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HOW BAKE TIME AND SUGAR INGREDIENT RATIOS AFFECT COOKIE TEXTURE

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ABSTRACT

How food tastes is strongly influenced by its physical properties, such as texture and appearance. The texture of baked goods in particular can be altered by adjusting variables like sugar ingredient ratios and baking times. To examine their effect on cookie chewiness, sugar ingredient ratio and baking time were varied in two sets of cookie batches. Chewiness and springiness was measured by performing a "two bite" double compression test on the texture analyzer. An initial analysis demonstrated that baking time is a more significant variable in influencing cookie physical properties than sugar ratio. This investigation also found that a positive quadratic relationship exists between baking time and chewiness, longer baking times of 14 min result in cookie fractures during data collection, and that optimal springiness can be achieved with a baking time range of 10 to 12 minutes. These results confirm previous research in that a positive correlation exists between baking time and cookie hardness.

1. INTRODUCTION

We often forget that how food "tastes" is influenced not only by its flavor, but also by what it smells like, feels like, and even looks like. "Taste" is a combination of many senses: a food's flavor, smell, texture, and appearance.

Cookies have been prepared in many ways to influence these properties and thus influence "taste". For example, due to the molasses content of brown sugar, using more brown sugar than granulated white sugar produces cookies that are more dense, moist, and chewy. Baking time is another influential factor, where longer baking times increase cookie brittleness and crispiness.

It is of interest to find a numerical relationship between texture and variables like sugar ingredient ratios and baking time, as well as their relative influence. Such information can be used to engineer a cookie with the perfect "taste".

In each set of cookies, one variable was altered at a time. The first set varied sugar ratios between batches while the second set varied baking times between batches. All cookies then underwent a "two bite" double compression test performed by a TA.XT Texture Analyzer to measure chewiness and springiness, as texture profile analysis is the preferred tool in performing related research in the food industry [3].

Although previous research examined temperature profiles instead of texture [1] and gluten free cookies enriched with blueberry pomace [2], a different type of cookie altogether, their results still guided this experiment's general expectations. It was expected that increasing the brown sugar ratio would increase the cookie chewiness [4] and that increasing baking time would increase cookie hardness [1][2].

2. INFLUENTIAL FACTORS ON COOKIE VARIATION AND MEASUREMENT TECHNIQUE

2.1 TYPES OF SUGAR

Hygroscopic ingredients, such as granulated white sugar and brown sugar, tend to absorb moisture in air and dough, which slows down the development of gluten protein. This results in dough that is less elastic and less chewy, because the amount of gluten present and the chewiness of a baked good are directly correlated. This explains why cookies (high in granulated white and brown sugar) are more crumbly and less chewy than bread (low in granulated white and brown sugar).

Additionally, white sugar is less hygroscopic than brown sugar, which also contains molasses. Molasses is what gives brown sugar its color, extra moisture, and slight acidity. This is why brown sugar cookies are more chewy and moist than white sugar cookies.

2.2 HOW BAKING TRANSFORMS COMPOSITION

Cookies undergo many complex transformations throughout the baking process. At 144°F, egg proteins denature and become solid, which stiffens dough and increases density. At 212°F, water boils away, which dries out cookies and makes them more crispy. Maillard reactions, when proteins and sugars break down and rearrange themselves, occur at 310°F. These reactions create strong taste and aroma compounds, and is what gives cookies their distinct rich gold color. Sugars break down at 356°F to leave behind slightly bitter but sweet flavors, and this process is called caramelization [5].

Maillard reactions and caramelization are two transformations that make cookies tasty and delicious. However, it is the properties of water that affect cookie texture the most. Increasing baking time means that more water will boil away and leave the dough; cookies with longer baking times have decreased moisture content and increased hardness [2].

2.3 MEASURING TEXTURE PROPERTIES

The texture analyzer is capable of measuring an object's hardness, fracturability, cohesiveness, springiness, gumminess, chewiness, and resilience [3]. In this experiment, a cookie's hardness and springiness are parameters of interest, as these values are used to calculate chewiness.

Texture profile analysis (TPA) is a specific type of "two bite" double compression test that models the action of a mouth biting into food twice. In the real world, measuring textural properties is useful in determining how to advertise and market baked goods, since different people have different preferences for their cookies and texture plays a large role in the taste of any food.

