Pecan Texture as Affected by Freezing Rates, Storage Temperature, and Thawing Rates

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ABSTRACT

Pecan texture was measured by texture profile analysis (TPA) at 80% compression before and after being frozen at 6 controlled rates, to 3 minimum temperatures and thawed at 2 rates. Freezing and thawing rates had more influence than storage temperature on pecan texture. Certain TPA parameters (i.e., hardness, area 1, fracturability and slope of linear segment of force vs. deformation curve) were more affected than others by freezing and thawing rates. Freezing and thawing at high rates had the least effect on pecan texture.

Key Words: pecans, texture, freezing, thawing, texture profile

INTRODUCTION

PECANS, LIKE OTHER HIGH-OIL NUTS, DETRIMENTAL IN QUALITY IF STORED AT OR ABOVE ROOM TEMPERATURE (~23°C). Shelled pecans held at temperatures above 20°C decrease in flavor within a few months and are likely to become unacceptable in 6–8 mo (Woodroof and Heaton, 1953). However, pecans stored at ~15°C will retain full flavor for 2 yr or longer. Considerable information has been published about the effects of freezing on the quality of many foods, especially vegetables. However, there is no reported research on texture changes of high-oil, nut products like pecans although most commercial operations utilize frozen storage. The industry has assumed that frozen storage of pecans maintains texture as well as flavor. That assumption has become questionable as instruments and techniques have become available to more precisely measure texture.

Many changes occur in texture during freezing, storage and thawing of frozen foods (Jansen, 1969). During freezing, three separate phases of heat transfer and temperature change occur (Joslyn, 1966). Temperature of product is reduced to the initial freezing point (just below 0°C) where ice formation begins. In the second phase, temperature changes only slightly as heat removal is offset by the exothermic transition from liquid water to ice. The duration of the second phase is a function of the amount of water in the sample and the rate of heat removal (hence storage chamber temperature). Minimizing the time of the second phase contributes to optimum product quality, including texture (Brennan et al., 1990). The third phase occurs as the frozen sample equilibrates with the chamber temperature. The cell walls of plant tissue appear to withstand the pressure of expanding ice (~9% volume increase for pure water at 0°C) and therefore changes in texture during freezing cannot be attributed to rupture and breakage of cells (Gutschmidt, 1968). Changes in the protoplasm may be caused by high pressure and in those plant cells containing large vacuoles, rapid cell deformation and cell wall breakage may occur during thawing.

The histological effects on freezing of fruits and vegetables were reviewed by Morris (1968) who described ice formation at, and below, 0°C. Ice crystallization can occur during cooling or thawing. The degree of crystallization can be reduced by minimizing the time held at the crystallization temperature range. Also, materials of lower water content are less likely to exhibit crystal formation.

Faster freezing has generally produced higher quality products. Certain products may crack or shatter if the freezing rate is too high, but these rates are usually above most commercially used methods (Erickson and Hung, 1997). Hung and Kim (1996) developed heat transfer and stress models to identify treatments to prevent freeze cracking. The objective of our study was to determine the effects of freezing rate, storage temperature and thawing rate on pecan texture.

MATERIALS & METHODS

PECANS (C.V. WESTERN SCHLEY) HARVEST 1997, never previously frozen, were used. A box was designed and constructed, with space for 6 layers of pecans (each 10–15 mm thick) separated by cardboard (2 layers, 0.8-mm thick each) or rigid styrofoam insulation (6.3, 12.7 and 76.2 mm thick). The pecans were placed in a 6.4-mm thick plywood inner box surrounded with 140-mm thick foam-in-place insulation, which was contained in an outer box of 6.4-mm thick plywood. Insulation at the ends of the layers minimized heat transfer from the “ends” so it was primarily one dimensional through the layers.

