

CHAPTER 5:

Results and Discussion:

5.1 Physical Data Measured 1 Hour Post Bake

5.1 A. Water Activity

5.1 A1. Liquid Honey

The result of the multiple comparison ANOVA demonstrated that the overall model for water activity approached significance with the usage of liquid honey in the muffin formula ($p=0.059$). Further investigation of the water activity variable demonstrated that the slight insignificance most likely occurred because of the block effect ($p= 0.12$), a particular component of the overall model. However, the p - value for the treatment (the other component of the model) was 0.048 demonstrating that there were significant differences among the treatments (Table 4).

A Paired Wise Difference test which determines significant differences among all treatments against each other demonstrated that none of the samples were significantly different from one another (Table 4). However, the 35% liquid honey replacement started to approach significance ($p=0.0118$ where $p<0.005$ was needed for significance), and therefore, it may be considered as a potential optimal level for sugar replacement when attempting to reduce water activity. Trend analysis showed no significant linear or quadratic trends among the data.

Table 4. “Water Activity of Muffins Measured 1 Hour Post Bake Using Liquid Honey.”

Trt.	Aw	Std. Er. *
Full cntrl	0.945a,f	± 0.0026
Red. cntrl	0.947a,f	± 0.0026
25% liq	0.943a,f	± 0.0026
35% liq	0.936a,f	± 0.0026
45% liq	0.938a,f	± 0.0026

Values with the same letter denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

5.1 A2. Dry Honey

Multiple comparison ANOVA results demonstrated that there was a significant difference in the model ($p=0.045$). Paired Wise Difference testing demonstrated that the 35% dry honey replacement for sucrose significantly increased water activity ($p=0.0050$) when compared to the full fat control (Table 5). Whereas, both the 25% and 35% dry honey replacement treatments significantly increased water activity ($p=0.0043$ and $p=0.0012$ respectively) when compared to the fat reduced control, while the 45% did not increase the water activity significantly ($p=0.0012$, where $p<0.005$ needed for significance).

All samples were within the range of microbial growth of yeasts and molds (Czuchajowska and Pomerang, 1989). Based on LS Means, the dry honey appeared to increase water activity by approximately 0.007, whereas the use of liquid honey appeared to decrease water activity. Since dry honey contained between 50% to 70% more honey than liquid honey (NHB, 1988), it was assumed that dry honey would have at least 50% to 70% stronger effect on lowering the water activity. However, the increase in water activity that was noted as being significantly different at the 25% and 35% levels was most likely due to the increase in water that had to accompany the use of dry honey in the product. Pilot work performed before the investigation demonstrated that in order to attain the rheological properties of muffin batters made with liquid honey 1 gram of water had to be added for every gram of dry honey used in the product.

Table 5. “Water Activity of Muffins Measured 1 Hour Post Bake Using Dry Honey.”

Trt.	Aw	Std. Er.*
Full cntrl	0.946a,f	± 0.0014
Red. cntrl	0.944a,f	± 0.0014
25% dry	0.952a,g	± 0.0014
35% dry	0.953b,g	± 0.0014
45% dry	0.951a,f	± 0.0014

Values with the same letter denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

The issue of statistical significance and practical importance can become a factor in these types of studies. If something is statistically significant, it does not imply that it is practically important, and vice versa. Therefore, it was demonstrated that there was a significant reduction in water activity when compared to the fat reduced control, however, a change of about 0.010 was not considered practically important because microbial growth would still flourish.

5.1 B. Color of Crust and Crumb

Quality factors can be divided into 3 major areas: color, flavor, and texture. Each factor can be addressed, however, if color is unacceptable, there may be little point considering flavor and texture (Francis and Clydesdale, 1975).

5.1 B1. Liquid Honey

Crust L value: The L value is designated by the Hunter Colorimeter to measure the degree of whiteness and blackness in the product. Together with the amount of yellowness measured (b), an interpretation on the degree of browning can be interpreted. The LS Means for crust L indicated that the product became darker as honey level increased (Table 6).

The ANOVA of the overall model for Crust L results demonstrated that the overall model was significant ($p=0.007$). Further investigation of the results using Pair Wise Differences demonstrated that all values were not significantly different from the full fat

Table 6. “Crust Color of Muffins Measured 1 Hour Post Bake Using Liquid Honey.”

Trt.	Crust					
	L	Std. Er. *	b	Std. Er. *	Delta E	Std. Er. *
Full cntrl	62.22 a,f	± 1.68	43.58 a,f	± 0.88	55.74 a,f	± 0.99
Red. cntrl	65.55 a,f	± 1.68	41.64 a,f	± 0.88	51.88 a,f	± 0.89
25% liq.	60.52 a,f	± 1.68	39.92 a,f	± 0.88	54.21 a,f	± 0.89
35% liq.	56.35 a,g	± 1.68	38.79 b,f	± 0.88	56.47 a,g	± 0.89
45% liq.	55.34 a,g	± 1.68	38.39 b,f	± 0.88	56.71 a,g	± 0.89

Values with the same letter within each column denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat muffin (full cntrl)

“f” compares all treatments to fat reduced muffin (red. cntrl)

* Std. Er. = Standard Error of the LS Means

L: 0 = black

100 = white

b: +70 = yellow

-70 = blue

control ($p > 0.005$: corrected significance level due to controlling for comparison wise error). However, there were significant differences in the L value when the fat reduced control was compared to the 35% and 45% treatments ($p = 0.0016$ and $p = 0.0007$ respectively). Trend analysis demonstrated a linear trend in L values ($p = 0.033$) among all three treatments suggesting that as the level of honey increased, darkness in the crust increased.

Crust b value: Results (Table 6) of degree of yellowness (b) showed that the products became less yellow and more blue with an increase in the amount of liquid honey ($p = 0.0045$). Pair Wise Differences demonstrated that the 35% and 45% treatments yielded significantly less yellow crusts than did the full fat control ($p = 0.0016$ and $p = 0.0008$ respectively). However, differences were not noted to be significant when treatments were compared to the fat reduced control ($p > 0.005$). No linear or quadratic trends were noted (linear, $p = 0.2426$; quadratic, $p = 0.7419$).

Crust Delta E value: The Delta E value is an overall measure of the change in color that resulted in the muffin formulation. According to ANOVA results, there were significant differences that existed between groups. Pair Wise Differences (Table 6) demonstrated that the significant differences existed between the 35% and 45% treatments when compared to the fat reduced control ($p = 0.0028$ and $p = 0.0017$ respectively). No significant differences were noted between the Delta E values of the full fat control and any of the replacement treatments. Trend analysis however did not show a significant linear trend in the rate of darkening as honey replacement increased ($p = 0.07$).

Crumb L value: The ANOVA for the model demonstrated significant differences in the crumb L values with liquid honey usage ($p=0.0009$). Paired Wise Differences (Table 7) demonstrated that crumb L values were not significantly different in all treatments from the full fat control. However, when the fat reduced control was compared to the replacement treatments, the results suggested that the 45% treatment was significantly darker ($p=0.0010$). No linear or quadratic trends were observed (linear, $p=0.1531$; quadratic, $p=0.9382$).

Crumb b value: The effect of liquid honey on the crumb b value demonstrated that there were significant differences in all treatments ($p=0.0001$). Significant differences were detected (Table 7) at the 35% and 45% ($p=0.0002$ and $p=0.000$, respectively) levels when compared to the full fat control, while all treatments showed a significant increase in crumb b value when compared to the fat reduced control ($p=0.0005$ for 25%, $p=0.0001$ for 35%, and $p=0.0001$ for 45%). This suggested that the addition of liquid honey had a yellowing effect on the crumb. Trend analysis also demonstrated that as honey replacement increased, the amount of yellowness increased linearly ($p=0.0126$).

Crumb Delta E value: ANOVA results showed a significant difference in treatments for the Delta E model ($p=0.0003$). The Paired Wise Difference test (Table 7) for Crumb Delta E followed the same pattern as Crumb b. The 35% and 45% replacement treatments showed significantly higher Delta E values when compared to the full fat control ($p=0.0025$ and $p=0.0003$) and all treatments showed significantly higher Delta E values when compared to the fat reduced control ($p=0.0029$ for 25%, $p=0.0002$ for 35%,

Table 7. “Crumb Color of Muffins Measured 1 Hour Post Bake Using Liquid Honey.”

