TEXTURAL CHANGES IN CHOCOLATE CHARACTERIZED BY INSTRUMENTAL AND SENSORY TECHNIQUES

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Accepted for Publication April 28, 2009

ABSTRACT

Cocoa butter has a distinct texture due to unique interactions of polymorphic lipid structures. Part of chocolate's appeal is smooth mouthfeel; as fat or sugar bloom forms, textural change is perceived. Correlation of instrumental and sensory texture analysis has not been conducted in stored chocolate. The objective of this study was to analyze texture and color of dark and milk chocolate stored under conditions leading to fat and/or sugar bloom by instrumental and sensory measurements. Milk and dark chocolate was stored 5 weeks at various temperatures and relative humidity (RH), followed by instrumental and sensory texture analysis. All attributes, except springiness, were significantly affected by treatments. According to partial least squares linear regression, instrumental hardness, cohesiveness, chewiness and gumminess modeled sensory hardness. The 30.0C incubator experienced temperature fluctuations, resulting in severe fat bloom. Temperature fluctuations during storage had more influence on texture perception than storage at high temperatures or high RH.

PRACTICAL APPLICATIONS

This research serves as an initial study on textural aspects of chocolate quality upon storage that is the first report to correlate instrumental textural analysis of chocolate to sensory evaluation. Storage temperature and humidity of chocolate greatly impacts consumer texture perception, which is valuable

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information to small chocolate handlers and manufacturers who have noted to us that many of the larger companies may have this information – but it is not widely available. It also sets the stage for more detailed studies on texture and flavor of chocolate during storage. Although many storage studies on chocolate exist, those that intertwine studies of quality from both an instrumental and a sensory standpoint are lacking.

KEYWORDS

Chocolate, fat bloom, sensory, storage, texture

INTRODUCTION

Chocolate is, in essence, cocoa mass and sugar suspended in a cocoa butter matrix. Cocoa butter has a distinct texture due to unique interactions of polymorphic lipid structures. Various storage conditions may lead to formation of either fat bloom or sugar bloom, each of which compromises both visual and textural quality. Bloom is the main cause of quality loss in the chocolate industry (Ziegleder 1997). Fat bloom occurs when chocolate is not properly tempered, or when the chocolate is exposed to elevated temperatures or temperature fluctuations. The most widely accepted mechanism attributes fat bloom formation to a phase separation of triglycerides within the cocoa butter matrix, eventually leading to recrystalization into a "needle and spike" or "bowtie" formation, causing diffusion of light and discoloration (Loisel *et al.* 1997; Bricknell and Hartel 1998; Widlak *et al.* 2001). Sugar bloom is caused by deposition of water from air onto the chocolate, dissolving sugar on the surface. When water diffuses back into the air, sugar recrystalizes on the surface of the chocolate, leaving a spotty appearance (Jensen 1931). Sugar bloom may also be a function of temperature; as frozen chocolate thaws, condensation is formed on the outside that dissolves the sugar and eventually evaporates, leaving sugar residue behind.

Texture is a combination of the physical structure of the material and its mechanical and surface properties (Szczesniak 1963). Chocolate has a unique mouthfeel because cocoa butter has a narrow melting point, very close to body temperature. Chocolate particle size is also extremely important to sample mouthfeel (Morgan 1994). Part of the appeal of chocolate is smooth mouthfeel; as bloom forms (both fat and sugar), the texture is changed and a difference is perceived. Previous instrumental texture studies on chocolate have been completed by Tscheuschner and Markov (1986a,b, 1989) and Markov and Tscheuschner (1989); however, very few studies have been done relating instrumental texture measurements with data collected from trained sensory panels. The most common method of instrumental texture analysis is a texture probe or texture analyzer.

Correlation of data from trained sensory panelists with instrumental data is an ongoing issue. Upkeep of trained sensory panels is expensive and tedious; therefore, researchers have turned to instrumental measurements to decrease input of time and money and to increase reproducibility by removing the physiological and psychological variation associated with human subjects. Sensory and instrumental correlations have been conducted on many food products, including tomatoes (Lee *et al.* 1999), apples (Abbot *et al.* 1984), bread (Gambaro *et al.* 2002), spaghetti (Martinez *et al.* 2007) and varying formulations of milk chocolate (Markov and Tscheuschner 1989; Guinard and Mazzucchelli 1999). Correlation of sensory and instrumental texture measurements is important for texture analysis and future chocolate storage studies.

Information is lacking on texture changes measured by either instrumental or sensory analyses that occur in chocolate stored in conditions that may lead to fat or sugar bloom formation. Therefore, the objectives of this study were (1) to evaluate textural changes in dark and milk chocolate associated with fat or sugar bloom and (2) to correlate instrumental and descriptive analysis measurements of texture.

