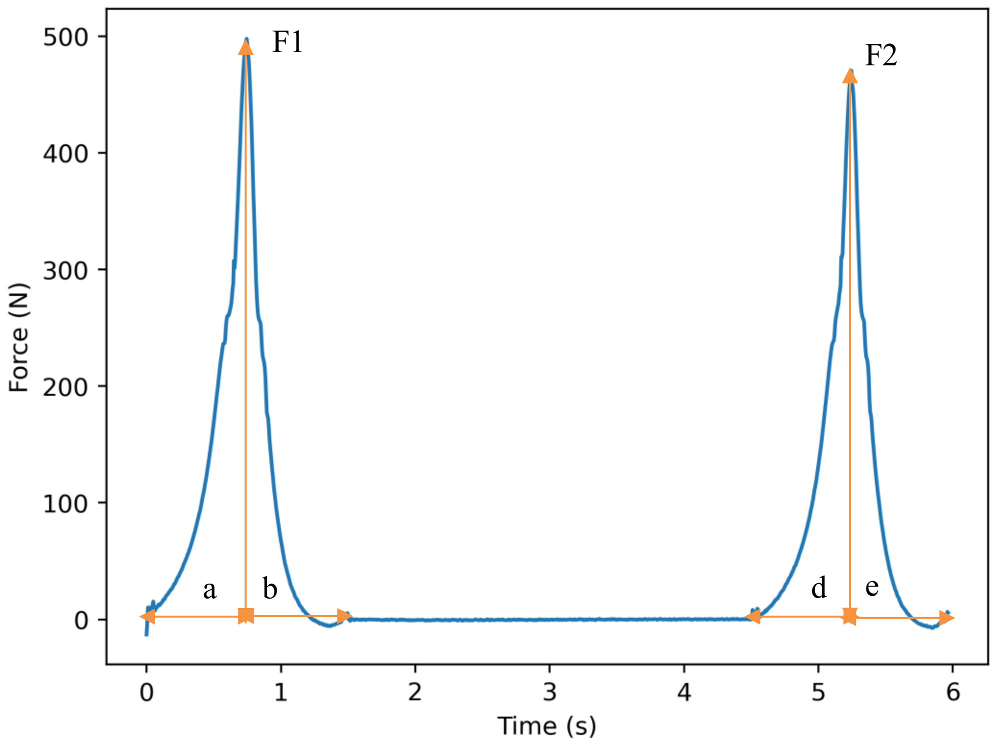

Figure 3: The composition of the raw data measured from the Texture Analyzer. The raw data is measured as two peaks over the span of 6 seconds. The two peaks are split between their maximum points (F1, F2) into two sections (a, b and d, e). These features are used to calculate various textures, or macro-data.

Table 2: Macro-data calculation formulas.

Macro-data	Equation
Chewiness (g*s)	$a + b + d + e$

Cohesiveness (%)	$\frac{(d+e)}{(a+b)}$
Hardness (g)	$F1$ (Highest peak)

4. Results and Discussion

Hardness, chewiness, and cohesiveness are calculated from the raw data. Then, a line is fitted through each time series for every concentration. The results are shown in Figure 4. The hardness slope is statistically significant at 0%, 20%, 40% and 50%. The hardness slopes at 10% and 30% is not statistically significant since the 95% confidence interval crosses 0, thus we cannot reject the null hypothesis. The chewiness slope is statistically significant at 20%, 40% and 50%. The chewiness slopes at 0%, 10% and 30% is not statistically significant since we cannot reject the null hypothesis, like the case for hardness slopes. All cohesiveness slopes are statistically significant. When slope against concentration is fitted linearly, there is a statistically significant positive correlation for hardness and chewiness, but not for cohesiveness.