Polyethylene bags containing ~100g of pecans were placed in the layers of the box, 2 packages/layer. For each layer, 2 thermocouples were placed, 1 taped to the bottom of the layer and 1 glued into a 12-mm dia wood dowel to simulate a pecan piece. The arrangement was put into the low-temperature cabinet (14 m³ freezer model ST-50T20-45 Sure Temp®, Raleigh, NC) set at the desired temperature, and sample temperature was recorded every 5 min for 24–48h. After cooling, the box was taken out of the low-temperature cabinet and 1 bag was removed from each compartment to thaw at room temperature (~23°C) for 6h. The other bags were placed in a refrigerator at 5°C for 24h and then moved to room temperature for 4h before texture measurements. A full factorial design was applied, with 3 variables: 3 storage-temperatures (~−20, −13, −5°C); 6 freezing-rates (corresponding to 6 layers in the box); and 2 thawing-temperatures (20 and 5°C).

Texture measurement

Texture Profile Analysis (TPA) (Bourne, 1982) was carried out with an Instron Universal Testing Machine (Model 1122) with a 490N compression load cell by compressing cylindrical samples. Cylinders (3 mm dia, 5 mm long) were taken from the pecan pieces using a cork borer (Shultz and Brusewitz, 1998) and cut to the desired length using a sharp blade. Readings were obtained using 80% compression and a 10 mm min⁻¹ crosshead speed (Ocón et al., 1995), using 12 replicates/treatment. The degree of compression was selected, based on preliminary experiments where a need to increase the degree of compression was detected (Anzaldúa-Mo-
races et al., 1998). Standard TPA parameters were read (Bourne, 1982): hardness, first compression energy, second compression energy, chewiness, cohesiveness, resilience, hardness/fracturability ratio, slope of linear segment of first curve, springiness and fractureability.

Statistical methods
Analysis of variance and Tukey’s test, as well as regression analysis, were applied using the program Systat 5.0 (Wilkinson, 1989). Significance of differences was defined at p<0.05.

RESULTS & DISCUSSION
PECANS COOLED EXPONENTIALLY AS EXPECTED except for bottom layer #1 which cooled slightly faster than layer 2 in the −20°C cabinet. The bottom layer lost heat through the bottom insulation faster than up through the other five layers of pecans and insulation layers. In the other two cabinets, 76.2 mm of insulation was added beneath the box to reduce heat flow in that direction. A point on the cooling curve, 0°C, was selected for comparison purposes rather than layer number since cooling rate was also a function of cabinet temperature. The times, by layer, for the pecans to reach 0°C starting from an initial 22°C were: 50, 160, 240, 300, 360 and 320 min in the −20°C cabinet; 110, 250, 315, 375, 420 and 435 min in the −13°C cabinet; and 210, 390, 470, 550, 600 and 630 min in the −5°C cabinet.

Freezing rate highly affected pecan hardness (p<0.0001). The other two variables did not have significant effects but the interaction cabinet temperature*thawing rate was significant (p<0.002). This indicated that these variables influenced hardness, but it could not be detected due to variability of the readings. The two lowest freezing rates differed from the 4 faster freezing rates. Apparently, pecans frozen at −20 and −13°C were 60% harder than those frozen at −5°C (Fig. 1). After faster thawing (20°C) more pecans were softer than the control (never frozen pecans, 19.1N) whereas almost all slow thawed samples (5°C) were harder than the controls. At lower freezing rates, hardness of the pecans increased. The hardest samples were observed in pecans frozen at −5°C at the lowest rates. Thus, the increase in ice crystal growth within the tissues, promoted by slow freezing, caused hardening.

The energy for first compression (Area 1) was affected by freezing rate (p<0.002). The lowest freezing rate produced Area 1 values higher than faster rates (Table 1). Trends were very similar to those observed for hardness, although the influence of thawing rate was less marked (Table 2). Most energy readings were higher than for never frozen pecans (38.9 mJ). The effect of freezing rate (higher energy for slower freezing) was more evident when the pecans thawed quickly.

Energy for second compression (Area 2) was affected by thawing rate (p<0.02). The interactions freezing temperature*freezing rate and freezing temperature*thawing temperature were highly significant (p<0.009 and p<0.0001, respectively). This indicated that freezing temperature and rate had some effect, but it did not appear in the analysis due to variability of data. This response is a common problem with TPA, since a minute difference in diameter or length of samples (which occurs frequently due to the very small samples) results in a large deviation in the TPA parameters (Bourne, 1982). This sensitivity is why cubes or cylinders of about 10×10×10 mm or 10-mm dia and 10 mm long are usually employed. However, such dimensions were not possible in the case of pecans.

