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Development of Methods for Assessing the Effect of Moisture and Aging On Sliceability of Cheese

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DEVELOPMENT OF METHODS FOR ASSESSING THE EFFECT OF MOISTURE AND AGING ON SLICEABILITY OF CHEESE

by

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ABSTRACT

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by

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Sliceability is a cheese's ability to cut cleanly into thin slices, resist breakage or fracture at slices edges, and undergo a high level of bending before breaking. Intuitively, sliceability depends on the chemistry, microstructural, and rheological properties of the casein network. Currently there is no reported scientific research investigating evaluation methods of cheese slice quality, as well as properties that influence a cheese's ability to slice.

In this study, a method for slice quality evaluation was developed on purchased cheese and performed on commercial cheeses and experimental cheeses manufactured at three different moisture contents (40.6%, 37.0%, and 33.9%). In addition, tack force, tack energy, flexibility force, G', G", and G* were examined to determine whether or not moisture content influences cheese sliceability. Overall, slice quality at all three moisture contents improved as storage time increased, and the high moisture cheeses produced the worst quality slices and the low moisture cheeses produced the best. Both tack energy and tack force increased with increasing moisture content, and G', G", and G* decreased with increasing moisture and did not change over time. Tack energy and G” were found to be slightly correlated with cheese slice quality. Flexibility force was not correlated with cheese slice quality.

Moisture and storage time, as well their interaction, had significant effects on dependent variables, potentially indicating that a higher moisture cheese texture changes differently compared to medium and low moisture cheeses during storage. Correlation tests did not express a strong connection between moisture content, age, and cheese slice quality, overall. This research lays the foundation for future slice quality evaluation, and is a starting point upon which other companies and scientists can build.

(84 pages)

PUBLIC ABSTRACT

Jess Perrie in supervision of Dr. D. J. McMahon, has worked on investigating the development of a method for slice quality evaluation of cheese. The method was first developed on purchased cheese, then performed on both commercial cheeses and manufactured experimental cheeses. There has not been any reported scientific research on the slicing qualities of cheese. In our study, commercial cheeses and experimental cheeses manufactured at three different moisture contents (40.6%, 37.0%, and 33.9%), were evaluated for slice quality, as well as, the textural properties of tack force, tack energy, flexibility force, and the rheological values of G', G", and G*. The textural and rheological values were examined to determine whether or not they influence cheese sliceability and could be used to predict slice quality. Overall, slice quality at all three moisture contents improved as storage time increased, and the high moisture cheeses (40.6%) produced the worst quality slices, and the low moisture cheeses (33.9%) the best. Both tack energy and tack force increased with increasing moisture content, and G', G", and G* decreased with increasing moisture and did not change over time. Tack energy and G" were found to be slightly correlated with cheese slice quality, but flexibility force was not correlated. Moisture and storage time, as well their interaction, had significant effects on the textural properties, potentially indicating that a higher moisture cheese texture changes differently compared to medium and low moisture cheeses during storage. Correlation tests did not express a strong connection between moisture content, age, and cheese slice quality, overall.

To Jennifer Betancourt

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LITERATURE REVIEW

Sliced cheese is a valuable and desirable product. Pre-sliced packages have become increasingly popular in grocery stores, and deli counters require cheese that is easy to slice and handle. Sliced cheese should appear appetizing and eye-appealing for both the delis and cheese sections of grocery stores, because it is the first attribute by which consumers measure quality and identity (Jack et al., 1993; Hort and LeGrys, 2001; Brown et al., 2003). Cheese that is easy to slice doesn't crumble, tear, or turn to mush as the slicing blade moves through it (Chen, 2000).

Emphasis on quality sliced cheese is placed on the integrity of the slices, so it is essential to ensure that the slices retain desirable characteristics during handling, distribution and storage (Ni and Gunasekaran, 2004; Childs et al., 2007). Sliceability is a term that embodies slicing qualities, and is defined as a cheese's ability to be cut cleanly into thin slices, resist breakage or fracture at slices edges, and undergo a high level of bending before breaking (Guinee and Kilcawley, 2004). Due to recent demand, it is important to understand the factors that influence cheese sliceability.

There has been no reported scientific research on the slicing qualities of cheese; however, there have been studies on shredding properties of cheese. Shreddability is a comparable property to sliceability because they are both influenced by the rheological and adhesive properties of the cheese. Childs et al. (2007) found that both composition and age influences cheese rheology and shreddability. Such research allows for predictions on how cheese texture and rheological properties affect cheese sliceability.

This review will consider how shreddability can be applied to understanding sliceability, and how cheese age and moisture may impact sliceability.

Factors That Influence Shreddability

Shreddability is defined as a cheese's ability to cut cleanly into long thin uniform strips, have low susceptibility to form curd fines, and resist sticking, matting or clumping when loosely packed (Guinee and Kilcawley, 2004). Shreddability is influenced by cheese composition and rheological properties as shown in Table 1. Both cheese moisture and fat content and extent of aging influence its shreddability.

Increases in moisture of Mozzarella cheese decreases elasticity, resulting in poor shredding properties (Masi and Addeo, 1986; Childs et al., 2007). In addition, a cheese's age affects its shredding quality (Kinstedt, 1995; Childs et al., 2007). Mozzarella, typically a young cheese, does not shred; however a 3-mo Monterey Jack does exhibit good shreddability. Serrano et al. (2004) also reported that cheese age had an effect on shred quality, in that the younger 1-d cheeses shredded more poorly than older 30-d cheeses. If a cheese is too sticky or too soft, i.e. too young or high in moisture, the shreds will be inconsistent in shape, bent or curled, and vary in length (Chen, 2007). Then as cheese ages and becomes more brittle, or is too low in moisture, it will end up with fractured shreds that are broken and inconsistent.

Physical properties, such as firmness and adhesiveness, also affect cheese shreddability as they impact how it behaves during shredding. For example, it is difficult to cleanly shred a hard cheese, such as Parmesan because it has a relatively low

Table 1: Factors influencing cheese shreddability

Factors	Effect	Shreddability	Source
High moisture	Matting of shreds	Decreases	Kindstedt, 1995 Masi and Addeo, 1986
High fat (≥45% fat in DM)	Matting of shreds	Decreases	Kindstedt, 1995 Masi and Addeo, 1986
Too young (i.e. Mozzarella within first few days of manufacture)	Excessive free moisture at the surface causes matting	Decreases	Kindstedt, 1995
Too old (i.e. Mozzarella at 20 d post-manufacture)	Soft and gummy body	Decreases	Kindstedt, 1995
Soft-bodied, pasty, or wet surface	Ragged edges, fines, matting, produces gummy balls	Decreases	Kindstedt, 1995
Too firm, too dry	Shatters into fines and small particles	Decreases	Kindstedt, 1995
Elastic Modulus (G') < 10^5 Pa	Adhesion due to pressure-sensitive adhesion	Decreases	Dahlquist, 1989

fracture strain. Also it is challenging to evenly cut an over-acid Cheddar cheese because it fractures in a jagged fashion and breaks at the edges (Guinee, 2002).

Childs et al. (2007) evaluated adhesive properties of cheese by measuring tack energy, which is the energy required to separate two materials that are not bound permanently. They concluded that an increase in tack energy was associated with an increase in cheese adherence to the cutting blade. Tack energy for Monterey Jack and process cheese was greater than the tack energy for Mozzarella cheese, meaning that 3-mo Monterey Jack had greater adhesion to the blade than the young Mozzarella. In this study, the tack energy and viscoelastic properties were the best indicators of shredding defects: adherence to the blade was positively associated cheese viscosity and the production of fines was associated with increases in firmness. Presumably, age, moisture and textural properties of cheese will have similar effect on cheese sliceability.

Effect of Moisture Content

If the moisture content of a cheese is increased, then the ratio of moisture to protein is increased and the protein matrix weakens because the protein volume fraction concentration decreases (Lucey et al., 2003; Guinee and Kilcawley, 2004). A high ratio of moisture to protein will give a softer cheese texture, which may lead to greater adhesion. Carunchia Westine et al. (2007) reported that increased moisture content contributed to softer texture and lower moisture content contributed to increased brittleness. Increasing from 40% to 48% moisture in a model Cheddar-like cheese resulted in a large decrease in elasticity and a large increase in adhesiveness (Watkinson et al., 2002). Such blade adhesion can then potentially result in poor sliceabilty.

Another potential indicator of poor sliceability as a result of increasing moisture content is decreasing values of the elastic modulus (G'), which reflects the solid and energy storage qualities of a cheese. There was a linear decrease in strength of the protein matrix as moisture of Cheddar increased from 34% to 40% (Creamer and Olson, 1982), also shown by the elastic moduli decreasing with increasing moisture (Masi and Addeo, 1986; Tunick et al., 1993). Increased moisture content of 7.5-mo Gouda cheese from 32% to 46% decreased G' and fracture stress (Luyten et al.,1991a,b). The elastic modulus of high moisture model Cheddar-like cheese (63% moisture compared to 58%) decreased with moisture content, implying that higher moisture made the cheese softer and less elastic (Venugopal et al., 2003). An increase in cheese moisture caused a decrease in G' and an increase in adhesiveness (Childs et al., 2007), and the cheese is more likely to stick to the blade leading to poor sliceability. Increasing moisture content of Cheddar cheese also decreases the texture profile analysis terms of firmness, chewiness, and springiness (Everard et al., 2006).

Effect of Age

Cheese texture changes during storage and Lawrence et al. (1987) identified 2 distinct phases in development of cheese texture during aging. The first phase occurs within the first 14 d, and the second during the remainder of the ripening period. Hort et al. (1996), Hort and LeGrys (2001), and Everard et al. (2006) reported that the textural properties of Cheddar cheese progressed during maturation. During the first phase, Cheddar is very springy, then as the cheese enters the second phase, there is a large decrease in springiness, and increase in crumbliness and creaminess, an increase in adhesion (Chevanen et al., 2006), and an increase in firmness (Creamer and Olson, 1982; Lawrence et al., 1987).

Springiness of cheese is important for sliceability, because as the cheese moves through the slicing machine, if it recovers quickly, cohesive slices will be produced (O'Callaghan and Guinee, 2004). In contrast, as the cheese becomes stickier with age, this can be detrimental to slicing as the cheese will greatly adhere to the blade. Therefore, a cheese that is springy and low in adhesiveness would be expected to have good sliceability. This would be a cheese that has completed the first phase of texture development but has not been aged for much longer.

On the other hand, Serrano et al. (2004) determined that younger 1-d cheeses were more difficult to shred compared to 30-d cheeses, a result of the younger porous, sponge-like protein network. Rasmussen (2007) found that as a cheese aged from 7 d to 12 mo, it increased in the frequency of fracturing, while decreased in hardness and cohesiveness, providing poor structural properties for sliceability. Brown et al. (2003) found that the magnitude to G' for Monterey Jack and Mozzarella cheeses only changed slightly with age (4 d to 38 d) and concluded that as cheese networks broke down, the elastic elements decreased and the cheese becomes more brittle. Both trends would lead to poor sliceability because the cheese would not be able to keep its shape while being sliced; therefore, younger cheeses around the age of 30 d will be easier to slice than older 3-mo cheeses. It is desirable to have both a hard cheese, as well as elastic, for good slice quality.

While there has not been specific scientific research on how cheese composition and texture influence slicing quality, it is apparent that sliceability will depend on the integrity and nature of the cheese structure. A cheese that is easy to slice does not crumble, tear, or turn to mush as the slicing blade moves through it. Cheese tack and flexibility will be investigated in order to examine textural influences on cheese sliceability. Tack force is the maximum force recorded during separation of two materials that are not permanently bound, and tack energy is the energy required to separate those two materials, and both directly relate to a cheese's capacity for blade adherence. Flexibility force is the maximum bent force recorded before a slice breaks in half, and reflects whether slices can maintain desirable characteristics during distribution, handling and storage. Since moisture and cheese age influence overall functionality of cheese, it is probable that they affect sliceability as well.

HYPOTHESES AND OBJECTIVES

- **Hypothesis Statement:** It is hypothesized that the ability for a cheese to be sliced can be predicted from its textural and rheological properties, which are influenced by the cheese's moisture and age.
- **Objective 1:** Develop a qualitative test for evaluating cheese slice quality from a commercial block of Cheddar Cheese by examining 4 progressively smaller thicknesses (1.1, 0.9, 0.6, and 0.3-mm) in order to differentiate slice quality between cheeses over a 35-d storage period.
- **Objective 2:** Compare the slice quality, as well as textural and rheological properties, of commercially sliced Cheddar cheese at three different thicknesses.
- **Objective 3:** Manufacture cheddar cheese with different moisture contents (33/34%, 36/38%, and 40/41%) and measure changes in cheese slice quality and cheese texture during storage. Manufactured cheeses will be measured for slice quality and textural properties every 2 wk during 12 wk of storage, and for rheological properties at 28 d and 84 d.
- **Objective 4:** Determine if rheological and/or textural measurements of cheese can be used to predict cheese slice quality, in addition to the developed slice quality evaluation method.

MATERIALS AND METHODS

Slice Quality Evaluation

A 12-kg block of Cheddar was purchased the day after manufacture from Gary H. Richardson Dairy Products Laboratory (Utah State University, Logan) for preliminary slice quality evaluation. The block of cheese was separated into 6 sections, and each section was evaluated for slice quality every 7 d for a 35-d storage period. Each section was sliced multiple times at four different thicknesses (1.1, 0.9, 0.6, and 0.3 mm) on a Berkel Manual meat and cheese deli slicer (Berkel, Inc., Troy, OH) equipped with a 31 cm stainless-steel slicing blade in order to determine a grading scale. The 1.1-mm slice represented a typical thickness found in most commercial cheeses. The 3 other thicknesses were chosen in order to determine quality differentiation between slices.

Cheeses

Commercial Cheese. Cheddar cheese (3 mo) was purchased as one 0.9 kg block and in 3 different thicknesses (1.20, 0.90, and 0.60 mm) that are normally used for sliced cheese, from Gossner's Food, Inc. (Logan, UT) on 3 separate occasions, and the occasions are referred to as replicates. Cheese composition, cheese grading, tack, flexibility, the elastic modulus (G'), viscous modulus (G"), and complex modulus (G*) were determined in as described below within 2 d of purchase.