MATERIALS AND METHODS

Materials

Hershey's Special Dark Chocolate and Hershey's Milk Chocolate Miniatures (Hershey, PA) were obtained from a local grocer. Potassium chloride and potassium nitrate were obtained from Fisher Scientific Co. (Fair Lawn, NJ) for establishing high relative humidity (RH) conditions.

Chocolate Storage

Chocolates were purchased and immediately stored in their original wrappers for 5 weeks in various atmospheric conditions listed in Table 1. Abbreviations are also found in Table 1. Chocolates were stored in conditions of high temperature (30 ± 1.7C and 32.2C), high RH (84.3%, 23C and 93.6%, 23C), refrigerator (1.7C), freezer (−27.2C) and an ambient temperature-controlled (23C) storage room. High RH was achieved in sealed storage desiccators with saturated salt solutions of potassium chloride (84.3% RH) and potassium nitrate (93.6% RH). Samples were analyzed by instrumental and sensory techniques in duplicate at 0 and 5 weeks of storage. All samples were allowed to equilibrate at least 2 h in a sealed container at room temperature prior to analysis.

TABLE 1.
DARK AND MILK CHOCOLATE STORAGE CONDITIONS AND ABBREVIATIONS USED

Condition	Temperature (F/C)	Relative humidity (%)	Abbr.*†
Ambient (storage room)	77.0/23.0	45.4‡	amb
Refrigerator	35.0/1.7	80.8‡	ref
Freezer	−17.0/−27.2	40.9‡	fre
Temperature fluctuations	86.0 ± 3/30.0 ± 1.7	77.0‡	86F
High temperature	90.0/32.2	44.1‡	90F
High relative humidity 1	77.0/23.0	84.3§	84%
High relative humidity 2	77.0/23.0	93.6§	94%

* Unstored chocolate is labeled as "ini."
† Milk chocolate abbreviations begin with "m" and dark chocolate begin with "d."
‡ Values were obtained using a Thermohygrometer Humidity Measuring Stick (Cole-Parmer Instrument Co., Vernon Hills, IL) and may be approximate.
§ Saturated salt solutions were used to attain these relative humidity conditions.

Instrumental Texture Analysis

Sample texture was analyzed with a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) and Texture Expert Software v. 1.11. A 20-mm acrylic cylinder probe (TA-25) was used for the two-bite compression test (25% compression). Test settings were as follows: pretest speed of 2 mm/s, test speed of 5 mm/s, posttest speed of 5 mm/s, 25% deformation, relaxation time of 5 s and force of 20 g. Dimensions of the chocolate bars were 22.5 mm × 25 mm × 10 mm (l × w × h). Sample orientation was kept constant in all texture analyzer tests. Parameters measured included hardness, cohesiveness, adhesiveness, springiness, gumminess and chewiness.

Sensory Analysis

Twelve panelists (three males and nine females, aged 18–37 years) were trained for 3 weeks in the technique of descriptive analysis. Panelists were trained to analyze chocolate appearance and texture using 15-cm line scales with word anchors, as well as time–intensity (T–I) measurements for melting time. All panelists were required to sign an informed consent document, as required by the Institutional Review Board of the University of Illinois. Judges were also asked to complete a short questionnaire containing contact information, gender and age information, chocolate consumption and preferences, and questions which may restrict the panelist, such as strict diet and/or health problems they may have. Terms (attributes), references and rinsing protocols were determined by panel consensus. Appearance terms included: dull/shiny, homogeneous/mottling, white/dark and wetness. Texture attributes included: hardness, chewiness, cohesiveness, toothpacking and fatty mouthcoating.

Panelists analyzed all samples in duplicate, tasting eight samples/session. Compusense Five 4.2 software (Compusense Inc., Ontario, Canada) was used for data collection. Appearance was evaluated under incandescent light and ambient temperature and RH, while texture was assessed monadically under black lighting and ambient temperature and RH. T–I measurements of chocolate melting were analyzed by placing 1/8 of the sample between the tongue and roof of the mouth and rating over 4 min or until the sample was completely melted.

Statistical Analysis

Analysis of variance (ANOVA) and Fisher's least significant difference for each significant attribute were performed on Statistical Analysis Software v. 8.02 (SAS Institute Inc., Cary, NC). Mean ratings of significant attributes ($P < 0.05$) were further analyzed using correlation matrices for principal component analysis (PCA) in SAS to visualize the relationship between the significant attributes and the chocolate samples evaluated. Partial least squares (PLS) regression analysis was conducted using the Unscrambler software (CAMO Technologies Inc., Woodbridge, NJ) to relate the instrumental and sensory data matrices. PLS is a technique combining features from principle component analysis and multiple linear regression where one would predict or analyze a set of dependent (response) variables from a set of predictors (Abdi 2007). In this PLS analysis, sensory attributes served as the response variables (Y) and instrumental measurements serve as the predictor variables (X). PLS2 was used to correlate all statistically significant instrumental measurements and sensory attributes, while relationships between instrumental texture data and a single sensory attribute were evaluated by PLS1.