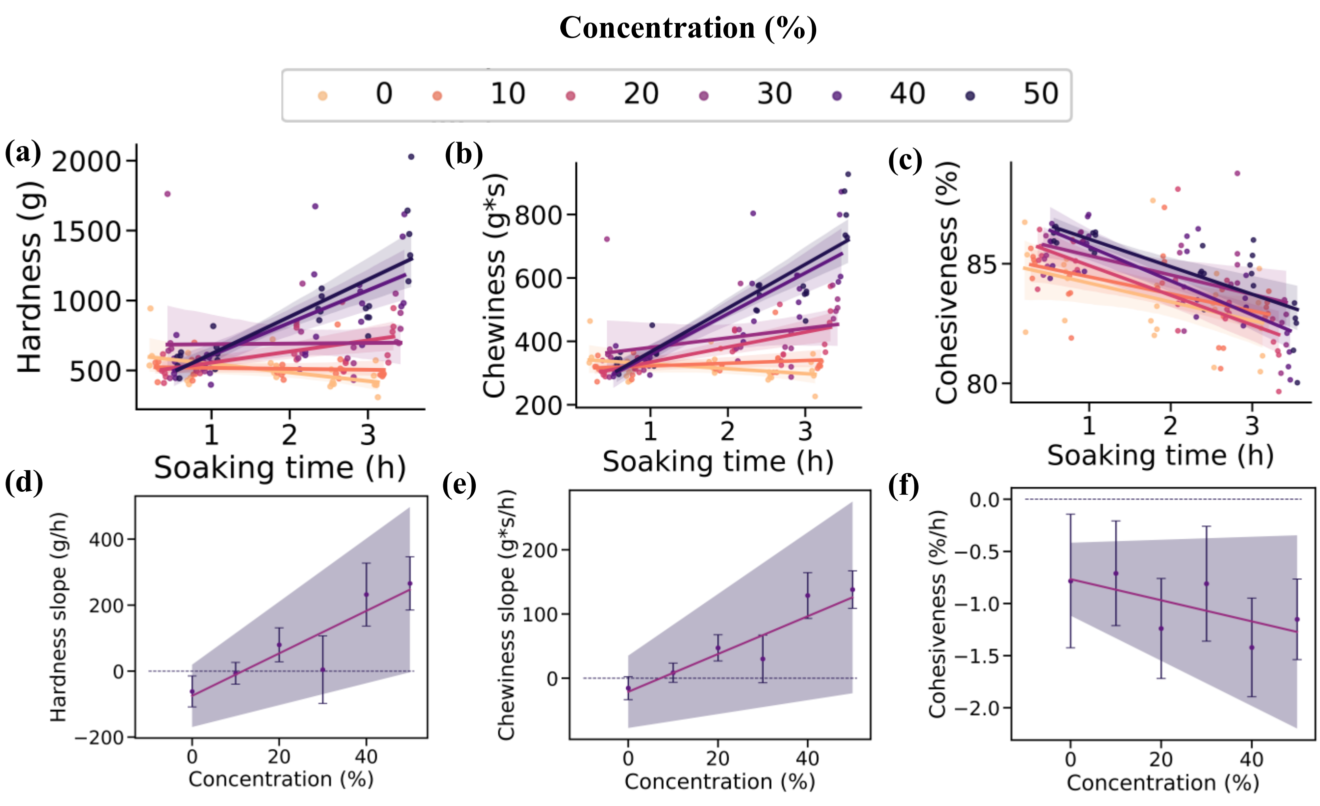

Figure 4: Top left to right: (a) Hardness (g), (b) chewiness (g*s), and (c) cohesiveness (%) calculated from the measured data. Bottom, left to right: slope of fitted line for (d) hardness, (e) chewiness, and (f) cohesiveness at different sugar concentration. The hardness slope (d) is statistically significant at 0%, 20%, 40% and 50%. The chewiness slope (e) is statistically significant at 20%, 40% and 50%. All cohesiveness slopes (f) are statistically significant. When slope against concentration is fitted to a linear curve, there is a statistically

significant positive correlation for hardness (d) and chewiness (e), but not for cohesiveness (f).

The results correspond to the theory that higher sucrose concentration yields tougher, chewier boba. Interestingly, for 0% sugar concentration, the hardness slope and the chewiness slope are near 0. In theory, for all sugar concentrations the slope should be positive since retrogradations happen in the presence of water, and sucrose just speeds up the process. A potential explanation for this phenomenon could be derived from the geometry of the boba pearls. Since the pearls are spherical, the outer layer of the pearl is constantly exposed to the soaking liquid. This can over-saturate the outer layer with water, causing it to turn mushy and slowly dissolve into the water. The structural integrity loss from the disintegration of the outer layer could be balancing out the effects of retrogradation for 0% soaking liquid. Standard error for all the datapoints is high, potentially from the irregularity of the purchased boba pearls as mentioned in the experimental setup section (see Figure 2). The result that for concentrations between 10 % - 30 % there is no statistically significant change was unexpected, since the relationship was assumed to be purely linear.