Experimental Cheddar Cheese. Batches of Cheddar cheese curd were manufactured, salted and pressed to produce cheese with 3 different moisture contents: low moisture (LM) of 33% to 34%, medium moisture (MM) of 36% to 38%, and high moisture (HM) of 40% to 41%.

Raw milk was obtained from the Gary H. Richardson Dairy Products Laboratory (Utah State University, Logan) to produce cheddar cheese, which was made in an enclosed vat using the same method as Rogers et al. (2009) and an open vat using the same method as Oberg et al. (2011). Milk was pasteurized at 74°C for 16 s, then adjusted to 31°C and inoculated with 96 g of *L. lactis* (DVS 850, Danisco Cultures Plant, Madison, WI) starter culture for 45 min. After the ripening period, 60 mL double-strength chymosin (Maxiren, DSM Food Specialties USA, Logan, UT) at a 1:20 dilution was added to provide a set time of 30 to 45 min.

Coagulum for the medium and high moisture curds were cut with 1/2” knives, and for low moisture curds were cut with 1/4” knives, and allowed to heal for 10 min. The curd and whey were gradually heated to 39°C, 37°C, and 35°C for LM, MM, and HM curd, respectively. For all cheeses, the whey was drained when the pH of the curd reached 6.30. The LM cheese was dry stirred after whey drainage for 5 min. The curd was allowed to matt together to form a pack for 10 min, and then the pack was cut into slabs (15 cm in width) and flipped every 5 min for 40 min in order to keep the curd warm. Acid development was monitored throughout the flipping period and at pH 5.85, the slabs were cut in half and stacked 2 high. LM curd slabs were cut milled using a kitchen knife at pH 5.40 and the MM and HM curd slabs were cut at pH 5.60.

Milled curd was salted (632 g) in 3 applications, with 5 min for each application, and put into a cheese hoops (12 kg each), and then placed in a horizontal cheese press (413.7 kPa) for 12 to 15 h. The cheese was then removed from the hoops. Each cheese block was cut into 6 separate cubes and the cubes were individually vacuumed sealed.

The 6 corresponding cubes were then placed into one box for ripening, and were allowed to ripen at 6°C.

Out of a total of 24 12-kg cheeses made, 9 were selected for analysis based on similar moisture contents and pH ranges. Cheeses within the moisture range of 33-34% will be referred to as LM, 36-38% as MM, and 40-41% as HM. Cheese composition was determined after one wk of aging as described below. Cheese grading, tack, and flexibility were determined as described below every 14 d, for 84 d. Rheological analysis was performed twice, at ages of 28 d and 84 d.

Cheese Composition

Moisture, salt, fat, mineral and pH were analyzed for composition on d 14 for experimental cheeses and day of purchase for commercial cheeses. Cheese pH was measured using the gold electrode/quinhydrone method (Marshal, 1992). Moisture was analyzed using a microwave oven (CEM Corp., Indian Trail, NC), and moisture was determined as weight loss (AOAC, 1990). Fat content was determined using a modified Babcock method (Marshall, 1992; method 15.8.A). Total NaCl content was measured using a chloride analyzer (Model 926; Corning Scientific, Medfield, MA) (Paulson et al., 1998). Mineral content was determined through dry ashing, in which the ash was sent to Analab (Fulton, IL) for further mineral analysis.

Cheese Grading

Each cheese was cut into a block (11 cm x 11 cm x 11 cm), and then the block was cut in half into a triangle. The triangular block was then sliced at three different thicknesses on a Berkel Manual meat and cheese deli slicer (Berkel, Inc., Troy, OH) equipped with a 31 cm stainless-steel slicing blade at 3 levels (10, 8, and 6) for 3 different thicknesses (1.20 mm, 0.90 mm, and 0.60 mm). The cheese was sliced at each thickness 5 times, and cheese slices were visually analyzed using the grading scale developed during the previous slice quality evaluation.

Texture Profile Analysis

Tack. Cheese adhesiveness was measured using a TAX-T2 texture analyzer (Texture Technologies, Scarsdale, NY) with a flat, 25.4 mm diameter stainless-steel probe (TA-11ss) using the same method as Childs et al. (2007). The cheeses were cut into 4-cm squares and sliced to a thickness of 6.35 cm with a modified wire cheese slicer. The cheese was placed on a platform below the probe arm, and the probe was brought to the surface of the cheese at a speed of 1 mm/s. Upon reaching the cheese surface, a force of 2.0 N was applied, held for 5 s, and removed at a speed of 0.1 mm/s. Tack force was determined as the maximum force recorded during separation. Tack energy was determined as the area under the force distance curve.

Flexibility. Cheese flexibility was measured using a TAX-T2 texture analyzer (Texture Technologies, Scarsdale, NY) with a 3-point adjustable breaker fixture and an aluminum plate platform (TA-92). The 3 different slice thicknesses for both commercial and experimental cheeses were prepared in triplicate from the original cheese samples. A single cheese slice was placed horizontally on the adjustable breaker fixture (5.08 cm in width) and a compression test was preformed, bending the cheese slice a distance of 25 mm at a speed of 2 mm/s. Flexibility was determined as the maximum bent force recorded before the slice broke in half (Guinee and Kilcawley, 2004).

Rheology

Dynamic oscillation tests were performed on cheese samples to evaluate the linear viscoelastic region. The elastic modulus (G'), viscous modulus (G"), and complex modulus (G*) was determined with an AR-G2 TA Instruments Rheometer (TA Instruments, New Castle, DE, USA) at 25°C with a 40-mm diameter parallel plate. The angular frequency was kept constant at 1 Hz, and the oscillatory stress was recorded in Pa to determine the linear viscoelastic region of the cheese samples. Rheological measurements were performed at 25°C rather than at room temperature because Childs et al. (2007) found more differentiation at this higher temperature.

Experimental Design

A randomized block design with fixed measures was used for the commercial cheeses and a randomized complete split-plot design with fixed measures was used for the experimental cheeses, with an alpha level of 0.05. For the experimental cheese, the different sub-plot treatments of the whole-plot unit were the days of testing (14, 28, 42, 56, 70, and 84 d).

The general linearized model (PROC GLM) in the SAS statistical software package (Version 9.3, SAS Institute, Inc., Cary, NC) allowed statistically significant differences between whole-plot and sub-plot treatments in the experimental cheeses to be distinguished. Correlation analysis (PROC CORR) using the SAS statistical software package allowed for determination of relationships among cheese properties.

RESULTS AND DISCUSSION

Slice Quality Testing

A slice quality grading scale was developed based on visual observation of defects in cheese slices as shown in Table 2. This takes into account that slices can be defective if they have splits and cracks or if the corners are broken and not intact. Such breaking of corners is especially problematic if slices are in a triangle shape as 2 of the corners form an acute angle of only 45°. Triangular cheese slices are commonly sold in the food service market for use in sandwich quick service restaurants, while square or round slices are more commonly sold in the retail market. This grading scale makes it possible to compare slice quality between different cheeses even though they may have different defects. Examples of cheese slices with the various defects and grading scores are shown in Figs 1 to 5.

Table 2: Grading scale for qualitative analysis of slice

Grade	Description
1	Slice does not have any cracks or breaks within interior of slice Slice contains all corners on the edges of slice, none are broken off
2	Slice contains one crack within interior and has all corners on edge Slice contains two cracks within interior and has all corners on edge Slice contains no cracks within interior and has one corner broken off
3	Slice contains three cracks within interior and has all corners on edge Slice contains one crack within interior and has one corner broken off
4	Slice contains three cracks within interior and has two corners broken off
5	Slice contains more than three cracks within interior and has two corners broken off

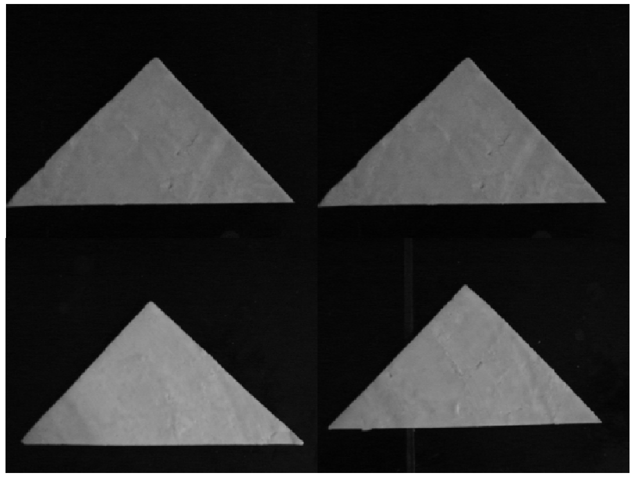

Figure 1: Examples cheeses with slice defect score =1.

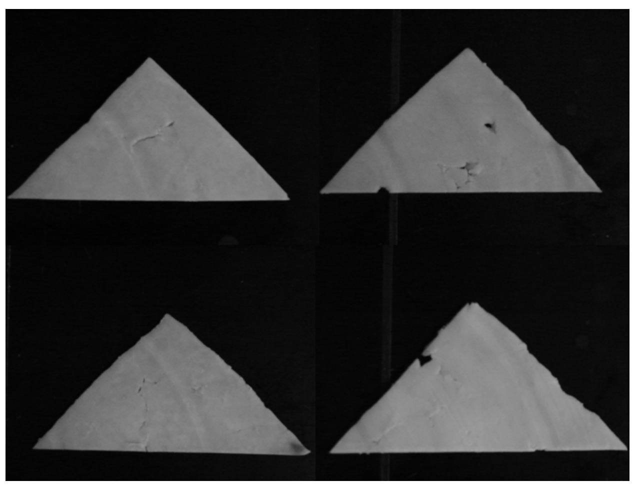

Figure 2: Examples cheeses with slice defect score =2.

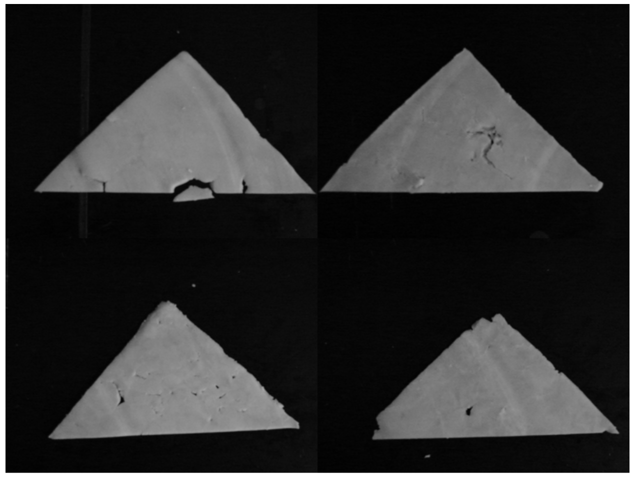

Figure 3: Examples cheeses with slice defect score =3.

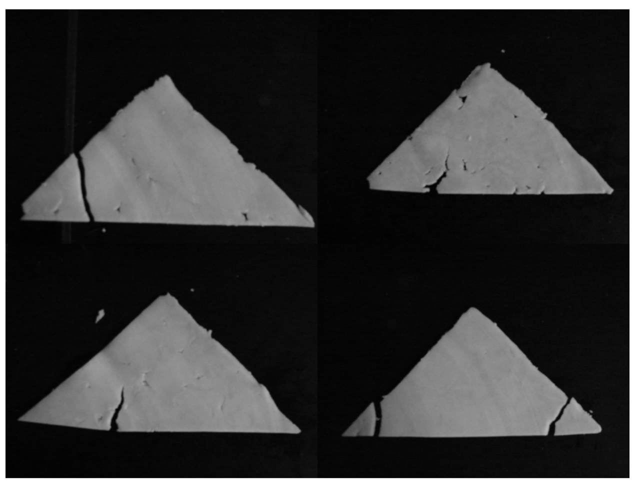

Figure 4: Examples cheeses with slice defect score =4.

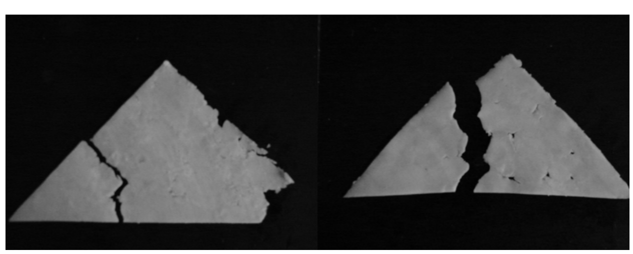

Figure 5: Examples cheeses with slice defect score =5.

The greater number of cracks and breaks a slice had, the higher the score and the worse its slicing quality. A grading score of one represents a highly sliceable cheese while a grading score of 5 indicates the cheese has very poor slicing attributes.

Composition of cheese used for the initial experiment was 36.4% moisture, 1.31% salt and 34% fat, with a pH of 5.09. Mean slicing grades for this cheese when sliced at 7, 14, 21, 28 and 35 d after manufacture are shown in Table 3. The 1.1-mm cheese slices represented a typical commercial cheese slice thickness, and thinner slices were used to investigate their potential for differentiating slice quality between cheeses by exaggerating the slices defects. At 7 d of age, the cheeses had poor slice quality with numerous defects (no cheeses were free of defects, i.e., all scores >1) with mean quality scores of 2.0 to 4.4 depending on slice thickness.

Slicing the cheese at 14 d compared to 7 d caused an improvement in slice quality in the 1.1- and 0.9-mm slices with grading scores of 1.6 and 1.4, respectively, being obtained. Serrano et al. (2004) also found that cheeses needed to be at least 15 d of age before shredding because 7-d cheese crumbled too much, which created many fines. With the 0.6-mm slices it required 21 d of aging to obtain any slices that were free of defects, (mean score = 1.2). Using a very thin slice (0.3 mm) provided no benefit to differentiating between cheese slicing quality as no cheese slices could be produced that

Table 3: Mean (±SD) slice defect scores for Cheddar cheese cut at a thickness of 1.1, 0.9, 0.6 and 0.3 mm at 7, 14, 21, 28 and 35 d after manufacture (n=5).