Trt.	Crumb					
	L	Std. Er.*	b	Std. Er.*	Delta E	Std. Er.*
Full cntrl	80.46 a,f	± 0.88	28.13 a,f	± 0.49	31.82 a,f	± 0.77
Red. cntrl	81.85 a,f	± 0.88	27.30 a,f	± 0.49	30.36 a,f	± 0.77
25% liq.	78.67 a,f	± 0.88	30.34 a,g	± 0.49	34.28 a,g	± 0.77
35% liq.	77.80 a,f	± 0.88	31.42 b,g	± 0.49	35.82 b,g	± 0.77
45% liq.	76.76 a,g	± 0.88	32.32 b,g	± 0.49	36.94 b,g	± 0.77

Values with the same letter within each column denote no significant differences ($p > 0.05$), such that:

“a” compares all treatments to full fat muffin (full cntrl)

“f” compares all treatments to fat reduced muffin (red. cntrl)

* Std. Er. = Standard Error of the LS Means

L: 0 = black

100 = white

b: +70 = yellow

-70 = blue

and $p=0.0001$ for 45%). A linear trend could be used to describe the relationship between the Delta E value and the amount of liquid honey that could be used to replace sugar ($p=0.0503$).

Theoretically, darkening would increase with the use of liquid honey due to the increase in the amount of reducing sugars available to participate in the Maillard Browning reaction. The nonenzymatic Maillard Browning reaction occurs when reducing sugars (such as fructose) and proteins are heated together. The end result is a product with a brown color. Since additional fructose was added to the batter with the addition of honey, an increase in the degree of Maillard Browning would be expected. Carmelization, the process that sugar undergoes when it is heated, may be an added participant in the darkening of the product. Moreover, since the temperature at the surface of the muffin is higher than within the muffin, there would be a higher degree of browning in the crust, rather than the crumb (Demetriades et al., 1995). These results are in agreement with other studies (Smith and Johnson, 1951; Demetriades et al., 1995; and Addo, 1997).

The results also suggested that no difference in overall crust and crumb color would be obtained from a 25% replacement of sugar with liquid honey, however, with an increase of greater than 35%, a significantly darker crust and crumb color would be obtained. Although the full fat control and the fat reduced control were not significantly different in both crust and crumb, the results demonstrated that the crumb and crust of the fat reduced control was consistently “lighter” than the full fat control (lower Delta E values for each parameter). Early research (Maninden and Jorgensen, 1983) had

demonstrated that the amylases in the fat reduced control would have increased the crust color, most likely due to the availability of more reducing sugars available for Maillard Browning. However, Valjakka et al. (1994) and Kuracina et al. (1984), showed that amylases had no effect on improving crust color. The present research supports work by Canterella (1995) who demonstrated that panelists perceived a lighter crumb in fat substituted muffins made with enzymes. In this investigation, a liquid honey replacement for sugar in a fat reduced muffin added at a rate of 25% would alleviate this problem.

5.1 B2. Dry Honey

Crust L value: The ANOVA results demonstrated that the overall model was significant ($p=0.0015$). Further investigation of the results using Pair Wise Differences (Table 8) demonstrated that the 35% and 45% honey replacement treatments were significantly darker than the full fat control ($p=0.0025$ and $p=0.0008$ respectively: corrected significance level due to controlling for comparison wise error). Also, when compared to the fat reduced control, only the 45% treatment showed significant darkening ($p=0.0020$). Trend analysis did not demonstrate a linear or quadratic trend in L values ($p>0.05$).

Crust b value: Results demonstrated that there was no significant differences between any of the controls or treatments ($p=0.2824$) which suggested that the use of dry honey had no significant effects on Crust b values. Pair Wise Difference testing (Table 8) confirmed the multiple comparison ANOVA results since all treatments were not significantly different from both controls ($p>0.10$ for all comparisons made with $p<0.0005$ recognized as significant). No linear or quadratic trends were noted (linear, $p>0.05$; quadratic, $p>0.05$).

Table 8. “Crust Color of Muffins Measured 1 Hour Post Bake Using Dry Honey.”

Trt.	Crust					
	L	Std. Er. *	b	Std. Er. *	Delta E	Std. Er. *
Full cntrl	73.34a,f	± 1.96	40.57a,f	± 1.31	47.03a,f	± 2.01
Red. cntrl	72.12a,f	± 1.96	40.32a,f	± 1.31	46.71a,f	± 2.01
25% dry	65.76a,f	± 1.96	39.40a,f	± 1.31	49.59a,f	± 2.01
35% dry	63.24b,f	± 1.96	40.07a,f	± 1.31	50.71a,f	± 2.01
45% dry	61.68b,g	± 1.96	37.35a,f	± 1.31	50.96a,f	± 2.01

Values with the same letter within each column denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat muffin (full cntrl)

“f” compares all treatments to fat reduced muffin (red. cntrl)

* Std. Er. = Standard Error of the LS Means

L: 0 = black

100 = white

b: +70 = yellow

-70 = blue

Crust Delta E value: According to ANOVA results, there were no significant differences that existed between groups ($p=0.1775$). Pair Wise Differences (Table 8) again confirmed these results, whereby no significant differences occurred among treatments and controls ($p>0.1616$ for all comparisons made with $p<0.0005$ recognized as significant). Trend analysis, however, did not show a significant linear or quadratic trend in the rate of darkening as dry honey replacement increased ($p>0.05$).

Crumb L value: The ANOVA for the model demonstrated a highly significant difference in the crumb L values was obtained from dry honey ($p=0.0001$). Paired Wise Difference testing (Table 9) demonstrated that a significant decrease in Crumb L value (darkening) existed between all treatments when compared to either the full fat or fat reduced control ($p<0.0025$ for all treatments). A linear trend was observed ($p=0.0446$), which also suggested that as the level of honey increased, a proportional amount of darkening occurred.

Crumb b value: Significant differences were detected at all treatment levels when compared to both the full fat or fat reduced controls ($p=0.0001$ for all treatments; Table 9). Trend analysis did not demonstrate a linear or quadratic trend ($p>0.05$).

Crumb Delta E value: ANOVA results indicated significant differences between all treatments for the Delta E model ($p=0.0001$). The Paired Wise Difference test for the

Table 9. “Crumb Color of Muffins Measured 1 Hour Post Bake Using Dry Honey.”

Trt.	Crumb					
	L	Std. Er.*	b	Std. Er.*	Delta E	Std. Er.*
Full cntrl	85.42a,f	± 0.71	27.45a,f	± 0.47	29.36a,f	± 0.65
Red. cntrl	82.42a,f	± 0.71	27.00a,f	± 0.47	29.75a,f	± 0.65
25% dry	78.74b,g	± 0.71	31.35b,g	± 0.47	35.38b,g	± 0.65
35% dry	78.73b,g	± 0.71	31.51b,g	± 0.47	35.30b,g	± 0.65
45% dry	76.62b,g	± 0.71	31.69b,g	± 0.47	36.38b,g	± 0.65

Values with the same letter within each column denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat muffin (full cntrl)

“f” compares all treatments to fat reduced muffin (red. cntrl)

* Std. Er. = Standard Error of the LS Means

L: 0 = black

100 = white

b: +70 = yellow

-70 = blue

Delta E parameter followed the same pattern as Crumb b (Table 9). Significant differences were detected at all treatment levels when compared to both the full fat or fat reduced controls ($p=0.0001$ for all treatments). No linear or quadratic trends existed among the treatments ($p>0.05$).

Since liquid honey demonstrated an increase in the darkening of crust and crumb at increasing replacement levels, it was considered that dry honey would affect crust and crumb color to a greater extent since the dry honey muffin formulations contained more fructose than the muffins containing liquid honey. It was expected that dry honey would have actually caused an increase in browning due to the higher presence of reducing sugars. However this could not be addressed in the present study, due to the fact that the muffin formulas containing liquid and dry honey were different. The results did indicate that dry honey did increase the degree of darkening in the crumb which was indicated from the Delta E values. However, the degree of darkening in the crust was significant in L values for both the 35% and 45% dry honey replacements (Table 8).