Figure 1 displays TPA data from a trial of cookies baked for 14 minutes. It is useful in understanding how hardness and springiness are measured, quantified, and calculated. Hardness is the peak force experienced after the first compression. The area of the second compression divided by the area of the first compression measures how well an object sticks to itself under stress, or how well an object withstands a second (or third, or fourth) deformation. Springiness measures how much an object can spring back after it has been deformed. This is measured by dividing Time 2 by Time 1.

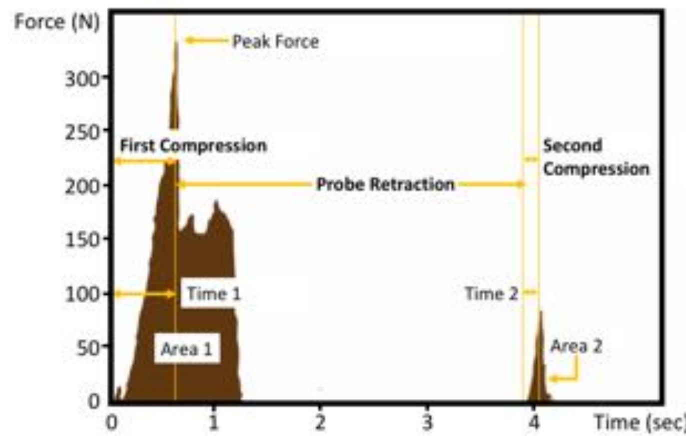

Figure 1: Texture Profile Analysis (TPA) Data from Trial of 14 Min Cookies

Chewiness is the value that will be compared amongst cookies, and is the relationship between an object's hardness, area ratio, and springiness. These values are in a directly proportional relationship with chewiness: when any variable increases, chewiness will increase. Chewiness, as defined by the texture analyzer, is calculated as [3]:

$$\text{Hardness} = \text{Peak Force}$$

$$\text{Springiness} = \frac{\text{Time 2}}{\text{Time 1}}$$

$$\text{Chewiness} = \text{Peak Force} * \frac{\text{Time 2}}{\text{Time 1}} * \frac{\text{Area 2}}{\text{Area 1}}$$

$$\text{Springiness} = \left[—\right] \text{ and Chewiness} = [\text{N}]$$

In sugar ratio and baking time cookies, chewiness is a relative value between cookies that is compared between batches. As previously mentioned, it is expected that increasing brown sugar will increase chewiness, and increasing baking time will increase hardness.

3. MEASUREMENT OF COOKIE TEXTURE

Sugar ingredient ratio and baking time are varied between different batches of cookies in two sets to examine their effect on cookie chewiness. The same cookie recipe is used for the control of the sugar ratio cookies and all baking time cookies [6].

3.1 SUGAR RATIO COOKIES PREPARATION AND BAKING

Cookie dough was prepared sequentially and then baked at the same time. As shown in Figure 2, cookies with different sugar ratios were baked in the same batch to reduce the influence of environmental factors between batches. The dough was scooped by a 1/8 measuring cup, spaced evenly on a baking pan. Each baking pan fits 12 cookies, so 3 of each type of cookie was included for each batch. A total of 5 batches of cookies were baked, and 15 cookie samples at each sugar ratio were produced.

Figure 2: Sugar Ratio Cookies from one batch from schematic diagram (left) to baking (right). Granulated white to brown sugar ratios from left to right are 1:0, 2:1, 1:2, and 0:1. Each cookie was produced from 1/8 cup of dough.

3.2 BAKING TIME COOKIES PREPARATION AND BAKING

Modifications to cookie preparation were made after analysis of sugar ratio cookies. The analysis revealed that chewiness values within the same batch were more similar than those of cookies with the same ingredient ratio. Since batches were unintentionally baked for different amounts of time, this demonstrated that baking time is more influential on cookie texture than varying sugar ingredient ratios.

As seen in Figure 3, to measure the influence of baking time, 5 batches of cookies were baked for 6 min, 8 min, 10 min, 12 min, and 14 min, since 10 min is the recommended recipe baking time. There were 10 cookies per batch, scooped with a 1 tablespoon measuring cup.

Figure 3: Baking Time Cookies, from left to right: 14 min, 12 min, 10 min, 8 min, 6 min

3.3 TEXTURE PROFILE ANALYSIS

To measure the chewiness of a cookie, a TPA test is executed with a TA.XT *Plus Texture* Analyzer. The texture analyzer is fitted with a 10mm diameter cylindrical probe and a load cell rated up to 50 kilograms-force (490 N). The texture analyzer measures the force required to reach a certain depth in the cookie, retracts, waits for the food to restore to its original position, and repeats the force measurement again. Figure 4 displays pictures of the texture analyzer in action, and Figure 5 displays corresponding TPA data. For this particular experiment, the pre-test, test, and post-test speeds were 5mm/sec, compression distance was 5mm, the trigger force was 8g, and the wait time between compressions was 1 second.