RESULTS

Storage of dark and milk chocolate in various conditions for 5 weeks resulted in decreased visual and textural quality of chocolate caused by formation of either sugar or fat bloom. Chocolate stored at high temperatures, especially at 86F (30C), were the most visually compromised due to fat bloom formation. Chocolate stored at 35F (1.7C) and at −17F (−27C) contained small amounts of sugar bloom. Samples stored at 94% RH were very wet due to condensation on the surface of the chocolate, not allowing sugar bloom formation.

Instrumental Texture Results

Significant treatment effects ($P < 0.05$), as noted by instrumental texture analysis, were hardness, cohesiveness, adhesiveness, gumminess and

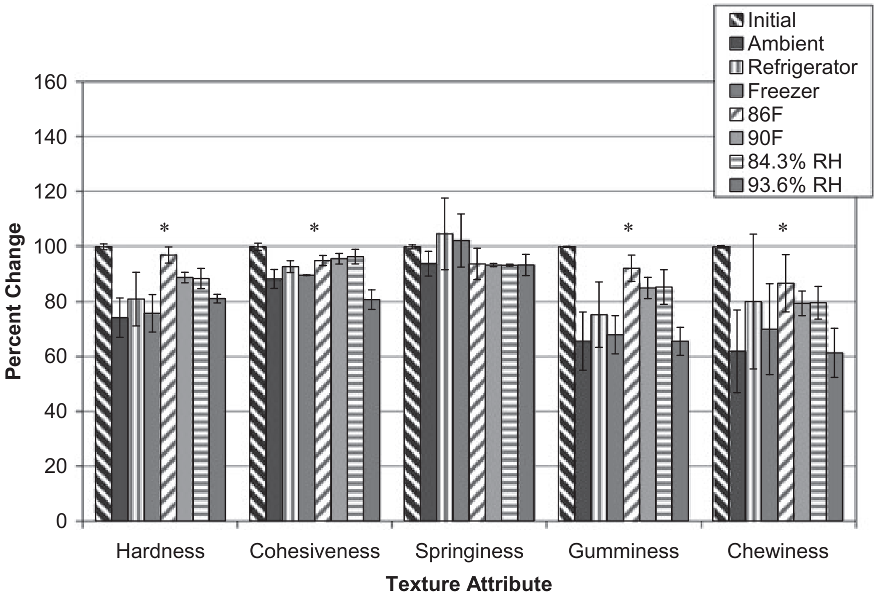

FIG. 1. INSTRUMENTAL TEXTURE ANALYZER RESULTS FOR DARK CHOCOLATE (±STANDARD ERROR OF THE MEAN)
*Texture attributes were significantly impacted by storage ($P \leq 0.05$). RH, relative humidity.

chewiness (Figs. 1 and 2). Replications were not a source of error in any attributes tested. Storage of dark chocolate in ambient conditions, refrigerator, freezer and 94% RH caused decreases in hardness, cohesiveness, gumminess and chewiness, while storage of milk chocolate in the same conditions caused increases in the same attributes. Adhesiveness was extremely variable, especially for dark chocolate (data not shown).

Sensory Results

Table 2 shows the ANOVA results for all statistically significant sensory attributes ($P < 0.05$). Judges were a significant source of variation in all 10 attributes. This is typical of descriptive analysis panels, where the judges could either not be using the entire scale or they may be using different parts of the scale to rate samples. Significant sources of variation came from storage conditions of the chocolate (treatment) and type of chocolate (dark or milk chocolate). Chocolate storage condition (treatment) caused a significant variation in all attributes, while chocolate type was not significant in appearance of mottling or wetness. Replications were not significant for any attributes evalu-