These results appear to suggest that a 25% dry honey replacement for sugar would cause significant changes in overall muffin color, and therefore, could potentially decrease consumer acceptance. Although the full fat control and the fat reduced control were not significantly different in both crust and crumb, the results demonstrate that the crumb and crust of the fat reduced control was consistently “lighter” than the full fat control (lower Delta E values for each parameter). Although not well established, it has been suggested that the enzymes in the fat reduced muffin coupled with the protein in the egg white (or

amino acids in the enzymes themselves) would increase color due to an increase in the Maillard Browning reaction (Maninden and Jorgensen, 1983). However, more recent research (Valjakka et al., 1994 and Kuracina et al., 1987) have shown that amylases had no effect on darkening of the crumb. Another possible explanation is that the addition of the enzymes, emulsifier, and fat substitute may have decreased the batter pH and therefore, decreased the rate of Maillard Browning. Therefore, a dry honey replacement for sugar in a fat reduced muffin added at a rate lower than 25% may alleviate this potential problem.

5.1 C Volume

5.1 C1. Liquid Honey

Results of the ANOVA for the volume characteristic using liquid honey demonstrated that there was no significant differences ($p=0.6273$) among the treatments (Table 10). The lack of statistically significant differences between both the controls and the 3 treatments was most likely due to the high standard error associated with the LS Means (Table 10). This error could have been caused by factors, such as, lack of precision on the caliper instrument as well as operator error. Also, an observation of the muffins after baking indicated that when muffin batter was measured first, the baked muffins had lower tops, and therefore lower volumes, as opposed to those measured last. Therefore, overmanipulation of the batter could have affected volume due to gluten development (Bennion, 1990b).

Table 10. “Volume of Muffins Measured 1 Hour Post Bake Using Liquid Honey.”

Trt.	Volume (cm³)	Std. Er.*
Full cntrl	191.8a,f	± 14.47
Red. cntrl	185.0a,f	± 14.47
25% liq.	219.0a,f	± 14.47
35% liq.	179.4a,f	± 14.47
45% liq.	217.4a,f	± 14.47

Values with the same letter denote no significant differences ($p > 0.05$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

Since muffins were randomly selected for volume measurements, it is apparent how an inconsistency could have arisen. Also, two measurements (height and diameter) were used to measure volume, and inconsistencies may have occurred in the determination of where the maximum heights and diameters were located.

5.1 C2. Dry Honey

As observed with the liquid honey results, no significant differences were noted in the ANOVA of the model. Therefore, Paired Wise Differences (Table 11) did not indicate any differences in either of the treatments when compared to the full fat or fat reduced controls ($p>0.05$). Trend analysis showed no linear or quadratic trends.

Reasons for this lack of statistically significant data may be attributed to the same factors which were noted with the liquid honey: sampling procedure, measuring technique, as well as instrument usage.

Research studies have presented contradictory findings concerning the effect of sweeteners on final volume. One researcher (Addo, 1997), believed that volume would have increased with the addition of honey due to an increase in the amount of sugar, and therefore a decrease in gluten structure formation. On the other hand, it was also thought that the increased amount of fructose would lower the gelatinization temperature of the batter and thus decrease volume (Bean et al., 1978; Coleman and Harbers, 1983; McCullough et al., 1986). Smith and Johnson (1952) noted that a decrease in volume may have been attributed to a decrease in batter pH (by the use

Table 11. “Volume of Muffins Measured 1 Hour Post Bake Using Dry Honey.”

Trt.	Volume (cm³)	Std. Er.*
Full cntrl	195.4a,f	± 7.87
Red. cntrl	200.7a,f	± 7.87
25% dry	191.8a,f	± 7.87
35% dry	186.2a,f	± 7.87
45% dry	181.9a,f	± 7.87

Values with the same letter denote no significant differences ($p>0.05$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

of honey), which would have led to a decreased efficiency of the leavening agents.

Unfortunately, this issue could not be addressed due to the high standard error noted in the measurement. However, it may be important to recognize, that although statistically insignificant, the volume did have a tendency to decrease with the addition of honey.

The reduced fat control was noted as having a higher volume when compared to the full fat control in one treatment (Table 11). This confers with Miller and Hosney (1993) and Canterella (1995) who noted that the fat substitute competed for water which in turn increased batter viscosity, which ultimately resulted in better air retention.

5.2 Physical Data Measured 1 Hour Post Bake and After 14 and 28 Days of Freezing

5.2 A. Moisture Content

5.2 A1. Liquid Honey

Table 12 and Figure 2 represent the moisture content of the muffins containing liquid honey 1 hour after baking, and then after 14 and 28 days of freezing. The multiple comparison ANOVA showed a significant difference in this model ($p=0.0001$). Further analysis of the means for all days in a given treatment suggested that there was a significant difference in treatments ($p=0.0001$). This significant difference is known as a treatment effect. Likewise, when a mean was determined for all treatments during a given time, there also existed a significant difference ($p=0.0001$). This significant difference is known as a time effect. Since there was interaction between treatment and time ($p=0.2640$), then

Table 12 - “Moisture Content of Muffins Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Liquid Honey.”

# days in storage	Full cntrl % Moisture	Red. cntrl % Moisture	25% liq. % Moisture	35% liq % Moisture	45% liq. % Moisture
day 1	37.4	41.0	41.5	42.0	42.1
day 14	37.4	39.6	41.2	40.1	40.2
day 28	36.1	40.2	40.6	40.1	40.5
Difference (day1-day28)	-1.3	-0.8	-0.9	-1.9	-1.6

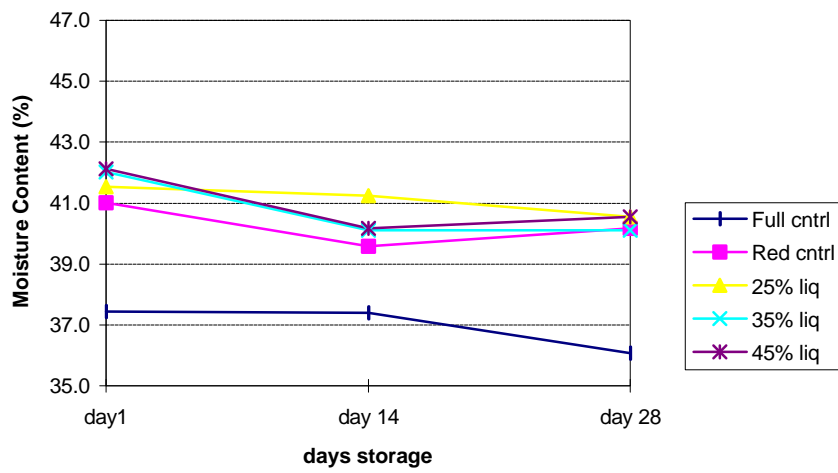


Figure 2 - “Results of Moisture Content Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Liquid Honey.”

conclusions can not be made as to which treatment performed more efficiently at moisture retention. If a significant treatment versus time interaction existed, then a statement could have been made about the changes in moisture content that occurred within each treatment group.

The most significant change during baking is the redistribution of water in the dough (in this case, batter) matrix (Ablett et al., 1986). Based on LS Means, it appeared that at Day 1 the fat substituted muffins contained more moisture than the full fat muffin. The lower water content of the full fat muffin as compared to all fat substituted muffins suggested that more water was allowed to redistribute into the air (evaporate). In the fat substituted muffins, the hydrocolloid fat replacer traps water while the monoglycerides absorbed and helped to maintain moisture (Sobczynska and Setser, 1991). Fructose, which is present in the honey also helped to bind water.

Figure 2 and Table 12 show, however, that the moisture content of the 25% liquid replaced muffin was better maintained, whereas the 35% and 45% liquid honey replaced muffins had a higher loss of moisture over time (statistical analysis not measured on this parameter). Canterella (1995) noted that the sugars produced by enzymes in fat reduced muffins may have competed for water thus leaving the hydrocolloids and monoglycerides with less water to bind. Therefore, the low moisture content of fat reduced muffins with enzymes may have been the result of the excess “sugar production” produced by the enzymes which provided less water availability to the hydrocolloid and emulsifier. It is also possible that the increase in dextrin formation may have increased the gelatinization

temperature of the starch granules, and a more limited amount of water was made available to the starch granule. This decrease in availability may have resulted in the observed loss of moisture.

5.2 A2. Dry Honey

Results of a dry honey replacement for sugar in fat reduced muffins on moisture content are represented in Table 13 and Figure 3. The multiple comparison ANOVA demonstrated that the model was significant ($p=0.0001$). Further investigation revealed similar results as with liquid honey usage: there was both a treatment and time effect ($p=0.0001$ for both effects), however there was no treatment versus time interaction ($p=0.9885$). For reasons mentioned above, no statements could be made about the changes in moisture content that occurred within each treatment group.