Slice	**Cheese age at slicing**				
Thickness	7 d	14 d	21 d	28 d	35 d
0.3 mm	4.4 (0.55)	3.4 (0.55)	3.6 (0.89)	2.6 (0.55)	3.2 (1.0)
0.6 mm	2.0 (0)	2.2 (0.45)	1.2 (0.45)	1.8 (0.45)	1.0 (0)
0.9 mm	3.0 (0)	1.4 (0.55)	2.2 (0.45)	1.2 (0.45)	1.4 (0.55)
1.1 mm	2.6 (0.55)	1.6 (0.55)	1.6 (0.55)	1.4 (0.55)	1.8 (0.45)

were free of defects with most cheeses receiving scores of 3 or higher. Such slices were never a complete piece and were broken in half or thirds. A thickness of 1.1 mm provided many examples of good slice quality, in that the cheese remained in a whole shape and did not crumble, break, or split during slicing. Aging the cheese for 35 d compared to 14 d before slicing did not produce any further increase in quality when it was sliced at 0.9 or 1.1 mm of thickness, due the increase of crumbliness and adhesion during the second phase of texture development (Creamer and Olson, 1982; Lawrence et al., 1987; Chevanen et al., 2006). However, the best slice quality for the 0.6-mm slices was not reached until the cheese was 21 d old when none of the slices contained any defects.

When linear regression analysis of defect scores vs. storage time was performed on the cheeses, the highest correlation was with the 0.3-mm cheese (R = 0.77). However, because this slice thickness never produced any defect-free slices it was not used in any subsequent trials. Using slice thicknesses of 0.6, 0.9 and 1.1 mm had similar decreases with respect to age at slicing as shown in Figure 6, with R-values of 0.74, 0.71 and 0.61, respectively. At slice thickness 1.1-mm, the defect scores start to plateau after 15 d of storage, which was similar to Serrano et al. (2004) results which expressed no changes in crumbliness or shreds between 15 d and 30 d of storage. Regression equations (x = storage time (d)) for each slice thickness were:

0.3-mm slice: $y=4.4-0.0457x$

0.6-mm slice: $y=2.36-0.0343x$

0.9-mm slice: $y=2.86-0.0486x$

1.1-mm slice: $y=2.43-0.0257x$

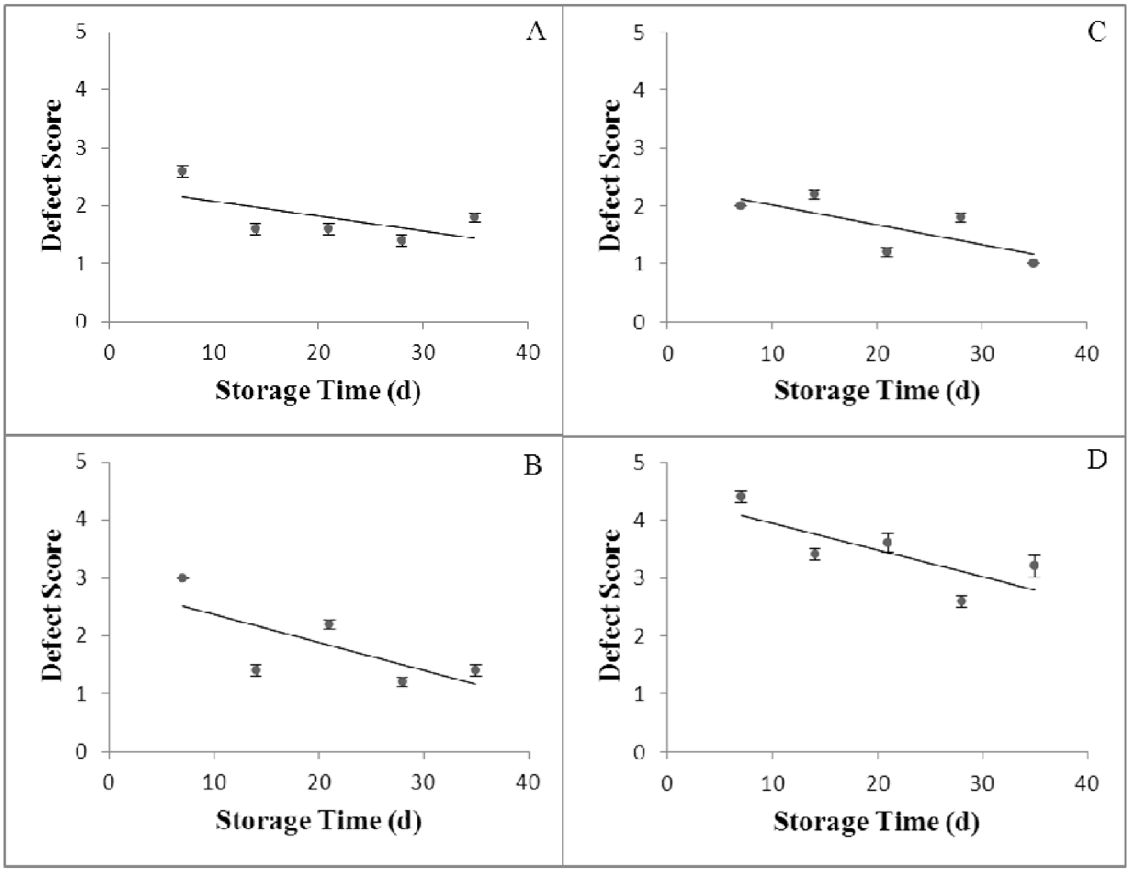

Figure 6: Mean slice score of 1.1-mm (A), 0.9-mm (B), 0.6-mm (C), and 0.3-mm (D) purchased Cheddar Cheese over 35 d storage period, Bars = SE (some bars smaller than symbol)

Table 4: Mean (±SD) values of moisture, pH, salt, fat, calcium and phosphate for Commercial Cheese (n=3).

	pH	**Moisture**	**Salt**	**Fat**	**Ca**	**PO_4**
		-------------------------------	----------	----%----	----------	-------------------------------
Mean	5.10(0.10)	37.5(1.12)	1.68(0.14)	35.0(0.51)	0.87(0.40)	1.42(0.06)

Cheese Composition

Commercial Cheeses. Mean composition values of the commercial cheeses are found in Table 4. The fat, salt, and moisture contents were 35%, 1.68%, and 37.5%, respectively, and the cheeses had a mean pH 5.10. Mineral analysis was performed and the mean calcium and phosphate contents were determined to be 0.87% and 1.42%, respectively.

Experimental Cheeses. The mean composition values of the experimental cheese groups are found in Table 5. The high moisture group had a mean moisture content value of 40.6%, the medium 37.0% and the low 33.9%. The higher moisture group had the lowest pH at 5.05, while the low moisture group had the highest pH at 5.28. Fat varied from 31% to 34%, salt varied from 1.27% to 1.83%, calcium from 0.64% to 0.71%, and phosphate from 37.0% to 42.7% for all cheeses.

Table 5: Mean values of moisture, pH, salt, fat, calcium and phosphate for experimental cheese groups

Cheese Group	**pH**	**Moisture**	**Salt**	**Fat**	**Ca**	**PO_4**
		------------------	-------	---%---	-------	------------------
HM	5.05^a	40.6^a	1.27^a	31.0^a	0.67^a	1.40^a
MM	5.17^b	37.0^b	1.44^a	30.0^a	0.71^a	1.49^a
LM	5.28^c	33.9^c	1.83^b	34.0^b	0.64^a	1.38^a

[a,b,c] Means with the same letter superscripts within the same column were not significantly different, α=0.05

Each moisture group was determined to be significantly different (see Appendix A). It was attempted to keep all other proximates constant, however, this was virtually impossible since some cheese chemical properties are concomitant. The pH was significantly different with all three moisture groups, which is a result of the presence of residual lactose in the curd and the cheese's buffering capacity. A high moisture cheese will have higher lactose and less protein and phosphate contents, thus less buffering capacity and a low pH value. There was no significant difference regarding salt and fat for the high and medium moisture groups, though the low moisture group was significantly higher for both contents. Mineral analysis was performed on all cheeses and was determined that there was no difference in calcium and phosphate content between all three cheese groups.

Slicing Analysis

The commercial cheese mean slice defect scores for 1.25, 1.15, and 1.05-mm thicknesses were 1.33, 1.46, and 1.88, respectively. Commercial cheese slices at progressively larger thicknesses were able to be graded using the slice quality evaluation method previously determined. This method, therefore, can be used on a variety of cheese slice thicknesses. All three commercial cheese thicknesses expressed relatively good slice quality, and all were virtually free of defects. Furthermore, at 3 mo, there was little variation in slice quality grades between thicknesses for the commercial cheeses.

Mean defect scores for experimental cheese sliced at 1.2-mm, 0.9-mm, and 0.6-mm thicknesses at 14, 28, 42, 56, 70, and 84 d after manufacture are shown in Figure 7. The slice evaluation was only performed during the first 3 mo of maturation because

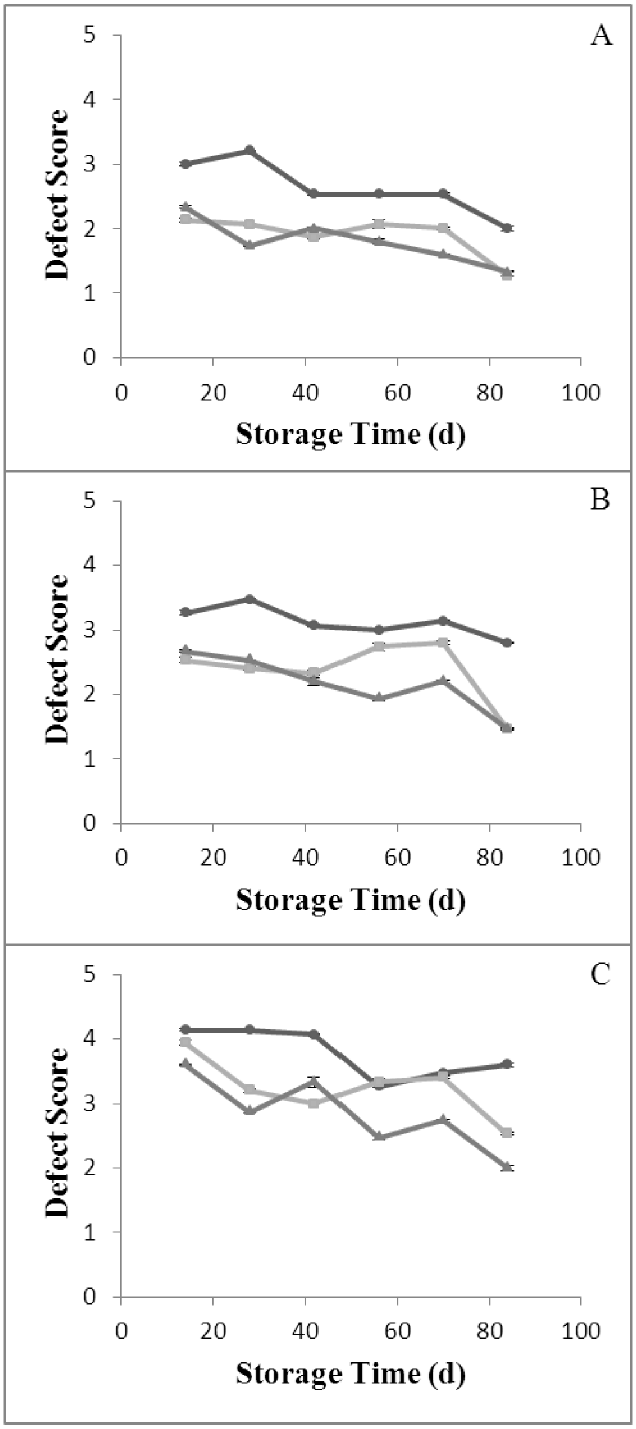

Figure 7: Mean slice defect score of 1.2-mm (A), 0.9-mm (B), and 0.6-mm (C) cheese slices with high moisture (●), medium moisture (■) and low moisture (▲) experimental cheeses during 84d storage at 6°C, Bars = SE (some bars smaller than symbol)

this is the time at which commercial companies typically slice cheese (reduced storage times decrease the cost of storage). Overall, the high moisture cheeses had significantly higher defect scores (poor quality scores) than the medium and low moisture cheeses, and all 3 moisture groups' scores improved over time (see Appendix F). At all 3 thicknesses, the HM slice defect score results were higher than the MM and LM groups, with the lowest scores coming from the LM group. The MM and LM groups were rarely different throughout slicing analysis, as well as textural and rheological analysis. The defect scores for all three moisture groups were the highest at 7 d, indicating the poorest quality slices at the youngest age. The best quality scores varied in age between the 3 moisture groups. Only the LM group at thickness 1.2-mm produced slices that were free of defects at 84 d.

The scores for 1.2-mm slices yielded the most difference between the 3 moisture groups than the other thicknesses. At this thickness, the LM scores improved with storage time, starting at 2.3 at 14 d, then dropping to scores between 1 and 1.8 after 56 d, producing slices free of defects. At 14 d, the MM and HM scores started at scores 2.1 and 3, respectively, followed by a plateau between defect scores of 3 and 2 at ages 42 d through 70 d. The MM and HM groups did not produce slices that were free of defects at any of the thicknesses. All of the best quality scores for the three moisture groups occurred at 84 d.

At both 0.9-mm and 0.6-mm thicknesses, the high moisture slice defect scores were significantly higher than the medium and low moisture slice scores (see Appendix F). At slice thickness 0.9-mm, the HM defect scores did not go below 3 throughout the entire storage period. The MM and LM scores did improve over time, starting at 2.5 and

2.6, respectively, on 14 d, and then decreasing to 1.5 at 84 d. With the 0.6-mm thickness, all 3 moisture group defect scores were higher than the other 2 thicknesses, with the HM group producing the highest defect scores and the poorest quality slices. Both moisture and age had significant effects on the slice scores at all 3 thicknesses, as shown in Table 6 (see also Appendix G).

Overall, it was visually observed that the higher moisture cheeses adhered and caked onto slicing blade more than the lower moisture cheeses, creating more fines and uneven slices. When the cheese stuck to the blade, the slicing did not result in whole pieces and many cracks resulted. Childs et al. (2007) found that high moisture Mozzarella adhered to the blade, producing more fines during shredding as well. The HM group also had the lowest pH value, and low pH values lead to a more crumbly cheese. The combination stickiness, due to high moisture content, and crumbliness, due to a low pH, created an overall bad combination for cheese sliceability.