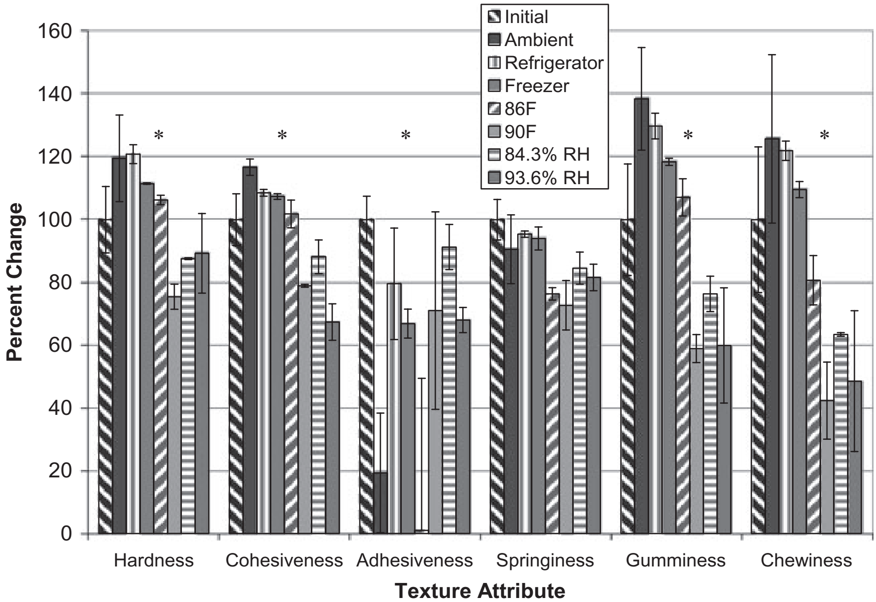

FIG. 2. INSTRUMENTAL TEXTURE ANALYZER RESULTS FOR MILK CHOCOLATE (±STANDARD ERROR OF THE MEAN)
*Texture attributes were significantly impacted by storage ($P \leq 0.05$). RH, relative humidity.

ated, signifying that the panel was reproducible. Judge by treatment interactions were significant for shiny, mottling, wet, hardness and chewiness, indicating that the panelists did not agree on the order of intensities for these attributes across the chocolate samples. Interactions of judge by replication were also significant for hardness, cohesiveness, toothpacking and melting terms, signifying that panelists did not rate samples in the same order upon replications for these attributes.

All significant attributes assessed by the panel, including T–I measurements, were evaluated by PCA using a correlation matrix as depicted in Fig. 3. Overall, samples were separated into three distinct groups, by chocolate type (dark and milk) and samples stored in 30.0C, labeled “Fat Bloom Group.” According to the PCA plot, dark chocolate was darker in color and shinier in appearance than milk chocolate. Dark chocolate was also harder and chewier in texture, more toothpacking and melted much slower than milk chocolate, while milk chocolate was much more cohesive and had more of a fatty mouthcoating than dark chocolate. Dark chocolate stored at 30.0 and 32.2C were the hardest and melted the slowest, while all samples stored at 30.0C were the most mottled due to severe fat bloom formation. Milk and dark

TABLE 2.
ANALYSIS OF VARIANCE ON SENSORY ATTRIBUTES RATED FOR CHOCOLATE SAMPLES†‡

Modality/attribute	Judge (J)	Treat (T)	DM§	Rep	J × T	J × R	J × DM	T × R
Appearance								
Shiny	8.65***	98.92***	159.48***	3.55	1.95***	1.02	5.68***	1.96
Mottling	3.87***	1,201.81***	0.48	1.87	2.16***	0.88	1.08	0.19
Dark	4.89***	4.81***	381.94***	0.42	0.66	0.47	2.72**	4.74***
Wet	4.58***	349.44***	2.90	2.73	4.59***	0.59	1.21	3.03**
Texture								
Hardness	6.78***	26.63***	568.28***	2.68	1.46*	3.07***	2.63**	1.38
Cohesiveness	18.71***	44.51***	93.60***	2.36	1.26	2.05*	2.67**	1.34
Chewiness	33.53***	15.85***	19.81***	0.40	1.58**	1.64	16.76***	2.19*
Fatty mouthcoating	50.19***	4.64***	567.17***	0.12	1.19	1.79	14.34***	1.10
Toothpacking	19.74***	2.44*	8.00**	0.11	1.22	2.40**	2.28*	1.02
Melting	38.92***	44.63***	353.99***	0.96	1.09	5.47***	3.29***	0.54

† *F* ratios used for source of variation.
‡ *, **, *** significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.
§ DM = variance represented by type of chocolate (Dark or Milk).