Based on LS Means, the dry honey followed the same trends as the liquid honey. As dry honey increased in the product, moisture content increased after day 1. Initial results indicated that the dry honey held onto more water than the liquid honey, however, this could not be verified because more water was originally used in the batter of muffins made with dry honey

Over time, muffins containing 45% dry honey actually lost more water, perhaps for the same reasons as those noted with liquid honey. Water loss was minimized in both the 25% and 35% dry honey replaced muffins. Therefore, perhaps the fructose content of muffins made with 25% or 35% honey replaced for sugar was ample enough to hold onto water during

Table 13 - “Moisture Content of Muffins Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Dry Honey.”

# days in storage	Full Cntrl % Moisture	Red. Cntrl % Moisture	25% dry % Moisture	35% dry % Moisture	45% dry % Moisture
day1	38.1	41.8	44.4	45.5	46.0
day 14	37.0	40.6	43.3	44.7	45.1
day 28	37.0	40.6	43.4	44.6	44.6
difference (day1-day28)	-1.1	-1.2	-1.0	-0.9	-1.4

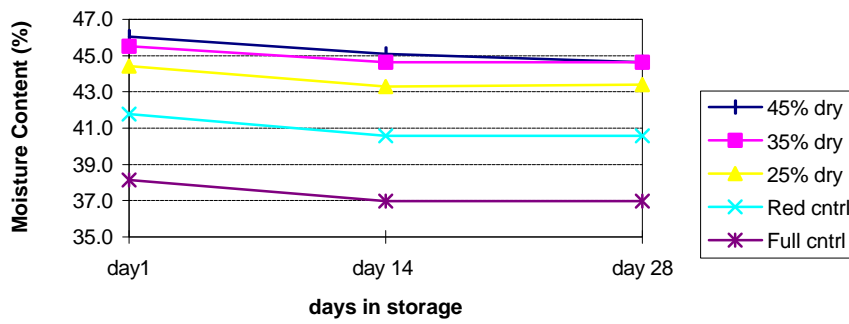


Figure 3 - “Results of Moisture Content Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Dry Honey.”

the extended frozen storage, whereas muffins made with 45% honey actually may have been responsible for an increased loss of water.

5.2 B. Staling Effect

5.2 B1. Liquid Honey

It has been generally recognized that the staling mechanism is due to a gradual transition of starch from an amorphous structure to a partially crystalline state (Hebeda et al., 1990). The moisture which is associated with the starch is redistributed, and its loss is not dependent on staling. The increase in starch crystallinity is caused by an intramolecular association of amylopectin via hydrogen bonding, known as retrogradation.

A sample and a reference were placed on a metal heat sink. The difference of heat flowing from the heat sink into the sample and reference substance is proportional to the temperature difference of the sample and the reference, and therefore heat flow is indirectly obtained by measuring the temperature difference. An upward direction (hump) in the DSC curve obtained in the present investigation demonstrated an endothermic response, whereas a downward direction in the DSC curve (pit) represented an exothermic response.

Retrogradation of starch, or the “hardening of starch”, resulted in an endothermic response. The change in heat flow (height of the hump, Delta H) as measured in the present investigation is shown in Table 14 and in Figure 4. Over time, Delta H increased

Table 14 - “Staling Measurements of Muffins After 1 Day, 2 Days, and After 14 and 28 Days of Freezing Using Liquid Honey.”

# days in storage	Full cntrl (Delta H)	Red. cntrl (Delta H)	25% liq (Delta H)	35% liq (Delta H)	45% liq (Delta H)
day 1	0.304	0.160	0.344	0.349	0.470
day 2	0.486	0.404	0.668	0.738	0.760
day 14	0.603	0.665	0.865	0.861	0.853
day 28	0.562	0.726	0.848	0.912	0.956

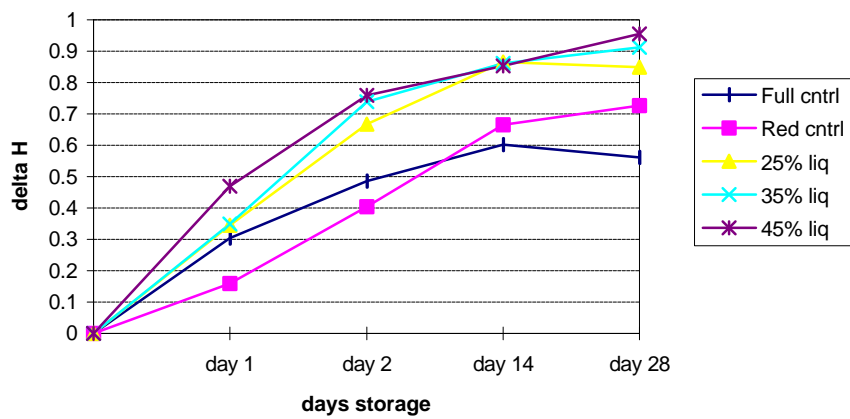


Figure 4 - “Results of Staling Measured After 1 day, 2 days, and then After 14 and 28 Days of Freezing Using Liquid Honey.”

due to the fact that more heat was absorbed into the crystalline starch structure before melting.

The multiple comparison ANOVA demonstrated a significant difference in the overall model ($p=0.0001$), as well as a significant difference among treatments and among time ($p=0.0001$ for both comparisons). However, there was no treatment versus time interaction ($p=0.5720$).

Based on LS Means, all samples made with liquid honey at all times resulted in a higher degree of staling when compared to either of the controls, suggesting that honey may have actually increased the staling rate in the fat reduced muffin. This was contradictory to Smith and Johnson (1952) and Addo (1997) who suggested a decrease in staling rates with the addition of honey in baked products. They cited that the decrease in staling rates were attributed to the hygroscopic nature of the honey. This concept was further reinforced in these studies because the dry honey (more hygroscopic) decreased staling more than the liquid honey.

In the present study, it had been hypothesized that staling rates would probably have decreased due to another mechanism. Although, the gelatinization temperature of the muffin batter was not measured, perhaps the addition of monosaccharides and less disaccharides in the product decreased the gelatinization temperature of the starch granule (Kim and Walker, 1992b and Coleman and Harbers, 1983), thus allowing for increased availability of water to the starch granule. If more time was allowed for the starch granule to swell, then more water would be trapped in the matrix of the starch chains, thus

separating the starch molecules farther apart from one another. The end result is that hydrogen bonding would occur at a slower rate and thus delay retrogradation.

5.2 B2. Dry Honey

The results of the use of dry honey on staling rates of muffins are shown in Table 15 and in Figure 5. Multiple comparison ANOVA for the effect of dry honey on staling rates demonstrated a highly significant difference in the model ($p=0.0001$). This effect was due mainly to significant differences that existed in the time variable ($p=0.0001$), but not according to the treatment variable ($p=0.4726$). This suggested that the treatments did change significantly over time. However, these particular treatments were not significantly different at any given time. Therefore, it can be concluded that the addition of dry honey did not have an effect on the staling rate of fat reduced muffins as with the liquid honey. In fact, based on LS Means, the dry honey actually hindered retrogradation after 2 days in the 25% and 45% replacement formulas. However, upon freezing, muffins made with dry honey at all replacement levels actually showed an increase in staling rate over the two controls. Perhaps in this instance, the honey pulled water away from the starch granule and thus promoted hydrogen bonding to occur.

Table 15 - “Staling Measurements of Muffins After 1 Day, 2 Days, and After 14 and 28 Days of Freezing Using Dry Honey.”

# days in storage	Full cntrl (Delta H)	Red. cntrl (Delta H)	25% dry (Delta H)	35% dry (Delta H)	45% dry (Delta H)
day 1	0.219	0.175	0.186	0.126	0.138
day 2	0.455	0.411	0.417	0.497	0.399
day 14	0.505	0.487	0.575	0.602	0.622
day 28	0.482	0.419	0.593	0.571	0.553

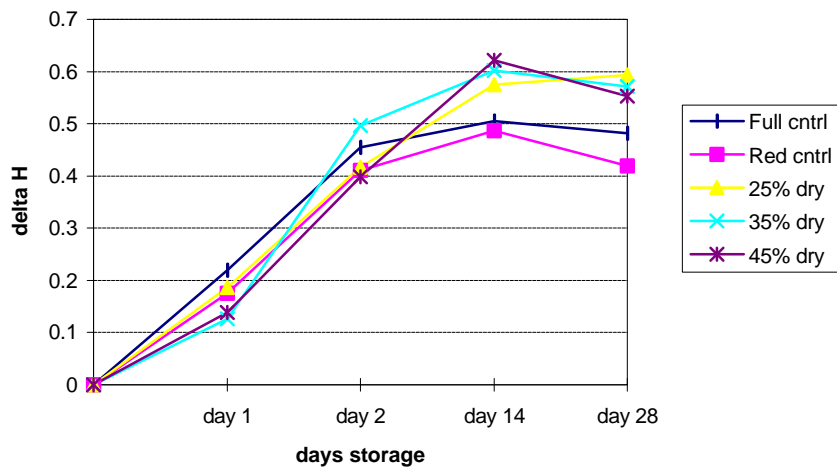


Figure 5 - “Results of Staling Measured After 1 day, 2 days, and then After 14 and 28 Days of Freezing Using Dry Honey.”