Blade adherence was the dominate observation during experimental cheese slice evaluation, as opposed to crumbliness; therefore, it was assumed that moisture content was more involved with slice quality than pH, though pH did correlate with slice scores.

Table 6: P-values for cheese tack force (TF) and tack energy (TE), and flex force (FF) and defect scores (DS) of 1.2-mm (1), 0.9 -mm (2), and 0.6-mm (3) for experimental cheeses

		P-values							
	dv	TF	TE	FF 1	FF 2	FF 3	DS 1	DS 2	DS 3
Experimental Moisture Group	2	<0.01	<0.01	<0.01	<0.01	0.92	<0.01	<0.01	<0.01
Experimental Storage Time	5	<0.01	0.04	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Experimental Moisture*storage	10	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01

At 28 d, moisture content and pH were significantly correlated with slice defect scores at 1.2-mm (R=0.60, R=-0.46) and at 0.6-mm (R=0.72, R=-0.55) (see Appendix K). Similar correlations were found at 84 d with slice defect scores at 1.2-mm (R=0.47, R=-0.47), at 0.9-mm (R=0.78, R=-0.62), and at 0.6-mm (R=0.69, R=-0.71) (see Appendix L). Higher moisture contents and lower pH values led to higher defect scores at all three thicknesses. However, as the cheese aged at all thicknesses, cheese slice quality improved. These small correlations indicate that there are other factors besides moisture that influence cheese sliceability.

Rheology

Mean values of commercial cheese rheological properties G', G", and G* are presented in Table 7. Within the linear viscoelastic region of the commercial cheeses, G' ranged from 5.03 to 4.49 log Pa, G" from 4.49 to 4.34 log Pa, and G* from 5.05 to 4.66 log Pa, with increasing oscillatory stress values of 20, 150, 1000, and 4000 Pa.

Mean values of G', G", and G* for 28 d and 84 d HM, MM, and LM experimental cheeses at the oscillatory stresses of 20, 150, 1000, and 4000 Pa are presented in Figure 8. The experimental cheese G', G", and G* values were in similar ranges to the commercial cheeses.

Table 7: Mean values for G', G", and G* of commercial cheeses

Oscillatory Stress (Pa)	G' (log Pa)	G" (log Pa)	G* (log Pa)
20	5.03	4.49	5.05
150	5.02	4.48	5.04
1000	4.93	4.45	4.95
4000	4.49	4.34	4.66

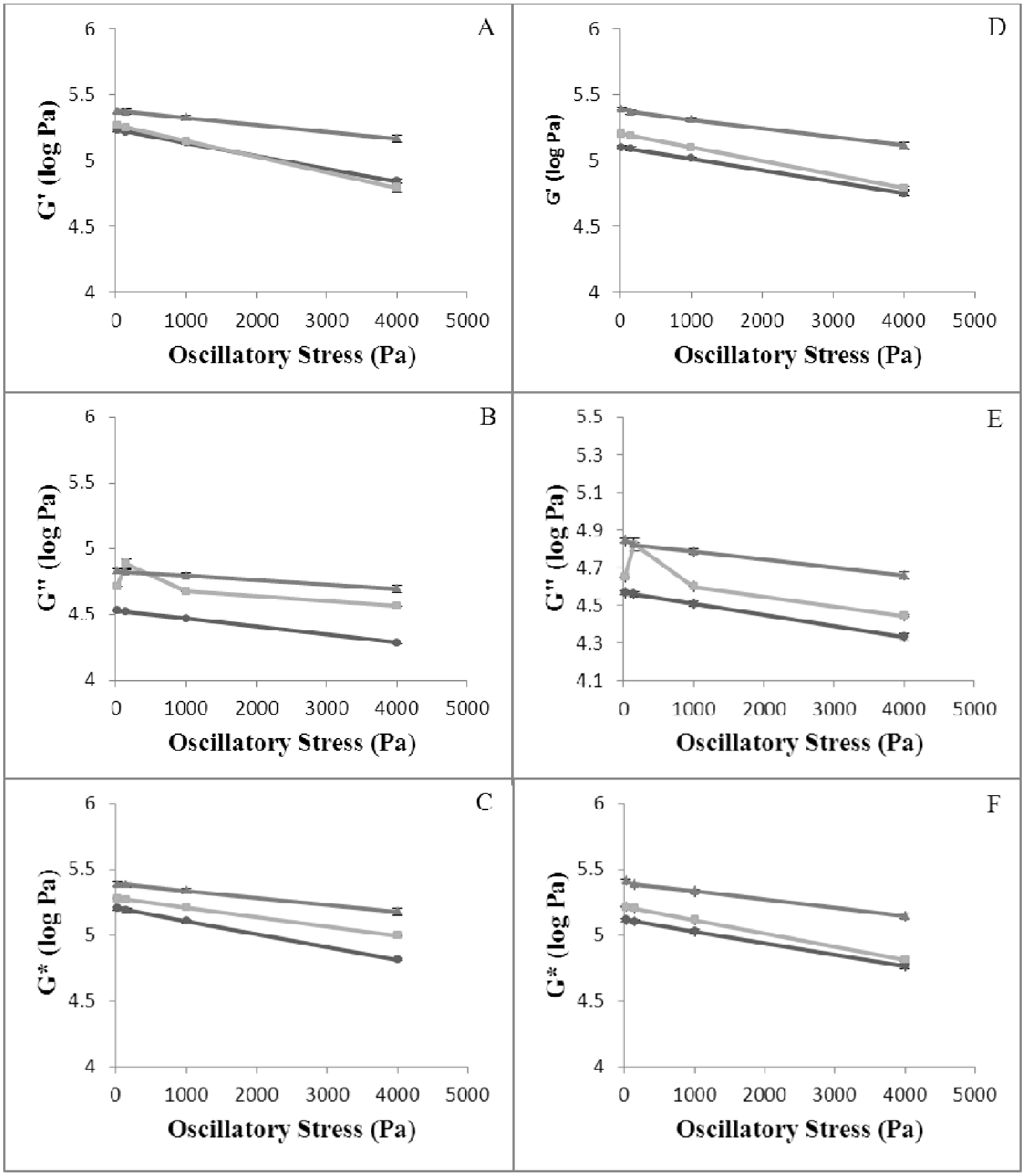

Figure 8: Pooled mean values for G' (A), G" (B), and G* (C) at 28 d and G' (D), G" (E), and G* (F) of high moisture (●), medium moisture (■) and low moisture (▲) experimental cheeses during 84d storage at 6°C, Bars = SE (some bars smaller than symbol)

At 28 d, the HM group had G' values in the range of 5.22 to 4.83 log Pa, G" values of 4.53 to 4.29 log Pa, and G* values of 5.20 to 4.81 log Pa with increasing oscillatory stresses. The MM group had G' values in the range of 5.20 to 4.79 log Pa, G" values of 4.71 to 4.56 log Pa, and G* values of 5.29 to 4.99 log Pa with increasing oscillatory stresses. The LM group had G' values in the range of 5.37 to 5.16 log Pa, G" values of 4.83 to 4.69 log Pa, and G* values of 5.39 to 5.18 log Pa with increasing oscillatory stresses. The G', G" and G* values of all three moisture groups at 84 d were similar to the values at 28 d, and not significantly different (see Appendix C).
Cheese is a viscoelastic material because during and after deformation part of the mechanical energy supplied to the cheese is stored (G') and part is dissipated (G") (Lucey et al., 2003). The elastic modulus reflects the solid parameters, and the viscous reflects the fluid. It was important to examine G' and G" of the three moisture groups in order to investigate what parameters influence cheese sliceability.

Pairwise comparison of the three moisture groups resulted in a significant difference between the HM and the LM groups for G' and G*, and between all three moisture groups for the G" at all stresses (see Appendix C). The elastic modulus for the HM group at all stresses was significantly lower than the LM groups at age 84 d (see Appendix E). The elastic modulus at 28 d significantly decreased at oscillatory stresses 1000 and 4000 Pa as cheese moisture increased. The viscous modulus of the HM group at all oscillatory stresses was significantly lower than both MM and LM groups at both 28 d and 84 d. The complex modulus of the high moisture group at an oscillatory stress of 20 Pa was significantly lower than the low moisture groups at both ages.

The current study expressed opposite results to Rasmussen (2007), in that as the cheese aged it did not become harder, more brittle, and less elastic. Since there was no change in G', G", and G* in this experiment, it was assumed that moisture content was a more dominant component in slice quality predictability.

Venugopal et al. (2003) and Tunick et al. (1992) also found that the G' of high moisture cheese was significantly lower than normal moisture cheese, and elevated moisture content makes cheese softer due to greater hydration of the casein network. Masi and Addeo (1986) found that increases in moisture contents of Mozzarella cheese were accompanied by a decrease in the modulus of elasticity, which caused difficulty in shredding. The low G' values of the high moisture cheeses could potentially be an indicator of poor sliceability. Conversely, the higher G' values of the low moisture cheeses may specify good slicebility, considering the LM cheeses received the best scores at all three thicknesses.

Specifically examining which rheological parameters influence cheese sliceabiltiy, it was determined that G" was correlated with the slice defect scores of the experimental cheeses at the typical commercial thickness of 1.2-mm. The viscous modulus at 20 Pa (R = -0.32), 150 (R=-0.32), 1000 Pa (R=-0.31) and 4000 Pa (R=-0.27) was found to have small correlations indicating that there are other factors that influence cheese sliceability (see Appendix H). Child et al. (2007) determined that blade adherence was positively correlated with cheese viscosity. Higher values for the viscous modulus were slightly correlated with the improvement of slice quality, which could be attributed to low blade adherence.

Tack Force

The mean tack force for the commercial cheeses was 0.37 N and is shown in Table 8. The tack force results for all the experimental cheeses are shown in Figure 9. When linear regression was performed on the experimental cheeses, the highest correlation was with the HM cheeses. The HM group showed an increasing linear trend in tack force (R = 0.84) as storage time increased, starting at 0.23 N at 7 d, then increasing to 0.69 N at 84 d. The MM and LM did not express any increasing or decreasing trends (R = 0.74, R = 0.12, respectively), and both appeared to remain constant as storage time increased. The MM group had a tack force of 0.18 N at 7 d, and then the force slightly increased to 0.33 N at 84 d. The LM group had a tack force of 0.20 N at 7 d, and then the force remained virtually constant to 0.22 N at 84 d. The mean tack force of the commercial cheese (3 mo) was similar to that of the 84 d MM group, which was expected because both groups had similar moisture contents. Within the experimental cheeses, moisture and age had significant effects on the tack force, as shown in Table 6.

Pairwise comparison expressed a significant difference between high, medium and low moisture groups, and between the older 70 and 84 d cheeses and the younger 14 and 28 d cheeses (see Appendix B). Not only is tack force dependent of moisture, but of cheese age as well. Investigating the interaction between moisture and age, all three moisture groups were not significantly different at 14 d, but there was a difference between high and low moisture groups at age 84 d (see Appendix D). Within the HM group individually, the young cheeses at 14 d had significantly lower tack force values

Table 8: Mean (±SD) values for commercial cheese tack force and tack energy, and commercial cheese flexibility forces at thicknesses 1.25-mm (1), 1.15-mm (2), and 1.05-mm (3) (n=3).

	Tack Force (N)	Tack Energy (mJ/m^2)	Flexibility Force 1 (N)	Flexibility Force 2 (N)	Flexibility Force 3 (N)
Mean	0.37 (0.13)	75.1 (19.95)	1.84(0.42)	1.19(0.18)	0.83(0.20)

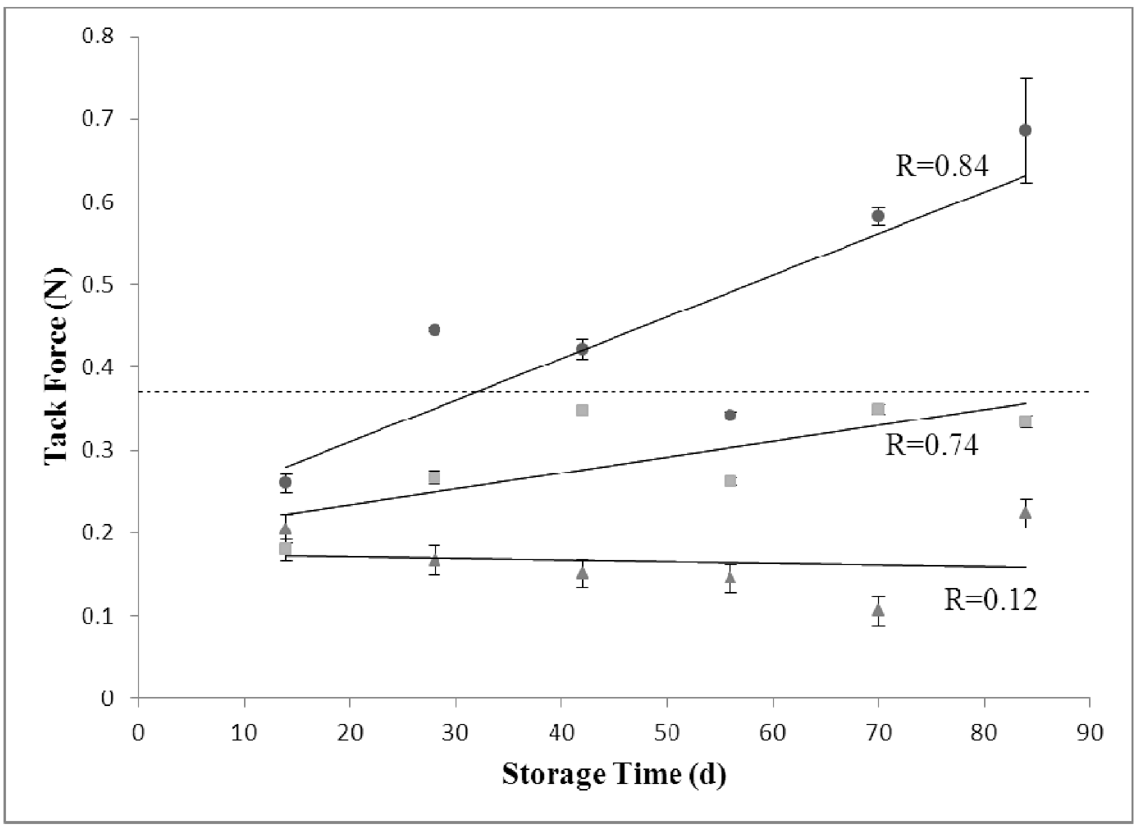

Figure 9: Mean tack force values for high moisture (●), medium moisture (■) and low moisture (▲) cheeses during 84d storage at 6°C, Bars = SE (some bars smaller than symbol), dashed line represents a typical tack for commercial cheeses.

than their older 70 and 84 d counterparts. Tack force was determined to increase with increasing moisture content and storage time.