There were limitations to the study. Since all sample preparation was done by hand, the handling might introduce some errors. For example, the pearls were picked up by the tweezer, which might have slightly deformed the pearls. The pearls were placed in the center of the petri dish to the best of my abilities, but they are not all measured at the same location in the perspective of the texture analyzer. At the beginning of the experiment the texture analyzer was calibrated incorrectly, leading to some false datapoints which were later removed. The sweetness of boba pearls, which would be affected by the sugar concentration and is also crucial to customer satisfaction, could not be measured within the scope of this study. Going forward, some ways to improve the accuracy of this experiment include proper calibration of equipment, automating the measuring process or using multiple machines to synchronize measurement, and developing an objective method to test sweetness.

5. Conclusions

The hardness slope is statistically significant at 0%, 20%, 40% and 50%. The chewiness slope is statistically significant at 20%, 40% and 50%. At 10% and 30%, we cannot reject the null hypothesis for the hardness slope, and at 0%, 10% and 30%, we cannot reject the null hypothesis for the chewiness slope. All cohesiveness slopes are statistically significant. When slope against concentration is fitted linearly, there is a statistically significant positive correlation for hardness and chewiness, but not for cohesiveness. This matches the theory that higher sucrose concentration yields tougher, chewier boba pearls. This research yields valuable results for boba tea vendors. The findings could be used by boba tea vendors to control the texture of their boba pearls by adjusting the sugar concentration in the soaking liquid they use. If a vendor would like to keep their pearls at textures like freshly cooked pearls, a sugar concentration range between 10 % - 30 % is desirable since the sugar does not statistically significantly change the texture of boba pearls. Further expansions of this research are desired to increase the value of this project. During this study, the effect of sugar concentration on sweetness of pearls is ignored. Since sweetness correlates to customer satisfaction, it needs to be considered when trying to choose the optimal sugar concentration. Certain boba tea franchises such as Tea-Do use honey as sweetener for their boba pearls. Further study on the effect of sweeteners other than sucrose would expand knowledge on this field.

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References

[1] "Bubble Tea Market Size, Industry Trends | Analysis Report, 2029" [Online]. Available: https://www.fortunebusinessinsights.com/industry-reports/bubble-tea-market-101564. [Accessed: 02-Mar-2023].
[2] Nguyen-Okwu, L., 2019, "Boba Explained: A Sipper's Guide to Taiwan's Signature Drink," Eater [Online]. Available: https://www.eater.com/21551108/boba-milk-bubble-tea-explained-how-to-order. [Accessed: 11-May-2023].
[3] "Espacenet - Bibliographic Data" [Online]. Available: https://worldwide.espacenet.com/publicationDetails/biblio?CC=US&NR=2022295834A1&KC=A1&FT=D&ND=&date=20220922&DB=EPODOC&locale=. [Accessed: 02-Mar-2023].
[4] Pongsawatmanit, R., Chantaro, P., and Nishinari, K., 2013, "Thermal and Rheological Properties of Tapioca Starch Gels with and without Xanthan Gum under Cold Storage," Journal of Food Engineering, **117**(3), pp. 333–341.
[5] Breuninger, W. F., Piyachomkwan, K., and Sriroth, K., 2009, "Chapter 12 - Tapioca/Cassava Starch: Production and Use," *Starch (Third Edition)*, J. BeMiller, and R. Whistler, eds., Academic Press, San Diego, pp. 541–568.
[6] Wang, S., Li, C., Copeland, L., Niu, Q., and Wang, S., 2015, "Starch Retrogradation: A Comprehensive Review," Comprehensive Reviews in Food Science and Food Safety, **14**(5), pp. 568–585.
[7] "Starch Gelatinization | Baking Processes," BAKERpedia [Online]. Available: https://bakerpedia.com/processes/starch-gelatinization/. [Accessed: 02-Mar-2023].
[8] Babić, J., Šubarić, D., Milicevic, B., Ačkar, D., Kopjar, M., and Tiban, N. N., 2009, "Influence of Trehalose, Glucose, Fructose, and Sucrose on Gelatinisation and Retrogradation of Corn and Tapioca Starches," Czech Journal of Food Sciences, **27 (2009)**(No. 3), pp. 151–157.
[9] Thirathumthavorn, D., and Trisuth, T., 2008, "Gelatinization and Retrogradation Properties of Native and Hydroxypropylated Crosslinked Tapioca Starches with Added Sucrose and Sodium Chloride," International Journal of Food Properties, **11**(4), pp. 858–864.
[10] "Texture Analysis And Texture Profile Analysis," Rheology Lab [Online]. Available: https://www.rheologylab.com/services/texture-analysis/. [Accessed: 25-Apr-2023].