5.2 C. Crumb Firmness

5.2 C1. Liquid Honey

Fat plays a major role in increasing tenderness (Bennion, 1990a) by interfering with the gluten starch complex and thus plays a major role in decreasing firmness. The fat reduced muffins utilized ingredients to increase tenderness. Soft wheat flour was used because of its low protein content (8-8.5%, Bennion, 1990b). This low protein content would result in a more tender product because of less gluten formation. Hydrocolloids, such as Methocel, increase tenderness by trapping and holding water (Miller and Hosoney, 1993). Alpha amylases from both fungal and bacterial sources help to breakdown starch to smaller dextrans and, therefore, compete for water and thus hinder gluten development as well starch gluten interactions. Finally, honey was to function much like the sugars formed by the alpha amylases by competing for water and increase tenderness through similar mechanisms. However, the egg whites in the fat reduced systems may actually have contributed to an added strength in the cell walls and may therefore have increased firmness (Medved, 1978).

The results from this investigation (Table 16 and Figure 6) demonstrated that a strong significant difference existed in the model for firmness ($p=0.0001$). Further analysis also demonstrated that there was a significant treatment and time effect ($p=0.0001$ for each, respectively). A treatment versus time interaction was also shown to exist ($p=0.0407$).

Table 16 - “Crumb Firmness of Muffins Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Liquid Honey.”

# of days in storage	Full cntrl (g Force)	Red. cntrl (g Force)	25% liq (g Force)	35% liq (g Force)	45% liq (g Force)
day1	0.63	1.01	0.98	0.82	0.89
day 14	0.77	1.41	1.42	1.46	1.53
day 28	0.77	1.41	1.43	1.59	1.49

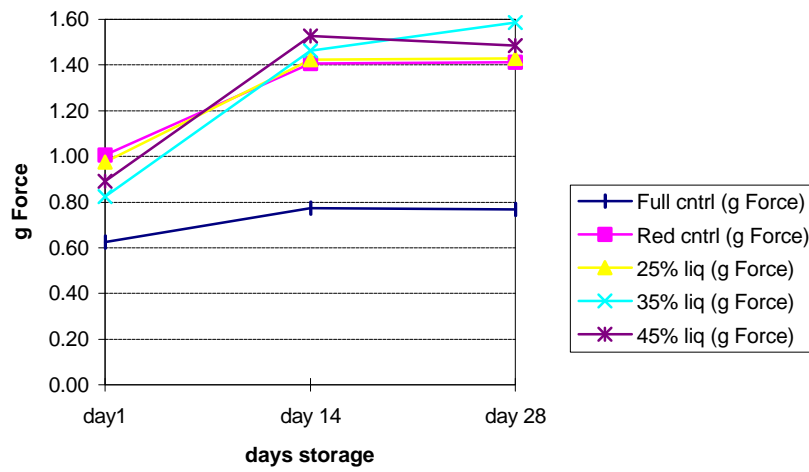


Figure 6 - “Results of Crumb Firmness Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Liquid Honey.”

Because of this interaction, a graph of the results (Figure 6) demonstrated that the full fat version was significantly less firm ($p < 0.05$) than all the other fat substituted muffins.

Sensory panelists also noted that samples made with liquid honey were more dense than the full fat muffin (Table 18).

After 14 days of frozen storage, all fat substituted muffins showed a marked increase in firmness with the 45% liquid honey replacement demonstrating the highest change (increase) in firmness. Firming, however, did not continue to increase linearly after 28 days. The firming in these products appeared to remain constant or actually decrease slightly. The 35% liquid honey muffin, however did not follow that trend. It continued to increase in firmness over the study period. These results suggested that liquid honey may have had little to no effect on decreasing firmness. The LS Means suggested that the addition of honey may have actually increased the firming of the fat reduced products (although statistics were not performed) because firmness measurements were higher in all treatments at all times when compared to the fat reduced control. This was noted by Coleman and Harbers (1983) who demonstrated that firmness increased with the addition of high fructose corn syrup in angel cakes.

An increase in the monosaccharides into the product may have decreased the gelatinization temperature of the starch granule (Kim and Walker, 1992b; Coleman and Harbers, 1983). This may allow an increase of water availability to the starch granule and a higher water activity (Table 4). In essence, the product would appear to have more

water, and a high moisture content (Table12). However, contradictory to theory, this increase in water did not manifest itself in a decrease, but rather, an increase in firmness.

5.2 C2. Dry Honey

The results (Table 17) of the effect of dry honey on firmness in reduced fat muffins showed very little difference than those made with liquid honey, and therefore, the same explanations given above would suffice. The overall model for the use of dry honey demonstrated that a highly significant difference existed ($p=0.0001$). Again, further investigation demonstrated a treatment and a time interaction ($p=0.0001$ for both comparisons) as well as an interaction between treatment and time ($p=0.0015$). Since this interaction existed, a graph of the results (Figure 7) demonstrated a significantly lower firmness in muffins made with fat as opposed to those made without fat. Again, the difference appeared to be the least after one day and appeared to increase after the 14 days of frozen storage.

Table 17 - “Crumb Firmness of Muffins Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Dry Honey.”

# of days in storage	Full cntrl (g Force)	Red. cntrl (g Force)	25% dry (g Force)	35% dry (g Force)	45% dry (g Force)
day 1	0.61	0.89	1.01	0.91	1.05
day 14	0.73	1.34	1.48	1.42	1.45
day 28	0.76	1.56	1.54	1.40	1.51

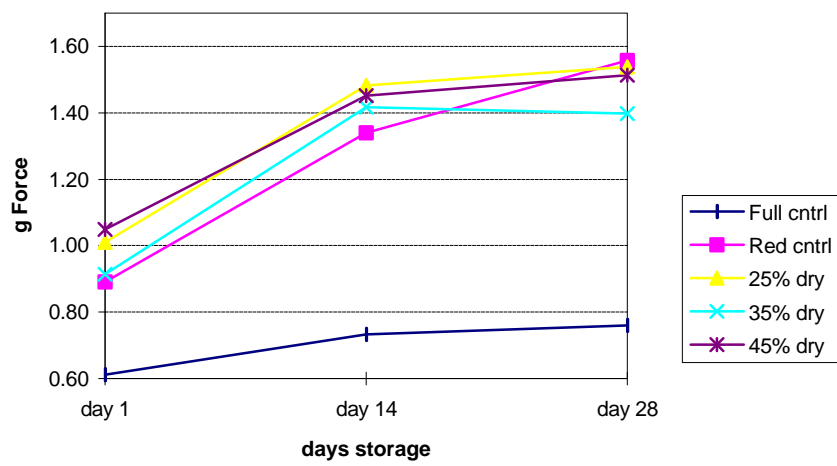


Figure 7 - “Results of Crumb Firmness Measured 1 Hour Post Bake, and After 14 and 28 Days of Freezing Using Dry Honey.”

5.3 Sensory Data

5.3 A. Liquid Honey

Crust Color: Table 6 indicated that muffins containing liquid honey at a 35% and 45% replacement level produced a crust that was significantly darker than the full fat control and the fat reduced control ($p < 0.005$; when comparing L values of crust color). It was also concluded that although the difference between the full fat and fat reduced controls were not significantly different ($p > 0.005$), the fat reduced control was lighter in color. This difference may have been attributed to the decreased alkalinity of the batter caused by the addition of the fat substitute, gums, and enzymes (Canterella et al., 1995). Therefore, when interpreting the results from the sensory panel, it would be expected that the results would follow the same trend.