Apparently, the trends for area 2 were similar to hardness and Area 1, although less marked, and the pecans seemed to be more affected by rapid thawing (20°C). Most values of area 2 were lower than the value for the control (2.53 mJ). This may mean either that freezing rendered pecans that could be chewed more easily or that freezing affected the integrity of pecans, so they recovered less after the first compression than unfrozen pecans. We considered the shape of the curves, parameters such as slope of the linear part of the force vs. deformation curve (Mohsenin, 1970), and fracturability/hardness ratio. Freezing, especially at very high rates, may promote internal cracking, which would result in narrower curves with a very steep linear segment.

Freezing temperature and rate strongly influenced resilience (p<0.001 and p<0.0001, respectively). The interactions freezing temperature*freezing rate, freezing temperature*thawing rate, and freezing temperature*freezing rate*thawing rate were highly significant (p<0.002, p<0.0001 and p<0.009, respectively). In general, freezing at −20 or −13°C made no difference in resilience, but those pecans differed in resilience from others frozen at −5°C. Almost all readings were lower than the control (p<0.02), indicating that freezing lowered the resilience of the samples. Slow freezing was different from fast freezing. Pecans thawed at 5°C had resilience values closer to those of the control, i.e. they were less affected by freezing-thawing. This parameter had a high coefficient of variability (CV). Its C.V. was 50.5%, whereas hardness and Area 1 had less variability (C.V. 34 and 21.7%, respectively). There are few reports of the use of resilience in TPA. It is related to instant springiness, since resilience is measured on the withdrawal of the first compression, before starting the waiting period (Texture Technologies, 1997). Resilience is calculated as the area during the withdrawal after the first compression, divided by the area of the first compression. (Area 4/Area 1, Fig. 2). Resilience has not always been reported in TPA testing. We modified our data acquisition program to obtain resilience values.

Chewiness did not show any significant effects for any of the main variables. The only significant effects were interactions of freezing temperature*freezing rate and freezing temperature*thawing temperature. Since its variability was high (C.V. 54%), this may

Fig. 1—Effect of freezing rates on TPA hardness of pecans.

Fig. 2—Typical TPA force vs. deformation curve showing areas considered for the calculation of resilience.
have had some influence on the ability to detect differences among means.

Cohesiveness was affected by freezing rate (p<0.016) and thawing temperature (p<0.05), as well as by the interactions freezing temperature*freezing rate and freezing temperature*thawing temperature (p<0.001 and p<0.0001, respectively). Most cohesiveness values for all treatments were lower than the value for unfrozen pecans (0.059). This again suggested a loss of compactness, maybe due to cracks and other internal failures (empty pockets, porous structure, etc.). Thawing rate influenced cohesiveness. Pecans frozen at −20°C, thawed slowly, retained cohesiveness values close to the controls but, when thawed rapidly, there was a drop in cohesiveness of about 50%.

The fracturability/hardness ratio had too much variability (C.V. 150%) to show any significant differences. The slope of the initial linear segment of the force vs deformation curve had more uniformity. It was affected by freezing temperature, thawing temperature and the interaction freezing temperature*freezing rate (p<0.0001, p<0.0001 and p<0.042, respectively). The slope of the linear segment decreased with decreasing freezer temperature, with differences between the 3 cabinet temperatures. There was no effect due to freezing rate, except for the lowest freezing rate where slope increased by almost 100%. Decreased slope is usually the result of a decrease in jaggedness of the TPA curve, which indicates less fracturability or crispiness. Pecans thawed slowly had slopes higher than the controls, whereas rapidly thawed samples were closer in slope to unfrozen pecans.

Springiness was influenced by freezing temperature and rate, as well as by their interaction. Pecans frozen at −13°C differed from those frozen at −5°C, and both were different from pecans frozen at −20°C. Slower freezing produced less springiness than faster freezing. Apparently, springiness decreased as freezing temperature and thawing rate decreased. All frozen samples, with one exception (−13°C cabinet, fast thawing), had less springiness than the control (1.18 mm). Thawing temperature did not affect the values, which ranged between 0.6 and 1.3 mm. There are no reported springiness values for pecans for comparison.