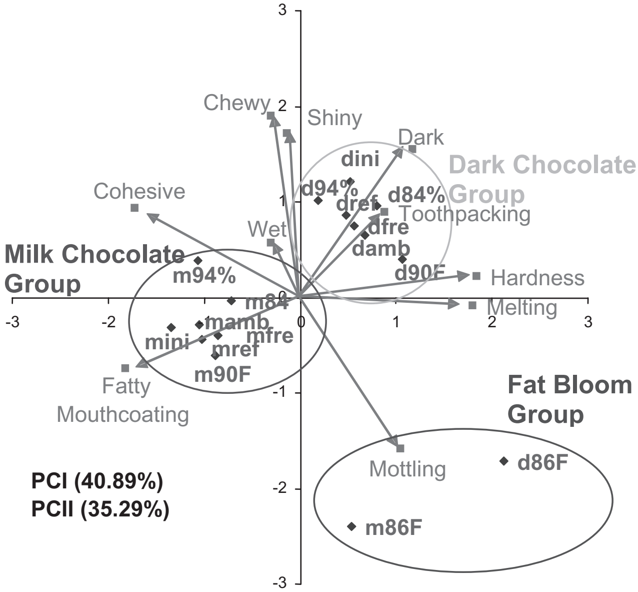

FIG. 3. PRINCIPAL COMPONENT ANALYSIS (PCA) PLOT OF SENSORY DATA

chocolate stored at 94% RH were wetter and shinier in appearance, and more cohesive and chewy than any other sample treatment. Dark chocolate stored in ambient, refrigerated, frozen and 84% RH conditions was harder and more toothpacking than dark chocolate that had not been stored (initial). The panel concluded that milk chocolate stored in ambient conditions, refrigerator, freezer, 32.2C and without storage (mini) had much more fatty mouthcoating than the remainder of the samples.

Instrumental and Sensory Correlation

Correlation of instrumental texture analysis with sensory data was evaluated by correlation analysis and PCA on the correlation matrix, while PLS was also conducted to relate instrumental texture results to all sensory data, dark chocolate sensory data and milk chocolate sensory data. The highest positive correlation between sensory and instrumental data found was between sensory hardness and instrumental cohesiveness, chewiness and gumminess ($r = 0.76$, $P < 0.001$) (Table 3). Sensory cohesiveness and instrumental adhesiveness had the highest negative correlation ($r = -0.63$, $P < 0.001$). Hardness was the only sensory measurement that was highly correlated ($P < 0.001$) with instrumental data. Sensory cohesiveness and fatty mouthcoating were significantly

TABLE 3.
CORRELATION MATRIX BETWEEN SENSORY AND INSTRUMENTAL TEXTURE DATA†

	Hardness‡	Cohesive‡	Adhesive‡	Springy‡	Gummy‡	Chewy‡	Shiny§	Mottling§	Dark§	Wetness§	Hardness§	Cohesive§	Chewy§	FattyMC§,¶	Toothpk§	Melting§
Hardness‡	1.00															
Cohesive‡	0.88***	1.00														
Adhesive‡	0.69***	0.55**	1.00													
Springy‡	0.57***	0.69***	–0.07	1.00												
Gummy‡	0.98***	0.96***	0.67***	0.63***	1.00											
Chewy‡	0.95***	0.95***	0.54**	0.76***	0.98***	1.00										
Shiny§	0.11	0.33	–0.22	0.66***	0.22	0.36**	1.00									
Mottling§	0.26	0.12	0.50**	–0.24	0.20	0.09	–0.74***	1.00								
Dark§	0.41*	0.49**	0.12	0.59***	0.45*	0.52**	0.64***	–0.25	1.00							
Wetness§	–0.30	–0.59***	–0.34	–0.33	–0.45*	–0.46**	–0.28	–0.04	0.00	1.00						
Hardness§	0.73***	0.76***	0.58***	0.52**	0.76***	0.76***	0.19	0.38*	0.68***	–0.37*	1.00					
Cohesive§	–0.53**	–0.55**	–0.63***	–0.11	–0.54**	–0.46**	0.34	–0.77***	–0.28	0.31	–0.80***	1.00				
Chewy§	–0.01	–0.02	–0.31	0.32	0.00	0.10	0.71***	–0.81***	0.56**	0.25	–0.08	0.58***	1.00			
FattyMC§,¶	–0.58***	–0.56***	–0.40*	–0.50**	–0.60***	–0.62***	–0.27	–0.23	–0.82***	0.17	–0.90***	0.65***	–0.17	1.00		
Toothpk§,††	0.11	–0.13	0.17	–0.04	0.01	0.00	0.04	–0.03	0.42*	0.43*	0.11	–0.05	0.36*	–0.44*	1.00	
Melting§	0.56**	0.38*	0.65***	0.07	0.50**	0.44*	–0.25	0.48**	0.44*	–0.04	0.71***	–0.73***	–0.11	–0.76***	0.52**	1.00

† *, **, *** significant at $P \le 0.05$, $P \le 0.01$ and $P \le 0.001$, respectively.
‡ Instrumental texture measurements.
§ Sensory attributes assessed.
¶ FattyMC = Fatty mouthcoating.
†† Toothpk = Toothpacking.