Table 18 demonstrates that the sensory panelists noted a darkening in crust color with increasing amounts of honey. However, this increase did not follow a linear or quadratic trend ($p = 0.1587$ and $p = 0.8337$ respectively). Also, the fat reduced control was found to be significantly ($p < 0.005$) lighter than the full fat control and all other treatments which is in agreement with Canterella et al. (1995), Mason et al. (1996).

Cohesiveness: Cohesiveness was defined as the amount of resilience that existed in the muffin samples (Appendix L) when the sample was touched by the evaluator. The full fat control muffin was rated as being the least resilient ($p < 0.005$).

Table 18 - “Crust Color, Cohesiveness, and Mouthfeel Parameters of Sensory Evaluation of Muffins Using Liquid Honey.”

Trt.	Color ~	Std. Er.*	Cohes.∇	Std. Er.*	Mouth.ψ	Std. Er.*
Full cntrl	7.2 a,g	± 0.3	5.0 a,g	± 0.3	4.5 a,g	± 0.3
Red. cntrl	5.7 b,f	± 0.3	7.9 b,f	± 0.3	9.0 b,f	± 0.3
25% liq.	8.8 b,g	± 0.3	8.9 b,f	± 0.3	9.5 b,f	± 0.3
35% liq.	9.5 b,g	± 0.3	8.8 b,f	± 0.3	9.3 b,f	± 0.3
45% liq.	10.0 b,g	± 0.3	8.7 b,f	± 0.3	9.5 b,f	± 0.3

Values with the same letter within each column denote no significant differences ($p > 0.005$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

~ Crust Color: the extent to which the muffin is pale yellow (0) or dark brown (15)

∇ Cohesiveness: the extent to which the muffin is springy (0) or dense (15) as evaluated by touch

ψ Mouthfeel: the extent to which the muffin is tender/cakelike (0) or chewy/breadlike (15)

The fat reduced control was noted as being more resilient, followed by those muffins made with honey.

An increase in firmness had been noted in fat reduced muffins by Canterella et al. (1995), Mason et al.(1996), and in the present study (Table 16) when compared to the full fat control. The increase in cohesiveness that had occurred with the addition of honey is contradictory with other findings. Studies done on frozen doughs (Smith and Johnson, 1951 and Addo, 1997) has shown a decrease in crumb firmness with the addition of 8 and 10% honey, chiefly due to the hygroscopic nature of honey. Perhaps this increase in cohesiveness that was noted by the sensory panelists was due to a difference in interpretation of the meaning of the parameter or a difference between the manipulation of a frozen dough and a batter.

Mouthfeel: Mouthfeel was chosen by the sensory panelists due to the fact that a major concern with fat free products is the texture of the product. Fat free products were noted by the sensory panelists during training sessions as being somewhat dry, firm, and chewy (Appendix L). Therefore, mouthfeel was chosen as the parameter that was used to measure the degree to which the muffin was “tender/cakelike” (0) or “firm/breadlike” (15).

The results (Table 18) show that the full fat control was at least twice as tender when compared to the fat reduced treatments ($p=0.0001$ for all comparisons). Fat interferes with gluten development and adds lubricity to baked products resulting in a more tender and softer product. It was thought that the fat substitute would bind and

retain water and therefore, increase tenderness. It was also believed that the DATEM would act as a dough softener by interfering with gluten structure and thus promote a more tender product (Kulp and Ponte, 1981). The amylases were added to breakdown starches into sugars that would compete for water and thus also retard gluten structure (Canterella et al., 1995). Finally, the addition of honey was thought to take on two roles: 1) it would bind water, which would thus 2) compete for water and prevent gluten structure formation. Collectively, these functions would help to increase the tenderness of the product. However, it appears from the results that these ingredients did not sufficiently increase tenderness.

Sweetness: One function of fat in baked products is to act as a flavor carrier. This may occur because the fat stays on the tongue longer and thus stimulates the taste buds. If the fat is removed then the resulting product may appear to have less flavor. Secondly, honey contains a high amount of fructose. Fructose is rated as being the sweetest of all mono- and disaccharides. Because of this, sensory panelists chose sweetness as a critical parameter to evaluate.

The results (Table 19) indicated that fat enhanced the sweetness of the product and when fat was removed (fat reduced control), the intensity of sweetness decreased ($p=0.0001$). However, the replacement of honey for sugar at the 25% and 35% levels did appear to

Table 19 - “Sweetness, Moistness, and Adhesiveness Parameters of Sensory Evaluation of Muffins Using Liquid Honey.”

Trt.	Sweet ∞	Std. Er.*	Moist Δ	Std. Er.*	Adhes. •	Std. Er.*
Full cntrl	8.6 a,g	± 0.3	10.1 a,g	± 0.3	4.8 a,g	± 0.3
Red. cntrl	6.9 b,f	± 0.3	7.0 b,f	± 0.3	8.3 b,f	± 0.3
25% liq.	7.3 b,f	± 0.3	6.6 b,f	± 0.3	9.3 b,f	± 0.3
35% liq.	7.4 a,f	± 0.3	6.5 b,f	± 0.3	8.8 b,f	± 0.3
45% liq.	6.8 b,f	± 0.3	6.2 b,g	± 0.3	9.1 b,f	± 0.3

Values with the same letter within each column denote no significant differences ($p > 0.005$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std Er. = Error of the LS Means

∞ Sweetness: the extent to which the muffin is bland (0) or sweet (15)

Δ Moistness: the extent to which the muffin is dry (0) or moist (15)

• Adhesiveness: the extent to which the muffin crumbled (0) or was rubbery (15) in the mouth.

increase the perceived sweetness of muffins when compared to the fat reduced control. The increase was not significant however when compared to the fat reduced muffin ($p > 0.0005$). The 25% and 45% honey treatments were significantly lower than the full fat control ($p = 0.0001$), however, the 35% honey replacement was not significant ($p = 0.0067$). These results suggest that although a quadratic relationship did not exist ($p = 0.5432$), a 35% replacement of honey for sugar would be the optimal replacement level to optimize sweetness. The decrease in sweetness noticed at the 45% level may have been attributed to the excess production of reducing compounds.

Moistness: As previously noted, fat acts as a lubricant during chewing; it aids in clearing food particles from the surfaces (teeth and palate) of the mouth. When fat is not present, the main lubricant is saliva (Stauffer, 1996c). Therefore, when developing fat reduced products, moistness is a key concern. Many of the ingredients in the formulation were added to “hold” or “bind” water in the product. The fat substitute used in the formulation is a hydrocolloid which traps water, while DATEM helps to improve the rate of hydration and water absorption by helping with the dispersion of the ingredients. The enzymes were added to create lower molecular weight sugars which compete for water, and honey has an increased ability to hold water. Dry (0) was the anchor used to describe a muffin that needed water to accompany it so that the panelist could swallow. Moist was chosen as the extreme anchor to describe a muffin that “melted in the mouth” and dissolved easily when eaten.

The results (Table 19) demonstrated that the full fat muffin was rated as being moister ($p=0.0001$ for all comparisons). This can be attributed to the fat in the product acting as a lubricant. When the honey replacements were compared to the fat reduced muffin control, no significant changes were noted ($p>0.0450$ for all treatments where $p<0.0005$ is recognized as significant). This would suggest that honey had no effect on increasing the moistness of the product. Based on the LS Means alone, the addition of honey actually decreased the moistness of the product. This is contradictory to what was originally speculated. Perhaps the addition of fructose to the product and with the increase of sweetness somehow decreased the perceived moistness of the product. Also, although definitions of moistness were given to panelists, the panelists' perceptions of moistness may have differed resulting in inconsistencies.

Adhesiveness: If a product is difficult to eat, then the product will not be consumed.

Adhesiveness was the characteristic chosen by the sensory panel that attempted to evaluate the force required to pull or tear a piece of the muffin away from the product with the hand and the mouth. According to the sensory panel, a product with little adhesiveness (0) broke apart easily and was considered very tender. On the other hand, a product that was very adhesive (15) required an unpleasant force to break apart the product and was classified as being "rubbery".

The results (Table 19) show that the full fat muffin was significantly less adhesive than the fat reduced muffin and all honey replacement muffins ($p=0.0001$ for all comparisons). This is consistent with the "mouthfeel" and "cohesiveness" parameters of

the sensory analysis. When the honey replacement treatments were compared to the fat reduced control treatment, no significant differences were noted ($p > 0.0450$ for all comparisons where $p < 0.0005$ needed for significance). However, like the “mouthfeel” and “cohesiveness” parameters, adhesiveness appeared to increase with the addition of honey. This also implied that the addition of honey caused a decrease in product quality. This, as mentioned earlier, was contradictory to what was originally speculated. It was thought that the hygroscopic nature of the honey and the increased moisture content (Table 12), would have led to a more tender product. Perhaps the liquid that was present in the formulation was able to interact with the protein in the flour and the protein in the egg white to form a stronger protein network which resulted in a more chewy, dense, rubbery product.