Figure 4: Texture Analyzer measuring Baking Time Cookies, from left to right: 6min, 10min, and 14min

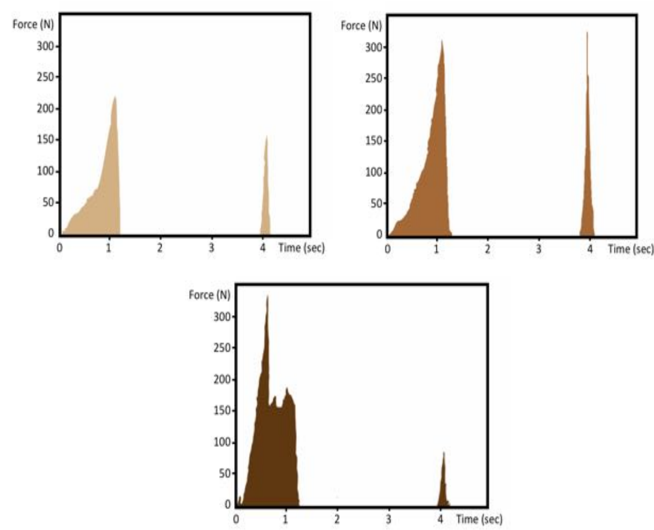

Figure 5: TPA Data of Baking Time Cookies, from left to right: 6min, 10min, and 14min

4. COOKIE TEXTURE RESULTS AND DISCUSSION

4.1 SUGAR RATIO COOKIE

Analysis of sugar ratio cookies revealed that baking time is more influential than sugar ingredient ratio on cookie chewiness, as seen in Figure 6, Figure 7, and Figure 8. Different baking times across batches caused large overlapping uncertainties that made differences in chewiness not statistically significant. These claims were further supported by performing t-test calculations in Excel that found p-values exceeding 0.05 for all pairs of data. Well-supported conclusions cannot be drawn between the quantitative relationship between sugar ratio and chewiness of cookies. This data, however, did suggest that baking time is a significant factor in influencing cookie texture.

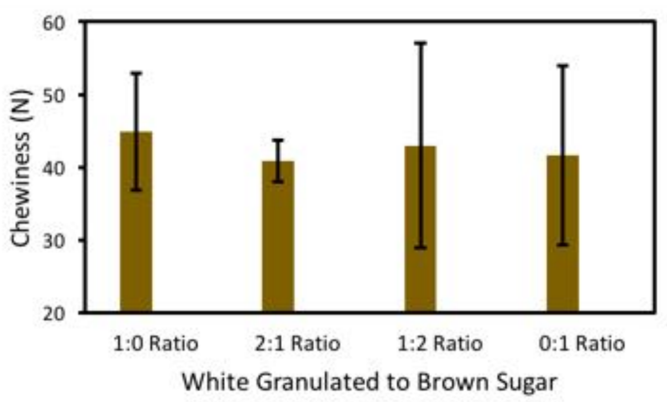

Figure 6: Cookies grouped by sugar ratios across five batches. There is a non-significant statistical difference in chewiness between cookies of varying sugar ingredient ratios, and too large uncertainty to determine a numerical relationship.

As seen in Figure 6 and Figure 8, there is more similarity in chewiness within batches than within the same sugar ingredient ratio. The uncertainty bars are large and overlap when cookies are grouped by sugar ratio, but are small and rarely overlap when cookies are grouped by baking time. Differences between chewiness in Figure 8 are nearly all statistically significant with 92% confidence ($p < 0.08$), with a two-tailed p value of 0.074 between Batches 3 and 4 and a two-tailed p value of 0.064 between Batches 4 and 5.