Tack force is the maximum force recorded during separation, and is important in that it relates to slicing blade adhesion. There were correlations between moisture content, pH and tack force measured at 14, 28, and 84 d storage times (see Appendix I, J and K). At 14 d, pH had a significant correlation with tack force (R=-0.33), and at 28 d the moisture content and pH were significantly correlated with tack force (R=0.69, R= -0.66), as well as at 84 d (R=0.53, R=-0.39). As the cheese moisture content increased, tack force increased due to greater adhesion to the tack probe. As pH increased, tack force decreased, due to the cheese becoming more crumbly and breaking apart upon compression. Small correlations indicate other influences besides moisture in cheese sliceability.

Tack Energy

The mean tack energy for the commercial cheeses was 75.1 mJ/m^2 and is shown in Table 8. The tack energies for all the experimental cheeses are shown in Figure 10. When linear regression was performed on the cheeses, the highest correlation was with the HM cheeses, similar to the tack force results. When considered on a linear basis, the HM group showed an increasing trend in tack energy (R = 0.85) as storage time increased, starting at 52.0 mJ/m^2 at 7 d, then increasing to 139 mJ/m^2 at 84 d. In addition, the relationship between storage time and tack energy appeared to express a peak followed by a drop in tack energy around 28 d of storage within the HM group.

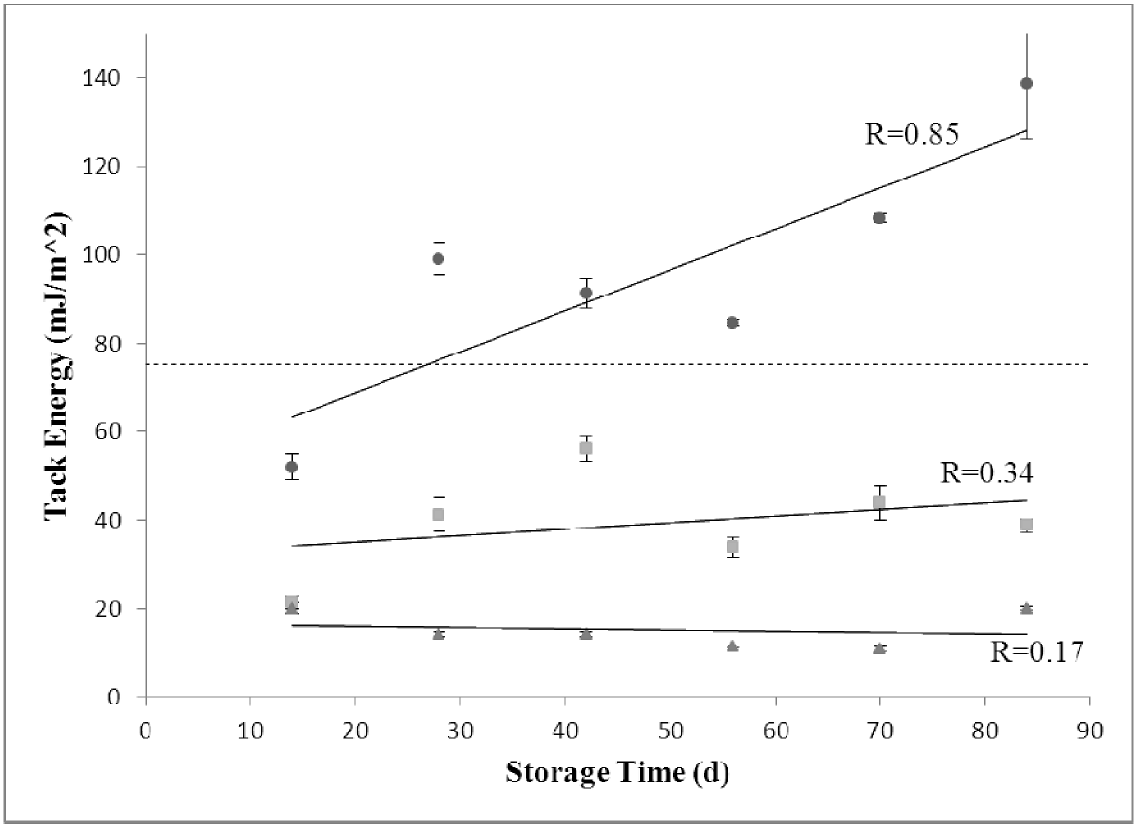

Figure 10: Mean values for tack energy for high moisture (●), medium moisture (■) and low moisture (▲)cheeses during 84d storage at 6°C, Bars = SE (some bars smaller than symbol), dashed line represents a typical tack for commercial cheeses.

This pattern may indicate that moisture and pH played a role in the amount of free water available on the cheese for probe adherence. There was no change in tack energy for the medium moisture (R=0.34) and low moisture (R=0.17) cheeses throughout storage. The MM group had a tack energy of 21.3 mJ/m2 at 7 d, and then slightly increased to 38.8 mJ/m2 at 84 d. The LM group had a tack energy of 20.0 mJ/m2 at 7 d, and then remained constant to 20.0 mJ/m2 at 84 d. The mean tack energy (75.1 mJ/m2) of the commercial cheese (3 mo) was not similar to any of the medium moisture values at any age. The commercial cheese's tack energy value did fall within the same range as the

HM group, which was not expected because the HM mean moisture content is higher than that of the commercial cheeses.

Both moisture and age had significant effects on tack energy, as shown in Table 6. There was a significant difference between high, medium and low moisture groups for tack energy, and between all of the older (70 and 84 d) and younger cheeses (14 d) as well (see Appendix B). There was no significant difference between moisture groups and all cheeses were similar at 14 d. At age 84 d, the medium moisture group was significantly larger than the low moisture group (see Appendix D). Within the HM group, the best time to slice the HM group was at 56 d, when it exhibited the lowest tack energy.

Tack energy is the energy required to separate 2 materials that are not permanently bound and relates to blade adherence. Childs et al. (2007) observed an opposite trend in tack energy with respect to moisture content when comparing Monterey Jack (42% moisture content) and Mozzarella (47% moisture content), and Monterey Jack adhered to the tack probe more than Mozzarella. The moisture content of the Monterey Jack is similar to that of the high moisture cheese group in the current study, which adhered to the tack probe more than the lower moisture groups. In addition, the Mozzarella may have had lower tack energy values as a result of the manufacture procedure, as well as the lower fat content of the cheese in comparison to the Monterey Jack. The results of the current study, as well as that of Child et al. (2007), emphasize that there may be other factors besides moisture, such as cheese manufacture and how well curd granules knit together, that influence cheese sliceability.

Examining if a cheese's tack energy would be an indicator of how it slices, tack energy was linearly correlated with the slice score at 1.2-mm thickness (R = 0.64). Higher tack energy values were correlated with higher defect slice scores (see Figure 11). A cheese that has a tack energy above 60 mJ/m^2 will likely have a higher defect score. A cheese that has a low tack energy value may or may not have a low defect score, because the low correlation indicates that sliceability may depend on other factors besides tack energy.

There were also correlations between moisture content, pH and tack energy measured at 14, 28, and 84 d storage times (see Appendix I, J, and K). It was determined at 14 d that moisture content and pH were significantly correlated with tack energy (R=0.47, R=-0.39), as well as at 28 d (R=0.71, R=-0.72), and at 84 d (R=0.59, R=-0.44). As moisture content increased, tack energy increased due to greater adhesion of the cheese to the tack probe. As pH increased, tack energy decreased, as a result of the cheese crumbling at compression.

Flexibility Force

The commercial cheese flexibility forces at three different slice thicknesses 1.25, 1.15, and 1.05-mm are 1.84, 1.19, and 0.83 N, respectively, and are shown in Table 8. Overall, flexibility force decreased with decreasing slice thickness. The experimental cheese flexibility force results at all 3 slice thicknesses (1.2, 0.9, and 0.6-mm) are shown in Figure 12. The results at slice thickness 1.2-mm expressed the most differentiation between the three moisture groups. In addition, all of the moisture groups except the LM group at slice thickness 0.9-mm, tended to peak in flexibility force at 28 d storage

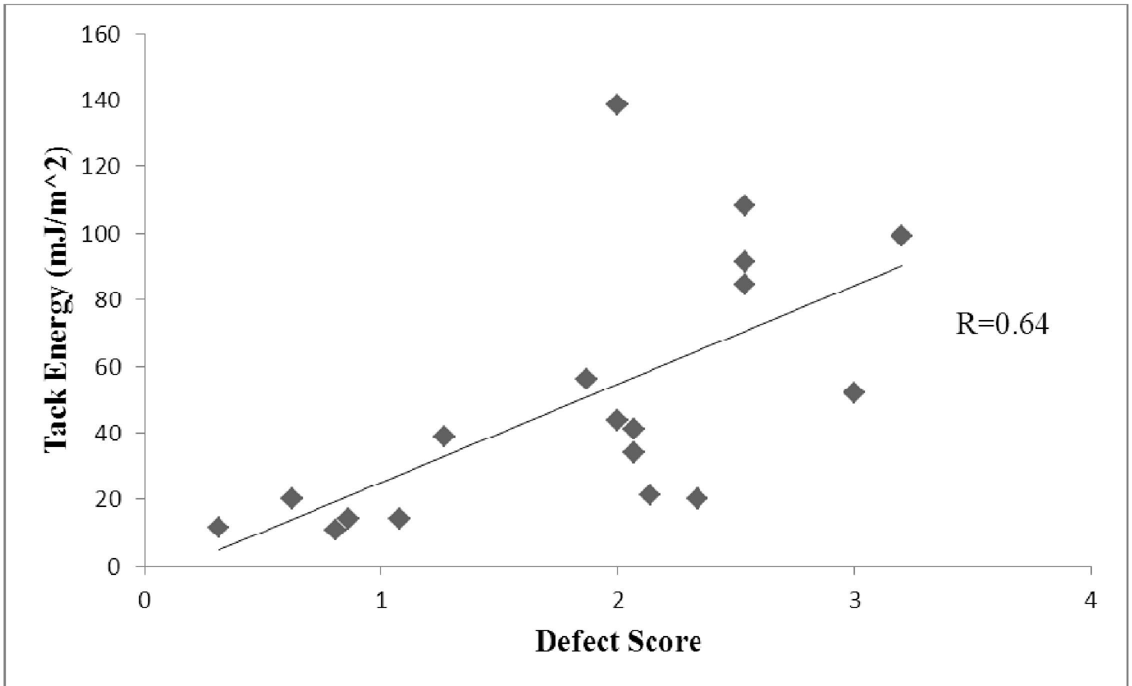

Figure 11: Linear correlation between tack energy (mJ/m^2) and slice defect scores at 1.1-mm thickness

time, followed by a plateau at lower force values. The commercial cheese flexibility force at 1.2-mm thickness was similar to that of the MM moisture group at 1.2-mm of the same age, which was expected considering they have similar moisture contents.

It was important to examine flexibility forces because it directly reflects cheese fracturability. The direct results of the texture profile analysis were similar to that of a compression test, and the first peak indicated the first fracture of a bent cheese slice (refer to Appendix L). Flexibility force is the maximum bent force recorded before a slice breaks in half. During shipping and handling, it is important for slices to maintain their integrity and not break or crumble. Higher flexibility force values indicate that the slice is firmer and takes more force to break when being bent than the lower values.

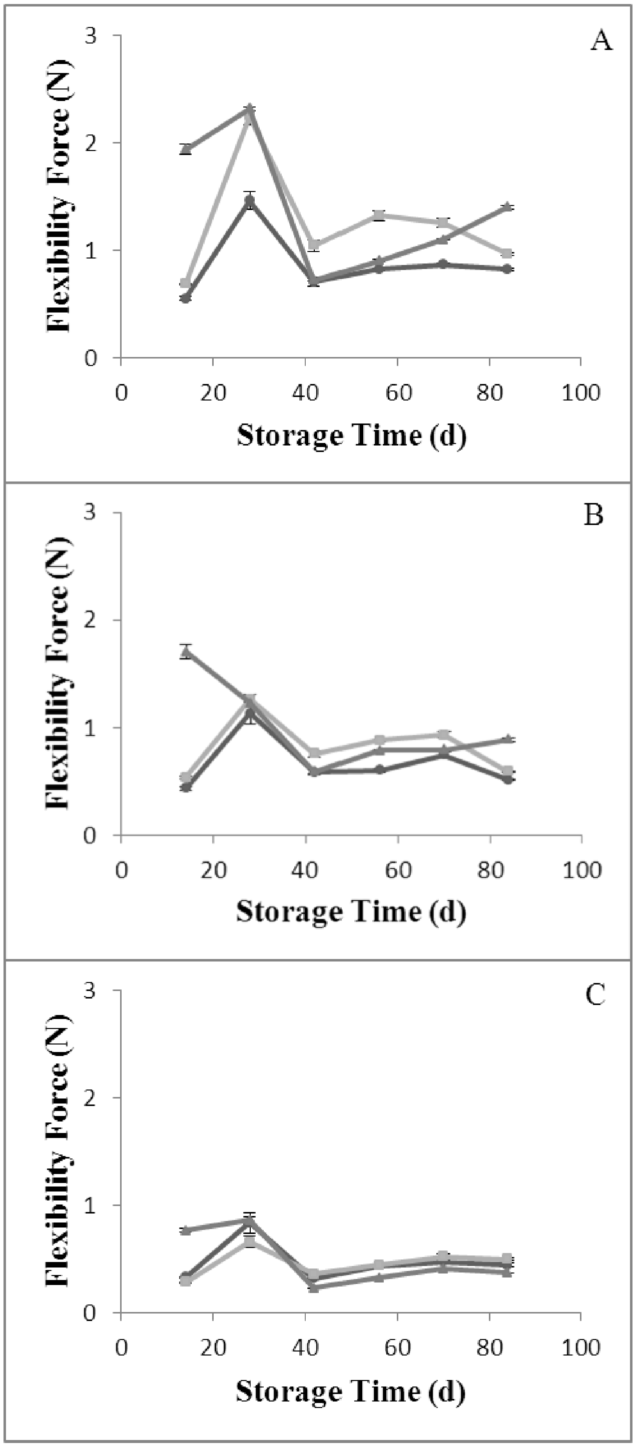

Figure 12: Mean flexibility force of 1.2-mm (A), 0.9-mm (B), and 0.6-mm (C) cheese slices with high moisture (●), medium moisture (■) and low moisture (▲) during 84d storage at 6°C, Bars = SE (some bars smaller than symbol)

Both moisture and age had significant effects on flexibility forces at 1.2- and 0.9-mm slice thicknesses, as shown in Table 6. Overall, there was a significant difference between the HM group and MM and LM groups, as well as between the young 28 d cheeses and the older 70 and 84 d cheeses, for flexibility force at slice thickness 1.2-mm, and 0.9-mm (see Appendix B). It was determined that a higher moisture content indicated lower flexibility forces, due to greater protein hydration and higher viscosity. Hort et al. (1999, 2001) determined that young, green cheddar was harder than older cheddar and Tunick et al. (2007) determined that increased storage resulted in decreases in TPA hardness. Similar to the previous research, the younger 14 d and 28 d cheeses in this study resisted breakage at bending more than the older cheeses, and as the cheese aged, the force required to bend the cheese to breakage decreased.