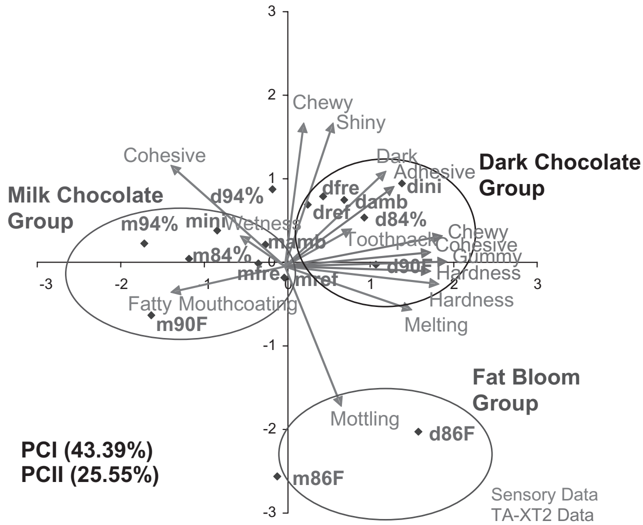

FIG. 4. PRINCIPAL COMPONENT ANALYSIS (PCA) PLOT OF SENSORY AND INSTRUMENTAL TEXTURE DATA

negatively correlated ($P < 0.05$) with texture analyzer results. T–I measures for melting time and light/dark appearance significantly correlated ($P < 0.05$) with all instrumental data, except springiness. Melting time was also highly correlated with instrumental hardness ($r = 0.56$, $P < 0.01$) and sensory hardness ($r = 0.71$, $P < 0.001$). Toothpacking was significantly negatively correlated with T–I measures of melting time ($r = -0.76$, $P < 0.001$). Fatty mouthcoating was significantly negatively correlated with sensory hardness ($r = -0.90$, $P < 0.001$) and melting time ($r = -0.76$, $P < 0.001$).

PCA biplot of instrumental and sensory data are illustrated in Fig. 4. The first two principal components accounted for 43.39 and 25.55% of the variance, respectively. Principal component 1 (PC1) was mostly loaded by hardness (sensory [S]), fatty mouthcoating (S), melting (S), hardness (texture analyzer [TA]), cohesiveness (TA), gumminess (TA) and chewiness (TA). Shiny (S), mottling (S), dark (S) and chewiness (S) explained PC2, while cohesiveness (S) and adhesiveness (TA) partially explained both components due to high factor loadings in each. Similar to the panel results stated earlier, dark chocolate was darker in appearance, harder and more toothpacking in texture, and had a higher melting time than milk chocolate. Milk chocolate was more cohesive and had a fattier mouthcoating than dark chocolate. Both types of chocolate stored at 30.0C were the most mottled. Dark chocolate stored at high temperatures (30.0 and 32.2C) leading to fat bloom were hardest in

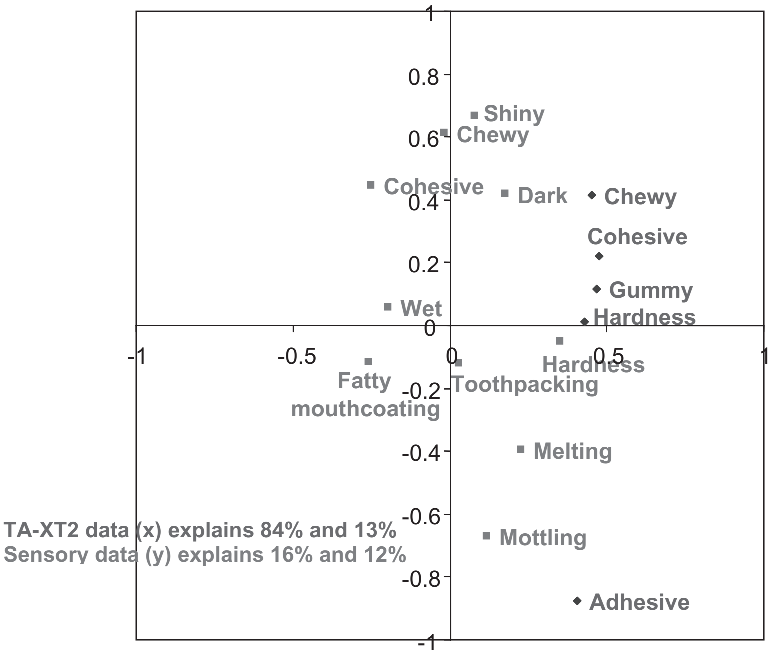

FIG. 5. PLS2 OF SENSORY AND INSTRUMENTAL MEASUREMENTS

texture and took the longest time to melt. According to the PCA biplot (Fig. 4), dark chocolate (d) stored at high RH (d84% and d94%), refrigerator (dref), freezer (dfre), ambient conditions (damb) as well as initial samples without storage (dini) were darker in color (S), shinier (S), chewier (S), more toothpacking (S) and more adhesive (TA).