Freezing rate and thawing temperature affected fracturability (p<0.02 and p<0.01, respectively). When pecans were thawed slowly, fracturability values were high and most were above the value for controls (1.12 N). Fracturability may be considered a positive attribute of pecans since it is related to crispiness. However, it may also indicate loss of cohesiveness and integrity of the food, and
thus brittle and crumbly pecans.

Regression analysis was performed to fit the data to the following mathematical model:

\[ Y = a_0 + a_1 T_f + a_2 L + a_3 T_t \]  (1)

where: \( Y \) is the response variable; \( a_0, a_1, a_2 \) and \( a_3 \) are the regression coefficients; \( T_f \) = cabinet temperature, °C; \( L \) = layer number (1 through 6); and \( T_t \) = thawing temperature, °C. The regression coefficients for Eq (1) were determined (Table 3). Area 2 and chewiness did not fit the linear model. The other parameters fit the linear model very well but freezer temperature, cooling rate and thawing rate did not contribute substantially to the variability in resilience, cohesiveness, or springiness. TPA parameters which had greater magnitude \( a_1, a_2 \) and \( a_3 \) coefficients were more affected by the freezing/thawing variables. Slope was the most affected by cabinet temperature. Fracturability/hardness ratio was most influenced by freezing rate and thawing temperature. The TPA parameters that best represent texture and had more consistent patterns were hardness, Area 1, slope, fracturability, and fracturability/hardness ratio. The TPA parameters least affected by freezing and thawing rates were: Area 2, chewiness, springiness, cohesiveness and resilience.

### Table 3—Regression coefficients for dependency of TPA parameters (\( Y \)) of frozen pecans on cabinet temperature (\( T_f \)), freezing rate (\( L \), layers) and thawing temperature (\( T_t \))

<table>
<thead>
<tr>
<th>TPA parameter</th>
<th>( a_0 )</th>
<th>( a_1 )</th>
<th>( a_2 )</th>
<th>( a_3 )</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>24.52</td>
<td>0.0006</td>
<td>-0.505</td>
<td>0.002</td>
<td>0.0001</td>
</tr>
<tr>
<td>Area 1</td>
<td>47.38</td>
<td>0.073</td>
<td>-0.447</td>
<td>-0.098</td>
<td>0.001</td>
</tr>
<tr>
<td>Area 2</td>
<td>2.249</td>
<td>0.008</td>
<td>0.010</td>
<td>-0.015</td>
<td>0.095 (NS)</td>
</tr>
<tr>
<td>Resilience</td>
<td>0.013</td>
<td>0</td>
<td>0.001</td>
<td>0</td>
<td>0.0001</td>
</tr>
<tr>
<td>Chewiness</td>
<td>4.891</td>
<td>0.014</td>
<td>-0.045</td>
<td>-0.016</td>
<td>0.357 (NS)</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.049</td>
<td>0</td>
<td>0.001</td>
<td>0</td>
<td>0.015</td>
</tr>
<tr>
<td>Frac/Hard ratio</td>
<td>559.0</td>
<td>-0.017</td>
<td>7.346</td>
<td>-1.560</td>
<td>0.022</td>
</tr>
<tr>
<td>Slope linear part</td>
<td>21.93</td>
<td>0.370</td>
<td>-0.216</td>
<td>-0.157</td>
<td>0.0001</td>
</tr>
<tr>
<td>Springiness</td>
<td>0.903</td>
<td>0.006</td>
<td>0.022</td>
<td>0</td>
<td>0.0001</td>
</tr>
<tr>
<td>Fracturability</td>
<td>12.85</td>
<td>0.020</td>
<td>-0.075</td>
<td>-0.045</td>
<td>0.018</td>
</tr>
</tbody>
</table>

ⁿMathematical model: \( Y = a_0 + a_1 T_f + a_2 L + a_3 T_t \).

Thus, TPA parameters than either freezing or thawing rate. TPA parameters most responsive to changes in freezing and thawing rates were: hardness, Area 1, slope, fracturability, and fracturability/hardness ratio. The TPA parameters least affected by freezing and thawing rates were: Area 2, chewiness, springiness, cohesiveness and resilience.

### REFERENCES


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