As seen in Figure 11, there is a steep peak at 28 d for all 3 moisture groups at all 3 thicknesses, with the most difference seen with the 1.2-mm slice. Lawrence et al. (1987) identified 2 distinct phases in cheese texture development; the first within the first 7-14 days, and the second stage embraces the remainder of the ripening period. These 2 texture phases were evident within the flexibility forces of the three moisture groups in this experiment. With all 3 moisture groups, there were increases in flexibility force up until 28 d, then progressive decreases, and eventually plateaus at roughly 42 d of storage. It became more difficult to create a fracture in the cheese while being bent until storage time 28 d, and then it became easier as storage time increased.

After 28 d of storage, all 3 moisture groups at 1.2-mm thickness significantly decreased in flexibility force, further supporting the textural development phases of Lawrence et al.(1987). At slice thickness 0.9-mm, only the LM group flexibility force decreased with increasing age. Slice thickness 0.6-mm did not express any overall significant difference between the moisture groups. There was, however, a significant difference between the 28-d cheeses and the 70- and 84-d cheeses, as previously seen with the other two thicknesses, again, further supporting a two phase textural development.

Flexibility force was found to not to correlate with cheese slice grades. There were, however, correlations between moisture content, pH and flexibility force measured at 14, 28, and 84 d storage times (see Appendix I, J and K). At 14 d, moisture content and pH were significantly correlated with flexibility forces at 1.2-mm (R=-0.77, R=0.58), at 0.9-mm (R=-0.74, R=0.55), and at 0.6-mm (R=-0.58, R=0.58). At 28 d the moisture content was significantly correlated with flexibility force at 1.2-mm (R=-0.47), and pH was significantly correlated with flexibility forces at 0.9-mm (R=-0.39) and at 0.6-mm (R=-0.45). Lastly, at 84 d the moisture content and pH were significantly correlated with flexibility forces at 1.2-mm (R=-0.81, R=0.66) and at 0.9-mm (R=-0.77, R=0.69). Increasing moisture content led to decreases in flexibility force, due to greater protein matrix hydration. Increasing pH led to increases in flexibility force, a result of a firmer, brittle cheese.

CONCLUSIONS

A slice quality evaluation method was created based on a combination of defects that were visually observed in manually sliced cheese. A defect score scale of one to 5 was generated, taking into account any splits, cracks, or broken corners that the slice may contain. A slice thickness that was less than 0.6 mm provided scores that were not considered useful or beneficial. A 1.1-mm thickness provided many examples of good slice quality, in that the cheese remained in a whole shape and did not crumble, break, or split during slicing. Slicing the cheese after a 14-d storage period produced better quality slices that younger cheeses.

Companies want to slice at earliest possible time; therefore early stages of maturation were examined. Overall, slice quality improved over storage time. All commercial cheeses expressed good slicing qualities at 1.25-, 1.15-, and 1.05-mm thicknesses. The HM experimental cheeses at thicknesses 1.2-, 0.9-, and 0.6-mm had higher defect scores than the MM and LM groups, with best sliceability coming from the LM group. The defect scores for all three moisture groups were the highest at 7 d, indicating the poorest quality slices at the youngest age. High quality slicing began at 56 d, and was the best quality at 84 d for all three moisture groups.

All rheological parameters (G’, G”, and G*) decreased with increasing moisture content and did not change over storage time. Higher G” values of the low moisture cheeses may specify good sliceability, considering those cheeses received the best scores at all three thicknesses. Both tack force and tack energy increased with moisture content, and storage time within the high moisture group. Tack energy was determined to be correlated with slice quality, and lower tack energy values may be an indicator of good sliceability. All cheeses had a peak in flexibility force at age 28 d, followed by decreases in force as storage time increased, indicating two phases of cheese textural development. Flexibility force was not correlated with sliceability. Overall, the low moisture cheeses were able to cut cleanly, resist breakage on slice edges and maintain desirable slice characteristics throughout storage.

Moisture and storage time, as well their interaction, had significant effects on dependent variables, potentially indicating that a higher moisture cheese texture changes differently compared to medium and low moisture cheeses during storage. Correlation tests did not express a strong connection between moisture content, age and cheese slice quality, overall. Knowing textural parameters assists in understanding slice quality. A combination of the slice quality evaluation and textural parameter tests will allow for a complete determination of cheese sliceability.

This research lays the foundation for future slice quality evaluation. Further examination should include other factors that may influence cheese sliceability besides moisture content, such as manufacturing procedures, in order to determine whether or not cheese slice quality is a function of the fusion of curd particles. Fat content is another compositional factor that may impact sliceability, in that lower fat cheeses tend to be more rubbery than higher fat cheeses. In addition, specific examination textural changes during storage, such as proteolysis and curd knitting between 0-30 d, will provide understanding as to what physical properties influences sliceability. This research is a starting point to which other companies and scientists can build upon.

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APPENDICES

A: Experimental Proximate Analysis

The GLM Procedure
Dependent Variable: Moisture

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	202.5286000	33.7547667	156.19	<.0001
Error	20	4.3222667	0.2161133		
Corrected Total	26	206.8508667			

R-Square	Coeff Var	Root MSE	H2O Mean
0.979104	1.249864	0.464880	37.19444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	199.6989556	99.8494778	462.02	<.0001
Cheese	2	2.6842889	1.3421444	6.21	0.0080
replicate	2	0.1453556	0.0726778	0.34	0.7184

Dependent Variable: pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	0.32973333	0.05495556	26.13	<.0001
Error	20	0.04206667	0.00210333		
Corrected Total	26	0.37180000			

R-Square	Coeff Var	Root MSE	pH Mean
0.886857	0.887654	0.045862	5.166667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.22935556	0.11467778	54.52	<.0001
Cheese	2	0.09975556	0.04987778	23.71	<.0001
replicate	2	0.00062222	0.00031111	0.15	0.8634

Dependent Variable: Salt

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2.46222222	0.41037037	26.20	<.0001
Error	20	0.31324444	0.01566222		
Corrected Total	26	2.77546667			

R-Square	Coeff Var	Root MSE	Salt Mean
0.887138	8.281906	0.125149	1.511111

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.46595556	0.73297778	46.80	<.0001
Cheese	2	0.98880000	0.49440000	31.57	<.0001
replicate	2	0.00746667	0.00373333	0.24	0.7901

Dependent Variable: Fat

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	79.33333333	13.22222222	28.33	<.0001
Error	20	9.33333333	0.46666667		
Corrected Total	26	88.66666667			

R-Square	Coeff Var	Root MSE	Fat Mean
0.894737	2.149710	0.683130	31.77778

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	66.66666667	33.33333333	71.43	<.0001
Cheese	2	12.66666667	6.33333333	13.57	0.0002
replicate	2	0.00000000	0.00000000	0.00	1.0000

Dependent Variable: Ca

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.00855516	0.00213879	1.18	0.4391
Error	4	0.00726722	0.00181680		
Corrected Total	8	0.01582237			

R-Square	Coeff Var	Root MSE	Ca Mean
0.540700	6.307261	0.042624	0.675792

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cheese	2	0.00658913	0.00329457	1.81	0.2751
replicate	2	0.00196603	0.00098301	0.54	0.6195

Dependent Variable: PO4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.02827126	0.00706782	1.04	0.4835
Error	4	0.02705613	0.00676403		
Corrected Total	8	0.05532740			

R-Square	Coeff Var	Root MSE	PO4 Mean
0.510981	5.770371	0.082244	1.425276

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Cheese	2	0.01799128	0.00899564	1.33	0.3607
replicate	2	0.01027998	0.00513999	0.76	0.5251

B: Experimental Texture Profile Analysis

The GLM Procedure
Dependent Variable: TackForce

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.26586088	0.36287343	13.19	<.0001
Error	152	4.18140788	0.02750926		
Corrected Total	161	7.44726877			

R-Square	Coeff Var	Root MSE	TackForce Mean
0.438531	54.35002	0.165859	0.305169

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	2.32106464	1.16053232	42.19	<.0001
Cheese	2	0.14544615	0.07272307	2.64	0.0744
Storage	5	0.79935010	0.15987002	5.81	<.0001

Dependent Variable: TackEnergy

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	206467.5327	22940.8370	19.14	<.0001
Error	152	182149.3982	1198.3513		
Corrected Total	161	388616.9309			

R-Square	Coeff Var	Root MSE	TackEnergy Mean
0.531288	67.70362	34.61721	51.13052

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	177873.0806	88936.5403	74.22	<.0001
Cheese	2	6692.2844	3346.1422	2.79	0.0644
Storage	5	21902.1677	4380.4335	3.66	0.0038

Dependent Variable: Flexibility Force 1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	32.77596739	3.64177415	22.44	<.0001
Error	152	24.66413643	0.16226406		
Corrected Total	161	57.44010382			

R-Square	Coeff Var	Root MSE	F1 Mean
0.570611	34.46283	0.402820	1.168854

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	7.85939508	3.92969754	24.22	<.0001
Cheese	2	0.93861081	0.46930540	2.89	0.0585
Storage	5	23.97796151	4.79559230	29.55	<.0001

Dependent Variable: Flexibility Force 2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	8.06720162	0.89635574	6.80	<.0001
Error	152	20.03420625	0.13180399		
Corrected Total	161	28.10140786			

R-Square	Coeff Var	Root MSE	F2 Mean
0.287075	42.94731	0.363048	0.845334

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	2.94893239	1.47446620	11.19	<.0001
Cheese	2	0.12632706	0.06316353	0.48	0.6202
Storage	5	4.99194217	0.99838843	7.57	<.0001

Dependent Variable: Flexibility Force 3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	3.31244815	0.36804979	5.52	<.0001
Error	152	10.13595287	0.06668390		
Corrected Total	161	13.44840102			

R-Square	Coeff Var	Root MSE	F3 Mean
0.246308	53.80377	0.258232	0.479952

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.01070368	0.00535184	0.08	0.9229
Cheese	2	0.08892996	0.04446498	0.67	0.5148
Storage	5	3.21281452	0.64256290	9.64	<.0001

C: Experimental Rheological Analysis

The GLM Procedure
Dependent Variable: elastic modulus (20Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.62551024	0.12510205	5.48	0.0005
Error	48	1.09514748	0.02281557		
Corrected Total	53	1.72065772			

R-Square	Coeff Var	Root MSE	eg20 Mean
0.363530	2.874813	0.151048	5.254195

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.41769825	0.20884913	9.15	0.0004
Cheese	2	0.15025918	0.07512959	3.29	0.0457
Storage	1	0.05755281	0.05755281	2.52	0.1188

Dependent Variable: elastic modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.64444528	0.12888906	5.65	0.0004
Error	48	1.09479918	0.02280832		
Corrected Total	53	1.73924446			

R-Square	Coeff Var	Root MSE	eg150 Mean
0.370532	2.880614	0.151024	5.242780

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.43867509	0.21933755	9.62	0.0003
Cheese	2	0.14924439	0.07462219	3.27	0.0466
Storage	1	0.05652580	0.05652580	2.48	0.1220

Dependent Variable: elastic modulus (1000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.80628416	0.16125683	6.29	0.0001
Error	48	1.23009189	0.02562691		
Corrected Total	53	2.03637605			

R-Square	Coeff Var	Root MSE	eg1000 Mean
0.395941	3.097501	0.160084	5.168169

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.59634122	0.29817061	11.64	<.0001
Cheese	2	0.15982466	0.07991233	3.12	0.0533
Storage	1	0.05011828	0.05011828	1.96	0.1684

Dependent Variable: elastic modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.90353118	0.38070624	5.05	0.0008
Error	48	3.61556832	0.07532434		
Corrected Total	53	5.51909949			

R-Square	Coeff Var	Root MSE	eg4000 Mean
0.344899	5.595552	0.274453	4.904839

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.43804780	0.71902390	9.55	0.0003
Cheese	2	0.43489038	0.21744519	2.89	0.0655
Storage	1	0.03059300	0.03059300	0.41	0.5270

Dependent Variable: viscous modulus (20Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.75993109	0.15198622	15.96	<.0001
Error	48	0.45698202	0.00952046		
Corrected Total	53	1.21691311			

R-Square	Coeff Var	Root MSE	vg20 Mean
0.624474	2.083047	0.097573	4.684141

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.70755199	0.35377600	37.16	<.0001
Cheese	2	0.05113887	0.02556943	2.69	0.0784
Storage	1	0.00124023	0.00124023	0.13	0.7197