PLS regression analysis, and more specifically, PLS2 for multivariate analysis, is commonly used to evaluate relationships between sensory and instrumental matrices (Hough *et al.* 1996; Lee and Noble 2006; Liggett *et al.* 2008). Figure 5 contains PLS2 results for instrumental (*x* variable) versus sensory measurements (*y* variable). Nearly 97% of instrumental data were explained by the first two factors, while only 28% of sensory data were explained by the same components. PLS1 was used to determine relationships between instrumental data and a single sensory attribute. For all samples, sensory hardness was the only texture attribute explained by instrumental data. When samples were separated into chocolate type, the explanation of sensory attributes by instrumental measurements increased for sensory hardness and melting attributes.

DISCUSSION

Texture is a combination of the physical structure of the material and its mechanical and surface properties, also known as mouthfeel (Szczesniak 1963). Mechanical characteristics are the reaction of food to stress as measured by kinesthetics. Primary characteristics include hardness, cohesiveness, viscosity, springiness and adhesiveness, while secondary parameters consist of fracturability, chewiness and gumminess. According to Dobraszczyk and Vincent (1999), texture parameters such as chewiness, cohesiveness and gumminess are complex processes to analyze sensorially, involving the tongue, teeth, cheeks, saliva and food matrix. These multifaceted attributes are even more difficult to determine and interpret by instrumental measures. One major downfall of the texture analyzer is the inability to discriminate between samples, possibly because the calculation of hardness, cohesiveness, springiness, gumminess and chewiness are all interrelated. Adhesiveness was the only attribute calculated separately, as the negative area of the first bite, although the texture analyzer was extremely variable for this attribute.

Previous instrumental texture research by Tscheuschner and Markov (1986a,b, 1989) determined that melting time, compression and shear strength of milk chocolate was less than plain (dark) chocolate due to more milk fat. Correlating these results to sensory measures determined that sensory "bite firmness" linearly correlated with instrumental "compression strength." Overall, our panel results determined that dark chocolate was harder, chewier, more toothpacking and melted slower than milk chocolate, while milk chocolate was more cohesive and left more fatty mouthcoating behind, as compared with dark chocolate. Markov and Tscheuschner (1989) also determined that dark chocolate had greater bite firmness and slower melting rate than milk chocolate.

Chocolate stored at 30.0C contained much more fat bloom than samples stored at 32.2C. It was later determined that the 30.0C water bath fluctuated ±1.7C in temperature, while the 32.2C water bath was constant. All samples stored at high temperature (30.0 and 32.2C) were hardest in texture and melted the slowest. Recent studies have confirmed an increase in instrumental hardness with fat bloom formation (Afoakwa *et al.* 2008; Afoakwa *et al.* 2009). Full *et al.* (1996) determined that a strong positive correlation exists between instrumental hardness and solid fat content (SFC) of chocolate at 20C. SFC of a food product is greatly dependent upon temperature and thermal history (Saggin and Coupland 2002) and influences sensory characteristics such as hardness, mouthfeel and spreadability. Chocolate stored at high temperatures may have experienced slight melting of the chocolate, increasing phase separation of the solid and liquid fat, causing the liquid triglycerides to seep to the outer surface of the chocolate. At high temperatures, molecular mobility also increases, further facilitating liquid migration to the surface. Upon removal of chocolate from high temperatures to ambient conditions, the liquid fat on the surface quickly solidified, thus increasing the SFC of the chocolate. Ambient conditions, frozen conditions and the 90 incubator were kept at nearly the same RH (40.9–45.4%), so conclusions may be drawn on temperature effects associated with quality changes in chocolate during storage. For both types of chocolate, temperature fluctuations associated with incubation at high temperature caused the greatest changes, including an increase in mottled appearance, sensory hardness and melting time. These changes are associated with bloom formation as stated previously and an increase in SFC.

Generally, storage of chocolate at RH higher than 50–55% should cause sugar bloom due to deposition of water on the surface and evaporation, leaving behind gritty sugar on the chocolate surface. Milk and dark chocolate stored at 94% RH were wetter, more cohesive and chewier than any other treatment. Sugar bloom did not form at 94% RH because the humidity was so high that condensation on the chocolate was not allowed to evaporate, leaving behind sugar to recrystalize. When stored at high RH, chocolate texture was affected, most notably cohesiveness and chewiness. Storage at 94% RH increased the cohesive texture of both dark and milk chocolate. Wodecki *et al.* (1984) determined that the moisture content of cheese significantly impacted hardness. Because chocolate samples stored at ambient conditions and at high RH (84% and 94%) were kept at the same temperature (23.0C), conclusions may be drawn on the effect of RH on quality changes in chocolate. As RH increased, sensory chewiness increased and toothpacking decreased for dark chocolate. As RH increased for milk chocolate, wet appearance and sensory cohesiveness increased, while fatty mouthcoating decreased. These results are expected because as chocolate absorbs more water from the atmosphere, it would most likely become more cohesive. Fatty mouthcoating may have decreased due to the inclusion of water into the chocolate matrix, therefore lessening the impact of a fatty aftertaste.