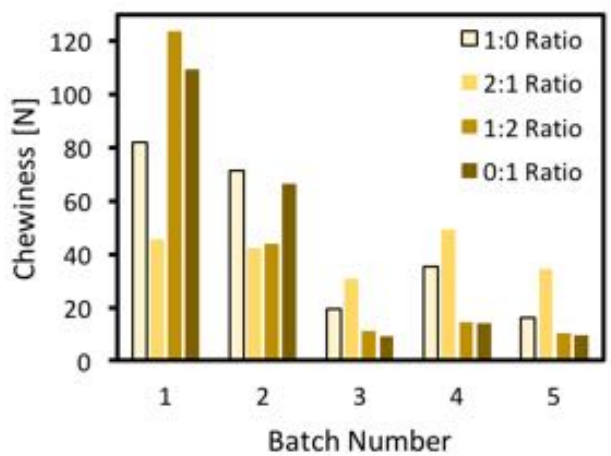

Figure 7: Batches 1 and 2 cooked for 18 minutes while the remaining batches cooked for 16 minutes.

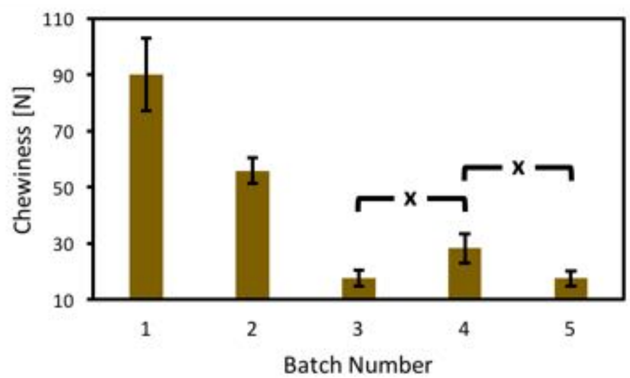

Figure 8: Cookies grouped by batch across four sugar ratios. These cookies are more similar to each other when grouped by batch number, where cookies were baked for different times, than when separated by sugar ratio. x= Statistically significant with 92% confidence ($p < 0.08$)

4.2 BAKING TIME COOKIE CHEWINESS AND SPRINGINESS

As illustrated in Figure 9 and Figure 10, there is a baking time range of 10-12 minutes for ideal springiness, but a positive quadratic relationship between baking time and chewiness until cookies become too hard and fracture. Springiness has an ideal range because undercooked cookies are moist and sticky with not enough formed air pockets to bounce back when compressed, and overcooked cookies are brittle, dry, and fracture easily when compressed. In regard to Figure 9, all differences in springiness are said to be statistically significant with 95% confidence. Precisely, the p value is 0.032 (two-tail) between the 10 and 12 minute cases and the p value is 0.0051 (two-tail) between the 6 and 8 minute cases.

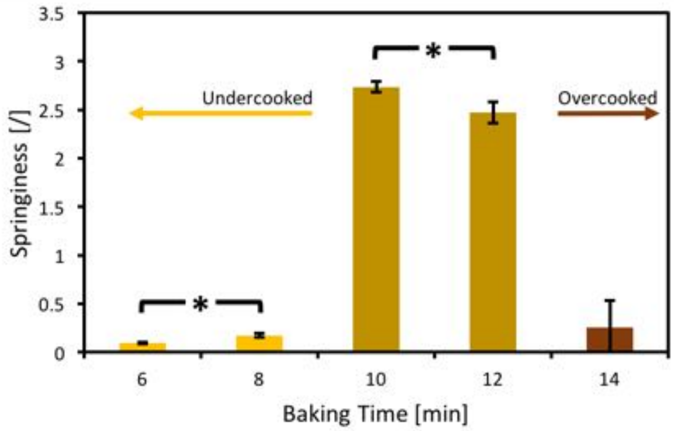

Figure 9: There is an optimal baking time range for maximum springiness in cookies of 10 to 12 minutes. Both overcooked and undercooked cookies have significantly lower springiness.

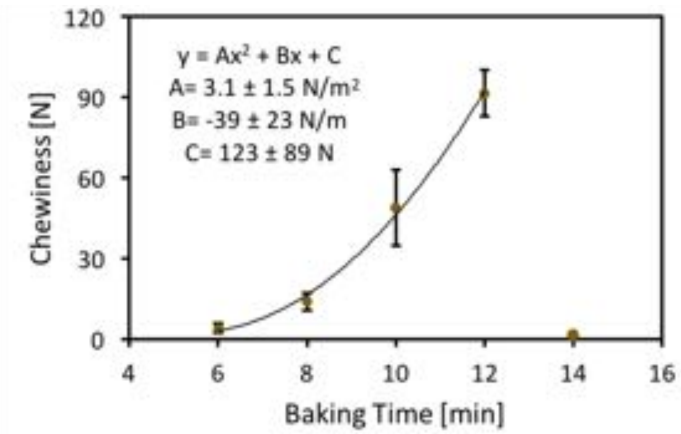

Figure 10: There is a positive quadratic relationship between chewiness and baking time until cookies become too hard and fracture. The chewiness of 14 min cookies are not included in the quadratic fit because they would break upon compression testing and result in nearly zero readings.