Dependent Variable: viscous modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.77839716	0.15567943	15.89	<.0001
Error	48	0.47026806	0.00979725		
Corrected Total	53	1.24866523			

R-Square	Coeff Var	Root MSE	vg150 Mean
0.623383	2.115894	0.098981	4.677978

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.72178571	0.36089285	36.84	<.0001
Cheese	2	0.05510951	0.02755475	2.81	0.0700
Storage	1	0.00150195	0.00150195	0.15	0.6971

Dependent Variable: viscous modulus (1000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.90748849	0.18149770	15.40	<.0001
Error	48	0.56564419	0.01178425		
Corrected Total	53	1.47313268			

R-Square	Coeff Var	Root MSE	vg1000 Mean
0.616026	2.340724	0.108555	4.637681

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.81850206	0.40925103	34.73	<.0001
Cheese	2	0.08515618	0.04257809	3.61	0.0345
Storage	1	0.00383026	0.00383026	0.33	0.5713

Dependent Variable: viscous modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.47890439	0.29578088	13.92	<.0001
Error	48	1.02020413	0.02125425		
Corrected Total	53	2.49910852			

R-Square	Coeff Var	Root MSE	vg4000 Mean
0.591773	3.243014	0.145788	4.495459

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.21046000	0.60523000	28.48	<.0001
Cheese	2	0.24784102	0.12392051	5.83	0.0054
Storage	1	0.02060337	0.02060337	0.97	0.3298

Dependent Variable: complex modulus (20Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.66284760	0.13256952	6.33	0.0001
Error	48	1.00553640	0.02094868		
Corrected Total	53	1.66838401			

R-Square	Coeff Var	Root MSE	cg20 Mean
0.397299	2.748782	0.144737	5.265480

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.50363238	0.25181619	12.02	<.0001
Cheese	2	0.12620611	0.06310306	3.01	0.0586
Storage	1	0.03300911	0.03300911	1.58	0.2155

Dependent Variable: complex modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.68629629	0.13725926	6.56	0.0001
Error	48	1.00436751	0.02092432		
Corrected Total	53	1.69066380			

R-Square	Coeff Var	Root MSE	cg150 Mean
0.405933	2.752558	0.144652	5.255200

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.52365929	0.26182965	12.51	<.0001
Cheese	2	0.12786944	0.06393472	3.06	0.0564
Storage	1	0.03476756	0.03476756	1.66	0.2036

Dependent Variable: complex modulus (1000 Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	0.85800698	0.17160140	8.04	<.0001
Error	48	1.02435872	0.02134081		
Corrected Total	53	1.88236570			

R-Square	Coeff Var	Root MSE	cg1000 Mean
0.455813	2.815831	0.146085	5.187987

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.66461284	0.33230642	15.57	<.0001
Cheese	2	0.14600451	0.07300225	3.42	0.0408
Storage	1	0.04738963	0.04738963	2.22	0.1427

Dependent Variable: complex modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.71906443	0.34381289	11.17	<.0001
Error	48	1.47807650	0.03079326		
Corrected Total	53	3.19714092			

R-Square	Coeff Var	Root MSE	cg4000 Mean
0.537688	3.544505	0.175480	4.950765

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.30086706	0.65043353	21.12	<.0001
Cheese	2	0.31066673	0.15533337	5.04	0.0103
Storage	1	0.10753063	0.10753063	3.49	0.0678

D: Interaction Term of Experimental Texture Profile Analysis

The GLM Procedure
Dependent Variable: TackForce

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	6.41490140	0.12103588	12.66	<.0001
Error	108	1.03236737	0.00955896		
Corrected Total	161	7.44726877			

R-Square	Coeff Var	Root MSE	TackForce Mean
0.861376	32.03801	0.097770	0.305169

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	2.32106464	1.16053232	121.41	<.0001
Cheese	2	0.14544615	0.07272307	7.61	0.0008
Type*Cheese	4	0.30135066	0.07533767	7.88	<.0001
Storage	5	0.79935010	0.15987002	16.72	<.0001
Type*Storage	10	0.82625490	0.08262549	8.64	<.0001
Cheese*Storage	10	0.83670473	0.08367047	8.75	<.0001
Type*Cheese*Storage	20	1.18473023	0.05923651	6.20	<.0001

Dependent Variable: TackEnergy

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	339399.3023	6403.7604	14.05	<.0001
Error	108	49217.6286	455.7188		
Corrected Total	161	388616.9309			

R-Square	Coeff Var	Root MSE	TackEnergy Mean
0.873352	41.75114	21.34757	51.13052

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	177873.0806	88936.5403	195.16	<.0001
Cheese	2	6692.2844	3346.1422	7.34	0.0010
Type*Cheese	4	13061.4530	3265.3632	7.17	<.0001
Storage	5	21902.1677	4380.4335	9.61	<.0001
Type*Storage	10	24832.7009	2483.2701	5.45	<.0001
Cheese*Storage	10	36287.7218	3628.7722	7.96	<.0001
Type*Cheese*Storage	20	58749.8939	2937.4947	6.45	<.0001

Dependent Variable: Flexibility Force 1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	56.23498785	1.06103751	95.09	<.0001
Error	108	1.20511597	0.01115848		
Corrected Total	161	57.44010382			

R-Square	Coeff Var	Root MSE	F1 Mean
0.979020	9.037374	0.105634	1.168854

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	7.85939508	3.92969754	352.17	<.0001
Cheese	2	0.93861081	0.46930540	42.06	<.0001
Type*Cheese	4	1.07924884	0.26981221	24.18	<.0001
Storage	5	23.97796151	4.79559230	429.77	<.0001
Type*Storage	10	10.78298900	1.07829890	96.63	<.0001
Cheese*Storage	10	7.26685410	0.72668541	65.12	<.0001
Type*Cheese*Storage	20	4.32992853	0.21649643	19.40	<.0001

Dependent Variable: Flexibility Force 2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	27.36724420	0.51636310	75.96	<.0001
Error	108	0.73416366	0.00679781		
Corrected Total	161	28.10140786			

R-Square	Coeff Var	Root MSE	F2 Mean
0.973874	9.753405	0.082449	0.845334

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	2.94893239	1.47446620	216.90	<.0001
Cheese	2	0.12632706	0.06316353	9.29	0.0002
Type*Cheese	4	1.39045217	0.34761304	51.14	<.0001
Storage	5	4.99194217	0.99838843	146.87	<.0001
Type*Storage	10	8.50895999	0.85089600	125.17	<.0001
Cheese*Storage	10	5.12929284	0.51292928	75.46	<.0001
Type*Cheese*Storage	20	4.27133759	0.21356688	31.42	<.0001

Dependent Variable: Flexibility Force 3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	13.07190216	0.24663966	70.75	<.0001
Error	108	0.37649887	0.00348610		
Corrected Total	161	13.44840102			

R-Square	Coeff Var	Root MSE	F3 Mean
0.972004	12.30190	0.059043	0.479952

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.01070368	0.00535184	1.54	0.2201
Cheese	2	0.08892996	0.04446498	12.75	<.0001
Type*Cheese	4	0.47692833	0.11923208	34.20	<.0001
Storage	5	3.21281452	0.64256290	184.32	<.0001
Type*Storage	10	2.02078149	0.20207815	57.97	<.0001
Cheese*Storage	10	3.69194556	0.36919456	105.90	<.0001
Type*Cheese*Storage	20	3.56979862	0.17848993	51.20	<.0001

E: Interaction Term of Experimental Rheological Analysis

The GLM Procedure
Dependent Variable: elastic modulus (20Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	0.94369367	0.05551139	2.57	0.0085
Error	36	0.77696405	0.02158233		
Corrected Total	53	1.72065772			

R-Square	Coeff Var	Root MSE	eg20 Mean
0.548449	2.796038	0.146909	5.254195

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.41769825	0.20884913	9.68	0.0004
Cheese	2	0.15025918	0.07512959	3.48	0.0415
Type*Cheese	4	0.18149357	0.04537339	2.10	0.1007
Storage	1	0.05755281	0.05755281	2.67	0.1112
Type*Storage	2	0.03721989	0.01860995	0.86	0.4307
Cheese*Storage	2	0.01914591	0.00957296	0.44	0.6452
Type*Cheese*Storage	4	0.08032406	0.02008101	0.93	0.4572

Dependent Variable: elastic modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	0.97497658	0.05735156	2.70	0.0060
Error	36	0.76426788	0.02122966		
Corrected Total	53	1.73924446			

R-Square	Coeff Var	Root MSE	eg150 Mean
0.560575	2.779137	0.145704	5.242780

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.43867509	0.21933755	10.33	0.0003
Cheese	2	0.14924439	0.07462219	3.51	0.0403
Type*Cheese	4	0.19584144	0.04896036	2.31	0.0769
Storage	1	0.05652580	0.05652580	2.66	0.1115
Type*Storage	2	0.03561684	0.01780842	0.84	0.4405
Cheese*Storage	2	0.01753984	0.00876992	0.41	0.6647
Type*Cheese*Storage	4	0.08153317	0.02038329	0.96	0.4411

Dependent Variable: elastic modulus (1000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.25375673	0.07375040	3.39	0.0010
Error	36	0.78261933	0.02173943		
Corrected Total	53	2.03637605			

R-Square	Coeff Var	Root MSE	eg1000 Mean
0.615680	2.852905	0.147443	5.168169

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.59634122	0.29817061	13.72	<.0001
Cheese	2	0.15982466	0.07991233	3.68	0.0353
Type*Cheese	4	0.31364807	0.07841202	3.61	0.0143
Storage	1	0.05011828	0.05011828	2.31	0.1377
Type*Storage	2	0.02675271	0.01337636	0.62	0.5461
Cheese*Storage	2	0.01339314	0.00669657	0.31	0.7368
Type*Cheese*Storage	4	0.09367864	0.02341966	1.08	0.3821

Dependent Variable: elastic modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	3.26721935	0.19218937	3.07	0.0023
Error	36	2.25188014	0.06255223		
Corrected Total	53	5.51909949			

R-Square	Coeff Var	Root MSE	eg4000 Mean
0.591984	5.099136	0.250104	4.904839

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.43804780	0.71902390	11.49	0.0001
Cheese	2	0.43489038	0.21744519	3.48	0.0417
Type*Cheese	4	1.06350195	0.26587549	4.25	0.0064
Storage	1	0.03059300	0.03059300	0.49	0.4888
Type*Storage	2	0.01791667	0.00895834	0.14	0.8671
Cheese*Storage	2	0.08655729	0.04327865	0.69	0.5072
Type*Cheese*Storage	4	0.19571226	0.04892807	0.78	0.5442

Dependent Variable: viscous modulus (20 Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.02770060	0.06045298	11.50	<.0001
Error	36	0.18921251	0.00525590		
Corrected Total	53	1.21691311			

R-Square	Coeff Var	Root MSE	vg20 Mean
0.844514	1.547725	0.072498	4.684141

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.70755199	0.35377600	67.31	<.0001
Cheese	2	0.05113887	0.02556943	4.86	0.0135
Type*Cheese	4	0.16676373	0.04169093	7.93	0.0001
Storage	1	0.00124023	0.00124023	0.24	0.6301
Type*Storage	2	0.02365187	0.01182594	2.25	0.1200
Cheese*Storage	2	0.00315430	0.00157715	0.30	0.7426
Type*Cheese*Storage	4	0.07419961	0.01854990	3.53	0.0157

Dependent Variable: viscous modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.05438308	0.06202253	11.49	<.0001
Error	36	0.19428215	0.00539673		
Corrected Total	53	1.24866523			

R-Square	Coeff Var	Root MSE	vg150 Mean
0.844408	1.570388	0.073462	4.677978

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.72178571	0.36089285	66.87	<.0001
Cheese	2	0.05510951	0.02755475	5.11	0.0112
Type*Cheese	4	0.17252538	0.04313135	7.99	0.0001
Storage	1	0.00150195	0.00150195	0.28	0.6010
Type*Storage	2	0.02457214	0.01228607	2.28	0.1172
Cheese*Storage	2	0.00326512	0.00163256	0.30	0.7408
Type*Cheese*Storage	4	0.07562328	0.01890582	3.50	0.0163

Dependent Variable: viscous modulus (1000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.24214878	0.07306758	11.39	<.0001
Error	36	0.23098390	0.00641622		
Corrected Total	53	1.47313268			

R-Square	Coeff Var	Root MSE	vg1000 Mean
0.843202	1.727184	0.080101	4.637681

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.81850206	0.40925103	63.78	<.0001
Cheese	2	0.08515618	0.04257809	6.64	0.0035
Type*Cheese	4	0.21335079	0.05333770	8.31	<.0001
Storage	1	0.00383026	0.00383026	0.60	0.4448
Type*Storage	2	0.03105513	0.01552757	2.42	0.1032
Cheese*Storage	2	0.00403904	0.00201952	0.31	0.7320
Type*Cheese*Storage	4	0.08621532	0.02155383	3.36	0.0195

Dependent Variable: viscous modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	2.08930902	0.12290053	10.80	<.0001
Error	36	0.40979950	0.01138332		
Corrected Total	53	2.49910852			

R-Square	Coeff Var	Root MSE	vg4000 Mean
0.836022	2.373342	0.106693	4.495459

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.21046000	0.60523000	53.17	<.0001
Cheese	2	0.24784102	0.12392051	10.89	0.0002
Type*Cheese	4	0.40115935	0.10028984	8.81	<.0001
Storage	1	0.02060337	0.02060337	1.81	0.1869
Type*Storage	2	0.06039572	0.03019786	2.65	0.0842
Cheese*Storage	2	0.00745500	0.00372750	0.33	0.7229
Type*Cheese*Storage	4	0.14139456	0.03534864	3.11	0.0271

Dependent Variable: complex modulus (20Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	0.97782882	0.05751934	3.00	0.0027
Error	36	0.69055519	0.01918209		
Corrected Total	53	1.66838401			

R-Square	Coeff Var	Root MSE	cg20 Mean
0.586093	2.630329	0.138499	5.265480

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.50363238	0.25181619	13.13	<.0001
Cheese	2	0.12620611	0.06310306	3.29	0.0487
Type*Cheese	4	0.13881786	0.03470446	1.81	0.1484
Storage	1	0.03300911	0.03300911	1.72	0.1979
Type*Storage	2	0.02073021	0.01036511	0.54	0.5872
Cheese*Storage	2	0.02016117	0.01008058	0.53	0.5957
Type*Cheese*Storage	4	0.13527198	0.03381799	1.76	0.1578