5.3 B. Dry Honey

Crust Color: The results (Table 20) of the dry honey replacement for sugar demonstrated that both the full fat and fat reduced controls were significantly lighter when compared to each of the honey replacement treatments ($p = 0.0001$ for all comparisons). According to these results, dry honey had a similar darkening effect as did the liquid honey when evaluated by the trained sensory panelists. These results were in accordance with the physical data summarized in Table 8, as well as Smith and Johnson (1951), Demetriades et al. (1995) and Addo (1997). Results between the usage of liquid and dry honey and their effect on sensory panelist’s perception of crust darkening (Table 18 and 20), appear to

Table 20 - “Crust Color, Cohesiveness, and Mouthfeel Parameters of Sensory Evaluation of Muffins Using Dry Honey.”

Trt.	Color ~	Std. Er.*	Cohes.∇	Std. Er.*	Mouth.ψ	Std. Er.*
Full cntrl	5.3 a,f	± 0.3	4.0 a,g	± 0.3	3.9 a,g	± 0.3
Red. cntrl	5.2 a,f	± 0.3	7.4 b,f	± 0.3	8.4 b,f	± 0.3
25% dry	8.4 b,g	± 0.3	8.2 b,f	± 0.3	8.9 b,f	± 0.3
35% dry	7.9 b,g	± 0.3	7.6 b,f	± 0.3	8.2 b,f	± 0.3
45% dry	8.8 b,g	± 0.3	7.9 b,f	± 0.3	8.2 b,f	± 0.3

Values with the same letter within each column denote no significant differences ($p>0.005$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std. Er. = Standard Error of the LS Means

~ Crust Color: the extent to which the muffin is pale yellow (0) or dark brown (15)

∇ Cohesiveness: the extent to which the muffin is springy (0) or dense (15) as evaluated by touch

ψ Mouthfeel: the extent to which the muffin is tender/cakelike (0) or chewy/breadlike (15)

suggest that dry honey decreased browning at a lesser degree than liquid honey.

However, this conclusion is beyond the scope of this investigation because the formulas for muffins made with liquid or dry honey were different in amount of reducing sugar as well as the amount of water present in the formulations.

Cohesiveness: The results (Table 20) suggested that the full fat muffin had a significantly lower degree of resilience ($p < 0.005$) when compared to other fat reduced muffins ($p = 0.0001$ for all comparisons). The honey replacements were not significantly different from the fat reduced control ($p > 0.0900$ for all comparisons where $p < 0.0005$ recognized as significant), however, they did show a trend towards being more resilient than the fat reduced control. Therefore, based on LS Means, it appears that the dry honey actually helped to make the product more firm (more resilient), which is in agreement with the results noted with liquid honey (Table 18).

Mouthfeel: The tenderness of the full fat muffin was (Table 20) significantly more tender than any of the fat reduced muffin formulas ($p = 0.0001$ for all comparisons). The fat reduced version made without honey was rated to be more than twice as chewy as the full fat control. Although the differences between the fat reduced control and any of the honey replacement formulas were not significantly different, the LS Means demonstrated that tenderness increased (values went down) with 35% and 45% dry honey. This could have been caused by the increased amount of water that had to be added to the formula to create a batter with the same rheological properties as those batters made with liquid honey.

Table 21 - “Sweetness, Moistness, and Adhesiveness Parameters of Sensory Evaluation of Muffins Using Dry Honey.”

Trt.	Sweet ∞	Std. Er.*	Moist Δ	Std. Er.*	Adhes. •	Std. Er.*
Full cntrl	8.9 a,g	± 0.3	11.0 a,g	± 0.3	3.9 a,g	± 0.2
Red. cntrl	7.9 a,f	± 0.3	7.7 b,f	± 0.3	8.0 b,f	± 0.2
25% dry	6.9 b,f	± 0.3	7.5 b,f	± 0.3	8.3 b,f	± 0.2
35% dry	7.0 b,f	± 0.3	8.4 b,f	± 0.3	8.5 b,f	± 0.2
45% dry	6.6 b,g	± 0.3	7.9 b,f	± 0.3	8.7 b,f	± 0.2

Values with the same letter within each column denote no significant differences ($p>0.005$), such that:

“a” compares all treatments to full fat control

“f” compares all treatments to fat reduced control

* Std Er. = Error of the LS Means

∞ Sweetness: the extent to which the muffin is bland (0) or sweet (15)

Δ Moistness: the extent to which the muffin is dry (0) or moist (15)

• Adhesiveness: the extent to which the muffin crumbled (0) or was rubbery (15) in the mouth.

Sweetness: The results of the sensory panel's interpretation of sweetness using dry honey (Table 21) did not appear to follow the same trend as with the liquid honey. The evaluation did show that the full fat control appeared to be sweeter than all the other fat reduced muffin formulas. However, the evaluation did not show a significant difference between the full fat control and the fat reduced control ($p=0.0212$ where $p<0.0005$ is recognized as significant). Although not significantly different ($p>0.0200$ in all comparisons where $p<0.0005$ recognized as significant), all samples made with dry honey were perceived as being less sweet than either the full fat control or the fat reduced control. This suggested that dry honey had no effect on increasing the perceived sweetness of fat reduced muffin, whereas, the addition of dry honey may have actually decreased muffin sweetness according to the panelists. Although no quadratic relationship existed, muffins made with dry honey showed an optimal sweetening effect with a 35% honey replacement. This may suggest that the use of 35% honey as a replacement for sugar, may be optimal in increasing the perceived sweetness of fat reduced muffins.

Moistness: Moistness results (Table 21) of muffins made with dry honey demonstrated that the full fat muffin was perceived as being significantly more moist than all the other fat reduced products ($p=0.0001$ for all comparisons). No significant differences were noticed between the sugar replaced formulas and the fat reduced muffin control ($p>0.1000$ for all comparisons with $p=0.0005$ recognized as significant). A quadratic relationship did exist between honey replacement groups such that the 35% dry honey replacement for sugar yielded the optimal moistness out of all treatments ($p=0.0180$ where $p<0.05$

recognized as being significant). The perception of moistness was shown to increase with the use of dry honey which was originally speculated (however not statistically significant). However, this investigation could not discriminate whether or not the increase in perceived moistness was due to the addition of dry honey or the addition of extra water to the formula.

Adhesiveness: The results (Table 21) indicated that the full fat control was significantly less adhesive ($p=0.0001$ for all comparisons where $p<0.0005$ recognized as significant). This is in agreement with the data involving the influence of fat on increasing tenderness (see Sensory results for liquid honey adhesiveness). All four fat reduced samples did not show any significant differences in adhesiveness as evaluated by the sensory panel ($p>0.0300$ for all comparisons where $p<0.0005$ recognized as significant). By comparing LS Means, it appears that dry honey or the water added to rehydrate the dry honey slightly increased the adhesiveness (chewiness) of the muffins. These results are similar to sensory results of the mouthfeel parameter (Table 20) which suggested that as dry honey increased, the product became more chewy. These results may have been the result of the water increasing gluten and other protein interactions, thus strengthening the structure of the product.

CHAPTER 6:

Summary, Conclusions, and Suggestions for Future Research

Due to the overwhelming concerns about the complications of obesity, the American Heart Association, the Surgeon General, and other health organization have called for a reduction in total dietary fat to 30% of kilocalories. The food industry has responded to this awareness with an array of fat reduced products that attempt to maintain the qualities of its full fat counterpart. These products have fallen short because of the multiple functions that fat plays in given systems. It appears that research which utilizes combinations of ingredients to mimic the functions of fat would be the best approach.

The objective of this study was to assess the effect that both liquid and dry honey would have on the keeping quality of a fat reduced muffin system containing a carbohydrate fat replacer, enzymes, and an emulsifier. It was speculated that due to the hygroscopic nature of the honey, water would be bound more efficiently. The “extra water” retained by honey would then contribute to a decrease in firmness, an increase in moisture content, a decrease in water activity, as well as a decrease in staling. The retention of water by honey would also affect the sensory qualities by improving the perceived moistness and tenderness of the muffin.