Sensory data (except T–I data) analyzed by cluster analysis (data not shown) resulted in the separation of chocolate samples by chocolate type (dark and milk) and storage at high RH (94%) and high temperature with fluctuations (30.0C). Temperature fluctuation was the most important factor causing quality changes in chocolate. Temperature fluctuations amplify the rate of fat bloom formation by constantly melting and recrystalizing lipids during temperature cycling. As fat recrystalizes upon cooling, the remaining liquid fat is “pumped” to the outer surface, where it finally recrystalizes. Temperature cycling is often used in research to quickly form fat bloom and determine bloom stability (Bolliger *et al.* 1998; Bricknell and Hartel 1998; Lonchampt and Hartel 2004; Briones and Aguilera 2005; Altimiras *et al.* 2007).

Full *et al.* (1996) determined that instrumental and sensory hardness of milk chocolate decreased with an increase in milk fat. Similar effects were noted in the current study between dark and milk chocolate, where milk chocolate, containing at least 12% milk solids (according to the FDA Standards of Identity, 21 Code of Federal Regulations 2003), was softer, more cohesive, chewier and had a fattier mouthcoating. As mentioned previously, dark chocolate stored at 94% RH had similar textural changes to milk chocolate, possibly due to increased liquid components. According to the correlation analysis (Table 3), fatty mouthcoating was negatively correlated with sensory hardness, melting time and cohesiveness. T–I measurements of melting time were positively correlated with instrumental hardness, mottling and dark color. These are logical results because as hardness increases, melting time would also increase. Mottling due to fat bloom also increases hardness and melting time attributable to the higher SFC. Similarly, dark chocolate correlated well with dark color, hardness and melting time. Milk solid content was strongly associated with the perception of fatty mouthcoating, as seen by the correlation of milk chocolate with fatty mouthcoating, while dark chocolate was associated with hardness and increased melting time. Guinard and Mazzucchelli (1999) also found similar results relating milk solid content to mouthcoating perception.

Instrumental and sensory results indicated that sensory hardness was significantly correlated with instrumental hardness, cohesiveness, gumminess and chewiness. Positive linear correlations between instrumental and sensory hardness have been found in milk chocolate with varying formulations (Full *et al.* 1996; Guinard and Mazzucchelli 1999), bread (Gambaro *et al.* 2002), cheese (Hough *et al.* 1996) and tomatoes (Lee *et al.* 1999). Gambaro *et al.* (2002) also determined that instrumental and sensory cohesiveness of bread correlated well, while chewiness was negatively correlated. In this study, instrumental and sensory cohesiveness were negatively correlated, possibly due to inadequate discrimination of chocolate samples by the TA-XT2 Texture Analyzer. Chewiness by both measures was not correlated. Sensory chewiness was orthogonal to hardness. Similar results were found by Lee *et al.* (1999).

Analysis by PLS2 of all significant attributes indicated that sensory hardness was explained by instrumental hardness, gumminess, cohesiveness and chewiness. Results were similar to correlation analysis and PCA data, although melting time was not explained. Sensory hardness may also be explained by sensory toothpacking and melting time. According to the PLS1 biplot, 53% of sensory hardness was explained by instrumental cohesiveness, adhesiveness and chewiness.

Based on this research, sensory hardness best correlated with instrumental measurements. High temperature storage, especially with fluctuations and fat bloom formation, significantly increased hardness and melting time.

Chocolate storage at high RH increased sensory chewiness and cohesiveness. Overall, sensory attributes of dark chocolate were explained better by instrumental data, as compared with milk chocolate.

Much of this research seems as if it is not new findings, but the majority of chocolate research has been conducted "in-house" and has not been published. The current study is the first published attempt to correlate sensory and instrumental texture analysis of stored chocolate. Because similar research has not been published, the authors used this study as preliminary research to determine if storage conditions significantly impacted chocolate texture before expanding into more complicated analyses. Therefore, this research shows for the first time that chocolate texture is greatly impacted by storage condition and that the TA-XT2 Texture Analyzer, a very common research tool, did not discriminate stored chocolate samples well. Future research is planned to broaden the spectrum of nondestructive instrumental methods for both texture and flavor analysis. If quality parameters are to be established for specific storage conditions, a consumer panel must also be conducted in the future. Overall, the current research is a great beginning to use the findings to build upon for future research.

ACKNOWLEDGMENTS

We thank Dr. Shelly Schmidt for use of the texture analyzer. The financial support provided by the College of Agricultural, Consumer and Environmental Sciences at the University of Illinois is greatly appreciated.

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