Dependent Variable: complex modulus (150Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.00605889	0.05917993	3.11	0.0021
Error	36	0.68460491	0.01901680		
Corrected Total	53	1.69066380			

R-Square	Coeff Var	Root MSE	cg150 Mean
0.595067	2.624095	0.137901	5.255200

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.52365929	0.26182965	13.77	<.0001
Cheese	2	0.12786944	0.06393472	3.36	0.0459
Type*Cheese	4	0.14499565	0.03624891	1.91	0.1306
Storage	1	0.03476756	0.03476756	1.83	0.1848
Type*Storage	2	0.02023673	0.01011837	0.53	0.5919
Cheese*Storage	2	0.02005227	0.01002614	0.53	0.5947
Type*Cheese*Storage	4	0.13447794	0.03361948	1.77	0.1567

Dependent Variable: complex modulus (1000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	1.22172795	0.07186635	3.92	0.0003
Error	36	0.66063775	0.01835105		
Corrected Total	53	1.88236570			

R-Square	Coeff Var	Root MSE	cg1000 Mean
0.649039	2.611148	0.135466	5.187987

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	0.66461284	0.33230642	18.11	<.0001
Cheese	2	0.14600451	0.07300225	3.98	0.0275
Type*Cheese	4	0.19205908	0.04801477	2.62	0.0511
Storage	1	0.04738963	0.04738963	2.58	0.1168
Type*Storage	2	0.02000893	0.01000447	0.55	0.5845
Cheese*Storage	2	0.01940504	0.00970252	0.53	0.5939
Type*Cheese*Storage	4	0.13224792	0.03306198	1.80	0.1499

Dependent Variable: complex modulus (4000Pa)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	17	2.41396318	0.14199783	6.53	<.0001
Error	36	0.78317775	0.02175494		
Corrected Total	53	3.19714092			

R-Square	Coeff Var	Root MSE	cg4000 Mean
0.755038	2.979248	0.147496	4.950765

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	1.30086706	0.65043353	29.90	<.0001
Cheese	2	0.31066673	0.15533337	7.14	0.0024
Type*Cheese	4	0.45065086	0.11266271	5.18	0.0021
Storage	1	0.10753063	0.10753063	4.94	0.0326
Type*Storage	2	0.06078493	0.03039247	1.40	0.2604
Cheese*Storage	2	0.01801904	0.00900952	0.41	0.6640
Type*Cheese*Storage	4	0.16544392	0.04136098	1.90	0.1314

F: Experimental Slice Scores

The GLM Procedure

Dependent Variable: score1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	63.3777778	7.0419753	21.21	<.0001
Error	260	86.3407407	0.3320798		
Corrected Total	269	149.7185185			

R-Square	Coeff Var	Root MSE	score1 Mean
0.423313	27.10648	0.576264	2.125926

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	34.89629630	17.44814815	52.54	<.0001
Cheese	2	2.49629630	1.24814815	3.76	0.0246
Storage	5	25.98518519	5.19703704	15.65	<.0001

Dependent Variable: score2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	71.2888889	7.9209877	23.63	<.0001
Error	260	87.1407407	0.3351567		
Corrected Total	269	158.4296296			

R-Square	Coeff Var	Root MSE	score2 Mean
0.449972	22.58820	0.578927	2.562963

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	43.82962963	21.91481481	65.39	<.0001
Cheese	2	0.71851852	0.35925926	1.07	0.3439
Storage	5	26.74074074	5.34814815	15.96	<.0001

Dependent Variable: score3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	76.0111111	8.4456790	20.74	<.0001
Error	260	105.8740741	0.4072080		
Corrected Total	269	181.8851852			

R-Square	Coeff Var	Root MSE	score3 Mean
0.417907	19.38073	0.638128	3.292593

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	37.82962963	18.91481481	46.45	<.0001
Cheese	2	0.56296296	0.28148148	0.69	0.5019
Storage	5	37.61851852	7.52370370	18.48	<.0001

G: Experimental Interaction Term of Slice Scores

The GLM Procedure
Dependent Variable: score1

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	96.9185185	1.8286513	7.48	<.0001
Error	216	52.8000000	0.2444444		
Corrected Total	269	149.7185185			

R-Square	Coeff Var	Root MSE	score1 Mean
0.647338	23.25637	0.494413	2.125926

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	34.89629630	17.44814815	71.38	<.0001
Cheese	2	2.49629630	1.24814815	5.11	0.0068
Type*Cheese	4	0.72592593	0.18148148	0.74	0.5640
Storage	5	25.98518519	5.19703704	21.26	<.0001
Type*Storage	10	4.30370370	0.43037037	1.76	0.0693
Cheese*Storage	10	16.57037037	1.65703704	6.78	<.0001
Type*Cheese*Storage	20	11.94074074	0.59703704	2.44	0.0009

Dependent Variable: score2

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	116.4296296	2.1967855	11.30	<.0001
Error	216	42.0000000	0.1944444		
Corrected Total	269	158.4296296			

R-Square	Coeff Var	Root MSE	score2 Mean
0.734898	17.20503	0.440959	2.562963

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	43.82962963	21.91481481	112.70	<.0001
Cheese	2	0.71851852	0.35925926	1.85	0.1601
Type*Cheese	4	4.28148148	1.07037037	5.50	0.0003
Storage	5	26.74074074	5.34814815	27.50	<.0001
Type*Storage	10	10.25925926	1.02592593	5.28	<.0001
Cheese*Storage	10	15.77037037	1.57703704	8.11	<.0001
Type*Cheese*Storage	20	14.82962963	0.74148148	3.81	<.0001

Dependent Variable: score3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	53	131.4851852	2.4808526	10.63	<.0001
Error	216	50.4000000	0.2333333		
Corrected Total	269	181.8851852			

R-Square	Coeff Var	Root MSE	score3 Mean
0.722902	14.67069	0.483046	3.292593

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Type	2	37.82962963	18.91481481	81.06	<.0001
Cheese	2	0.56296296	0.28148148	1.21	0.3013
Type*Cheese	4	3.25925926	0.81481481	3.49	0.0087
Storage	5	37.61851852	7.52370370	32.24	<.0001
Type*Storage	10	15.23703704	1.52370370	6.53	<.0001
Cheese*Storage	10	11.43703704	1.14370370	4.90	<.0001
Type*Cheese*Storage	20	25.54074074	1.27703704	5.47	<.0001

H: Correlation of slice score at 1.1-mm with Rheological Analysis

Pearson Correlation Coefficients
Prob > |r| under H0: Rho=0
Number of Observations

	score1	eg20	eg150	eg1000	eg4000	vg20	vg150	vg1000	vg4000	cg20	cg150	cg1000	cg4000
score1	1.00	-0.06	-0.06	-0.06	-0.04	-0.33	-0.32	-0.31	-0.27	-0.17	-0.17	-0.16	-0.14
		0.66	0.66	0.67	0.76	0.02	0.02	0.02	0.05	0.23	0.23	0.24	0.32
eg20		1.00	1.00	0.95	0.63	0.63	0.63	0.63	0.60	0.96	0.96	0.95	0.84
			<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
eg150			1.00	0.96	0.67	0.65	0.64	0.64	0.61	0.96	0.96	0.95	0.85
				<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
eg1000				1.00	0.84	0.68	0.68	0.68	0.66	0.91	0.91	0.92	0.87
					<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
eg4000					1.00	0.60	0.60	0.61	0.61	0.60	0.61	0.66	0.72
						<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
vg20						1.00	1.00	1.00	0.97	0.67	0.68	0.75	0.87
							<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
vg150							1.00	1.00	0.98	0.67	0.68	0.75	0.87
								<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
vg1000								1.00	0.99	0.66	0.67	0.75	0.88
									<.0001	<.0001	<.0001	<.0001	<.0001
vg4000									1.00	0.62	0.64	0.72	0.88
										<.0001	<.0001	<.0001	<.0001
cg20										1.00	1.00	0.99	0.86
											<.0001	<.0001	<.0001
cg150											1.00	0.99	0.88
												<.0001	<.0001
cg1000												1.00	0.93
													<.0001
cg4000													1.00

I: Correlation of Proximate Analysis with 14 d Experimental TPA

Pearson Correlation Coefficients, N = 34
Prob > |r| under H0: Rho=0

	H2O	**pH**	**salt**	**fat**	**TF**	**TE**	**F1**	**F2**	**F3**	**score1**	**score2**	**score3**
H2O	1.00	-0.87	-0.70	-0.74	0.39	0.47	-0.77	-0.74	-0.58	0.07	0.27	0.13
		<.0001	<.0001	<.0001	0.02	0.00	<.0001	<.0001	0.00	0.70	0.12	0.45
pH		1.00	0.88	0.64	-0.33	-0.39	0.58	0.55	0.58	0.14	-0.09	-0.10
			<.0001	<.0001	0.06	0.02	0.00	0.00	0.00	0.44	0.62	0.59
salt			1.00	0.64	-0.14	-0.19	0.52	0.52	0.66	0.14	0.10	-0.34
				<.0001	0.42	0.28	0.00	0.00	<.0001	0.43	0.56	0.05
fat				1.00	-0.01	-0.10	0.76	0.69	0.64	-0.04	0.11	-0.16
					0.97	0.57	<.0001	<.0001	<.0001	0.83	0.55	0.36
TF					1.00	0.98	-0.20	-0.24	0.03	-0.48	0.08	-0.11
						<.0001	0.27	0.16	0.86	0.00	0.66	0.52
TE						1.00	-0.26	-0.29	0.01	-0.44	0.11	-0.08
							0.14	0.10	0.97	0.01	0.54	0.67
F1							1.00	0.96	0.84	-0.19	-0.24	-0.28
								<.0001	<.0001	0.28	0.17	0.11
F2								1.00	0.84	-0.16	-0.26	-0.28
									<.0001	0.37	0.14	0.11
F3									1.00	-0.17	-0.11	-0.31
										0.33	0.54	0.08
score1										1.00	0.47	0.12
											0.00	0.49
score2											1.00	0.12
												0.51
score3												1.00

J: Correlation of Proximate Analysis with 28 d Experimental TPA

Pearson Correlation Coefficients, N = 27
Prob > |r| under H0: Rho=0

	H2O	pH	salt	fat	TF	TE	F1	F2	F3	score1	score2	score3
H2O	1.00	-0.87	-0.76	-0.77	0.70	0.71	-0.47	0.03	0.11	0.61	0.35	0.72
		<.0001	<.0001	<.0001	<.0001	<.0001	0.01	0.88	0.60	0.00	0.08	<.0001
pH		1.00	0.89	0.64	-0.65	-0.71	0.10	-0.39	-0.45	-0.46	-0.11	-0.55
			<.0001	0.00	0.00	<.0001	0.62	0.04	0.02	0.02	0.58	0.00
salt			1.00	0.65	-0.61	-0.69	-0.15	-0.57	-0.55	-0.40	-0.12	-0.43
				0.00	0.00	<.0001	0.45	0.00	0.00	0.04	0.56	0.03
fat				1.00	-0.45	-0.50	0.25	-0.15	-0.09	-0.30	-0.05	-0.57
					0.02	0.01	0.20	0.45	0.66	0.13	0.81	0.00
TF					1.00	0.94	-0.10	0.17	0.19	0.45	0.15	0.50
						<.0001	0.63	0.39	0.34	0.02	0.46	0.01
TE						1.00	-0.06	0.34	0.39	0.56	0.16	0.61
							0.77	0.08	0.04	0.00	0.42	0.00
F1							1.00	0.76	0.62	-0.42	-0.36	-0.60
								<.0001	0.00	0.03	0.06	0.00
F2								1.00	0.91	0.07	-0.13	-0.03
									<.0001	0.74	0.50	0.87
F3									1.00	0.25	-0.02	0.05
										0.21	0.93	0.80
score1										1.00	0.56	0.78
											0.00	<.0001
score2											1.00	0.36
												0.07
score3												1.00

K: Correlation of Proximate Analysis with 84 d Experimental TPA

Pearson Correlation Coefficients, N = 27
Prob > |r| under H0: Rho=0

	H2O	pH	salt	fat	TF	TE	F1	F2	F3	score1	score2	score3
H2O	1.00	-0.87	-0.76	-0.77	0.53	0.60	-0.81	-0.77	0.13	0.47	0.78	0.69
		<.0001	<.0001	<.0001	0.00	0.00	<.0001	<.0001	0.50	0.01	<.0001	<.0001
pH		1.00	0.89	0.64	-0.39	-0.44	0.66	0.69	0.15	-0.47	-0.62	-0.71
			<.0001	0.00	0.05	0.02	0.00	<.0001	0.47	0.01	0.00	<.0001
salt			1.00	0.65	-0.16	-0.20	0.62	0.67	0.17	-0.49	-0.39	-0.69
				0.00	0.44	0.32	0.00	0.00	0.41	0.01	0.05	<.0001
fat				1.00	-0.05	-0.12	0.60	0.58	-0.13	-0.25	-0.49	-0.34
					0.81	0.54	0.00	0.00	0.51	0.21	0.01	0.08
TF					1.00	0.99	-0.56	-0.46	0.26	0.04	0.53	0.46
						<.0001	0.00	0.02	0.19	0.84	0.00	0.02
TE						1.00	-0.64	-0.53	0.27	0.09	0.60	0.50
							0.00	0.00	0.18	0.67	0.00	0.01
F1							1.00	0.89	-0.48	-0.32	-0.68	-0.54
								<.0001	0.01	0.10	<.0001	0.00
F2								1.00	-0.34	-0.28	-0.59	-0.50
									0.08	0.16	0.00	0.01
F3									1.00	-0.29	0.19	-0.13
										0.14	0.33	0.53
score1										1.00	0.39	0.41
											0.04	0.04
score2											1.00	0.40
												0.04
score3												1.00

L: Example of flexibility force (N) results for medium moisture experimental cheese at 14 d (A), 28 d (B), 42 d (C), 56 d (D), 70 d (E), and 84 d (F) storage times