It was also speculated that since honey contains a rather large amount of fructose and glucose (Table 2), the addition of such an ingredient would have affected the darkening of both crust and crumb color due chiefly to Maillard Browning. Also, the added monosaccharides may have decreased the gelatinization temperature of the starch

and caused premature starch gelatinization. This in combination with the change in batter pH that may have resulted from the use of honey (Table 2) may have also contributed to a decrease in volume.

The results demonstrated that water activity for all liquid honey formulations did not change significantly ($p>0.05$), although a decrease was observed. The 35% liquid honey replacement approached significance and therefore may be concluded as a potential optimal level of replacement. The dry honey, however increased water activity significantly ($p=0.045$). This difference may have been attributed to the additional water added to the formula to obtain proper rheological properties of the batter. All samples fell within range of microbial growth of yeasts and molds.

Crust color results of the L parameter for both liquid and dry honey found that darkening increased with increasing levels of honey ($p=0.007$ and $p=0.0015$ respectively). However, it is interesting to note that the 25% dry honey replacement for sugar did not show a significant increase in crust color when compared to the full fat or fat reduced control. ($p=0.0164$ and $p=0.0388$)

Results of the L parameter for crumb color with liquid honey usage demonstrated that the 45% honey replacement was significantly darker than the fat reduced control ($p=0.0010$). A linear trend existed when increasing amounts of dry honey were added to the muffin formulations such that as dry honey replacement increased, darkening of crust and crumb increased ($p=0.0446$). These differences were significant at all replacement levels when compared to both controls ($p<0.0025$ for all comparisons). The increase in

darkening that had occurred was attributed to Maillard Browning as well as some caramelization.

The volume parameter for both liquid and dry honey suggested no significant effects ($p>0.05$ in both cases). The lack of statistically significant data were attributed to the high standard error which may have been the result of precision of the caliper instrument, human error, as well as over or under manipulation of the batter depending on where in the pan the muffin was sampled. Studies using HFCS also demonstrated that volume decreased due to premature gelatinization of the starch.

Measuring moisture content over time demonstrated that there was a highly significant difference in the overall model ($p=0.0001$). However, since there was no treatment vs. time interaction, a conclusion could not be drawn as to which formulation performed optimally. However it did appear that moisture was better maintained in all fat reduced formulations when compared to the full fat control, however, the 25% liquid honey replaced formulation was the best overall. The formulations utilizing 35% and 45% replacements showed decreased water retention perhaps due to fructose competing for water with the fat replacer and the monoglycerides, thus decreasing the muffin's water binding capacity. The dry honey appeared to follow the same trend, such that, as honey replacement increased, water loss increased. Water was retained best in the fat reduced muffin, suggesting that the addition of dry honey to the formulation may have been responsible for the water loss.

Staling of muffins appeared to increase with the addition of both liquid and dry honey (models being significant, $p=0.0001$). It was believed that the addition of honey would decrease staling rates for two reasons: 1) the hygroscopic nature of the honey would allow for more water to be retained in the product and 2) the addition of simple sugars would decrease the gelatinization temperature of the starch, thus increasing the time for the starch granule to swell and trap water in the starch matrix. The addition of water would separate the amylopectin molecules from one another and, therefore, decrease the transition rate of starch from an amorphous state to a crystalline state. This decrease in the transition rate would thus retard staling. When placed in a freezer, the lower temperature was expected to retard staling further. The results of this investigation suggested that the addition of honey did not retard staling by this mechanism.

Firmness results for both liquid and dry honey demonstrated that there was a highly significant ($p=0.0001$ for both comparisons) difference in the models. Fat plays a major role in decreasing firmness by interfering with the gluten starch complex, and therefore the full fat muffin control significantly decreased firmness as opposed to all fat reduced formulations ($p<0.05$). It was theorized that the added water in the product would have a tenderizing effect and thus decrease firmness, however, the addition of honey and the subsequent addition of water was found to have had a counteracting affect.

Sensory panelists went through a training regime which taught them to quantify the degree to which each characteristic had changed. This process is known as

quantitative descriptive analysis. The sensory data suggested that crust color darkened with increasing amounts of both liquid and dry honey.

Cohesiveness, or the amount of resilience evaluated by touch demonstrated that products made with either liquid or dry honey were more resilient than the full fat control. This agreed with results of firmness testing, whereby, the addition of liquid or dry honey was found to increase cohesiveness.

Mouthfeel, a parameter used in this investigation to distinguish the tenderness of the product, revealed that all fat reduced products were somewhat “cakelike” when compared to the full fat version. The addition of either liquid or dry honey resulted in products that were equally or slightly less tender than the fat reduced control made without honey.

Sweetness did appear to increase with the use of liquid honey however, sweetness scores reached a maximum at the 35% level, implying that a 35% replacement for honey would be optimal. The dry honey actually decreased sweetness ratings when compared to the fat reduced control. Perhaps the addition of wheat starch and calcium stearate to the dry honey as processing aids, decreased the sweetness intensity. The fat reduced products were, however, considered less sweet than the full fat version in both models, most likely because fat has the ability to “carry” or enhance flavor.

The moistness parameter was expected to increase due to the added moisture in the product that was obtained from the honey. There were no significant differences in perceived moistness when compared to the fat reduced control ($p > 0.005$) with either

liquid or dry honey. However, the full fat muffin was perceived as being the most moist ($p < 0.005$) in both models. This was attributed to the fact that fat aids in clearing the mouth of food. If fat is absent, then more saliva must be required to clear the food from the mouth. This lack of saliva may result in the perception of dryness in the mouth.

Finally, the full fat muffin was shown to have significantly less adhesion ($p < 0.005$) than any of the fat reduced products which utilized liquid or dry honey. This was consistent with the mouthfeel results, both of which implicated the full fat product as being more tender. Like the cohesiveness and mouthfeel parameters, the addition of honey increased the adhesiveness parameter. Perhaps the added water in the product actually helped to form a stronger protein network, resulting in a chewy, dense, and rubbery product.

From results of this study, it was clear that the addition of either liquid or dry honey at all replacement levels affected the color of both the crust and crumb. This could be deleterious to the acceptance of a product depending on the degree of darkening. However, the use of 25% liquid honey was shown to favorably increase the crust color of fat reduced muffins. This could be an asset due to the fact that fat reduced products do not brown to the same degree as their full fat counterparts.

The addition of fructose and glucose to the system also appeared to increase the moisture content of the product, and improved the water activity of the product although not to a statistically significant degree. However, this increase in water did not appear to improve the firmness of the muffin, in fact, the addition of honey may have actually

enhanced firming. This was further reinforced by the sensory panelists who noted that the addition of liquid or dry honey to fat reduced muffins did not affect or increase the cohesive and adhesive forces, as well as decrease tenderness (mouthfeel).

The addition of water into the system did not improve the perceived moistness of the product or the staling rates. It was noted that staling rates may have actually increased with the use of honey.

This project had a few shortcomings that future researchers may want to consider. This project may have been more beneficial if comparisons between liquid and dry honey could have been made. As previously mentioned, additional water had to be added to the batter containing dry honey in order for the batter to have the same rheological properties of the batter with liquid honey. Since water or moisture appears to have affected every parameter measured, conclusions could not be made. Future research may want to produce batters that are identical to those made with liquid honey in formulation so that these types of comparisons can be made.

Also, in the present investigation, dry and liquid honey was replaced for sugar at the given ratios based on weight. Since liquid honey contains approximately 17% moisture, and dry honey contains 2-5% moisture, the dry honey formulations contained more sugar, than did the liquid honey formulations. If research is to be done to compare liquid and dry honey, moisture content needs to be addressed.

In order to produce an acceptable fat free baked product, it is necessary to understand the role that water plays in the baked product. This study demonstrated that

over time, water is lost from the muffin system. Perhaps a study which investigates the movement of water in fat reduced systems would be vital. As mentioned, the loss of water has not been shown to be a direct correlation with staling, instead it appears to be the transition from an amorphous to a crystalline starch structure. It would be interesting to investigate how water affects this transition.

The decreased gelatinization temperature of the starch due to the addition of monosaccharides was implicated as a possible mechanism for the decrease in volume. It was also assumed that this decrease may have been able to delay staling (a point that was not supported by the present investigation). Future research should use differential scanning calorimetry to assess the effect of honey on the gelatinization temperature of the starch in baked products in order to better understand the role that honey or other products like high fructose corn syrup (HFCS) may play in the mechanisms noted in the present investigation.