4.3 COMPARISON WITH PRIOR RESEARCH

As seen in Table 1 and Figure 11, previous studies and results from this experiment differ by a factor of 10. However, this previous study was measuring gluten free cookies enriched with blueberry pomace, which is a different type of cookie altogether. In addition, those cookies were baked at 170℃ while these were baked at 350°F. Since different approaches were taken, the magnitude of results can not be compared but the trends within can be. These experimental results illustrate a positive linear correlation between baking time and hardness which is confirmed with previous results.

Table 1: Comparison of cookie hardness results between collected data and prior studies

This Experiment		Previous Study [2]	
Baking Time	**Hardness [N]**	**Baking Time**	**Hardness [N]**
6	168 ± 24	10	8.8 ± 1.0
8	169 ± 27	13	32.0 ± 1.4
10	159 ± 17	14	34.0 ± 4.0
12	257 ± 17	16	34.5 ± 2.2
14	307 ± 16	17	52.7 ± 4.0

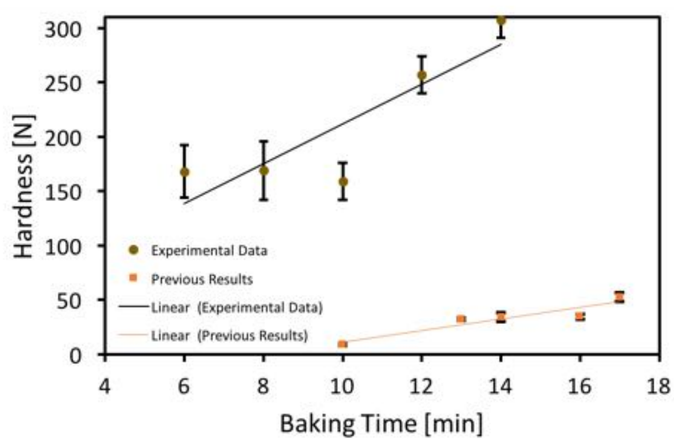

Figure 11: Experimental results found that cookies increase in hardness by 18.3 N per minute while previous results found the hardness rate to be 5.3 N per minute. Both found a positive correlation between baking time and hardness.

4.4 UNEXPECTED RESULTS AND FUTURE MODIFICATIONS

It was unexpected that sugar ingredient ratios would not have a strong relationship in altering cookie chewiness, and that variations between all cookies would be so large. There are potential sources of error in each step since there are many factors that influence the physical properties of a cookie. Temperature of dough, quality of oven, and accuracy of ingredient quantities influence cookie preparation and baking. Calibration of the texture analyzer, cookie inhomogeneity, and surface unevenness influence data collection methodology. There is a noticeable difference between force measurements taken at the center of a cookie versus the edge of a cookie, which is another potential source of error.

Limitations of the approach include the inability to measure the effect of other variables on the data, such as the effect of a poor-quality oven that bakes cookies unevenly across the baking pan, or the effect of room temperature butter versus chilled butter in forming air pockets in the dough to make cookies that are fluffier. For measuring baking time, two batches of dough were made sequentially and then split into 5 different batches to be cooked, as there were limitations to the amount of dough that one KitchenAid mixing stand could hold. It is possible that variations between the two batches of dough could have influenced results as well. To improve upon this experiment, more samples should be taken and measured, and environmental conditions and other factors should be more strictly monitored. The oven temperature can be tested over time, the influence of ingredient temperatures on dough can be tested as well, and more precise measuring cups can be used to create batches of dough that are more identical.

5. CONCLUSIONS

Initial results indicated that the longer the bake time, the chewier the cookies are overall, regardless of ingredient ratio. Thus, variation in baking time is more effective in influencing cookie chewiness and springiness than variation in sugar ingredient ratios. There is a positive quadratic relationship between cookie chewiness and baking time, and the ideal baking time range for maximum springiness in a cookie is 10 to 12 minutes. Increasing baking time increases cookie hardness, as confirmed by previous studies [2]. Longer bake times also result in cookie fractures during data collection.

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