Reproducible Texture Analysis of Potato Chips

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ABSTRACT
An Instron punch test with three point support of a potato chip was developed, and factors affecting the results were evaluated. Individual potato chips were fried in palm oil in a forced circulation glass container, and their moisture content and texture were determined. Sample handling parameters contributing most to variability of moisture and texture were the cutting device, and position of the sample within the tuber. For oil temperatures 140 and 180 °C, and two potato specific gravities, moisture and texture changes were studied during frying. Maximum force of break was in the 2-4% moisture region. Individual chips showed highly variable room temperature adsorption/desorption.

Key Words: potato chips, texture, puncture test, frying, maximum force

INTRODUCTION
Several procedures, subjective and objective, have been used to quantify fried potato textures (Warren and Woodman, 1974, Harada and Paulus, 1986, Kozempel et al. 1991, Du Pont et al. 1992, Kulkarmi et al. 1994, McComber et al. 1994, Verlinden et al. 1995). Katz and Labuza (1981) evaluated potato chip texture in two sensory tests: the crispness intensity as crispy or not, and a hedonic study where the texture was expressed as liked or disliked. Crispness intensity and overall hedonic textures were functions of water activity of the chips. Texture is usually quantified by plotting the force required to deform or break samples vs. their deformation (force-deformation curve, Fig. 1A). Different techniques have been used to quantify fried potato texture, making difficult any reliable comparison of results.

Bourne et al. (1966) gave objective measurements of potato chip textures, in terms of resistance to bending. They performed a punch test and measured the initial slope from the force-deformation curve. The maximum force of break varied considerably, and the initial slope was more reproducible. They recommended this variable as a measure of crispness (texture). Katz and Labuza (1981) performed snap and punch tests and found that none of the mechanical analyses of texture produced useful quantitative information. The potato chips did not show a consistently shaped force-deformation curve, which they assumed to be due to irregular shapes, sizes, and curvatures. Simple stress-strain analysis could not be performed, since the fracturing pattern was inconsistent.

Variation of texture results, variability of techniques used, and the processing and handling of potatoes prior to texture measurement are main variables which must be considered in fried potato texture studies. Our objective was to develop an improved procedure to analyze texture of fried potato products giving less variation in analytical results, and to use this method to correlate texture with moisture content.

MATERIALS & METHODS
Raw material
The raw materials for this study were Binjie potatoes from OLW, AB (Sweden), where they were stored at 7 °C at 95% relative humidity. The specific gravity of whole potatoes was measured using solutions of increasing NaCl content from 1.0801 to 1.1260 in increments of 0.005 specific gravity units (Smith 1975). Potatoes of either, 1.0914–1.0954 (LSG), or high specific gravity, 1.1028–1.1068 (HSG), were selected. These densities were representative of 24% TS and 26.3% TS (Mohler and Sulser, 1968).

Sample preparation
After washing and peeling the potatoes, two chips were cut from the center of each potato with two types of electric slicing machines, one “domestic” (Bosch, model EAS65), and the other “industrial” (Berkel, model 800). The nominal thickness of the chips was 1.6 mm. Immediately, the chips were cut with a stamp to provide chips with the same diameter, 30 mm. In preliminary experiments, slices were cut from the bud end to the stem end sequentially.

Frying
Chips were individually fried in palm oil at 185 °C for 120 s (unless otherwise mentioned) in a glass fryer designed in our laboratory. The fryer was designed for frying one vertical chip at a time in

Fig. 1—Texture measurement. (A) Typical force-deformation curve representing results by using the Universal Testing Machine; (B) Support used to measure texture of potato chips.
forced oil flow, and to record the process using a video camera. The heater of the fryer consisted of a thermostat (type N5412T, Waltow Controls, USA), and a cartridge heater of 25A/230V and 6.5 mm diameter (Waltow Controls, USA). The oil was circulated by a 2-paddle stirrer (paddles 4 mm wide and 160 mm long) with a variable speed drive (Type RW10R, IKA Works, INC.) for up to 1000 rpm, but it was usually run at 1000 rpm. Oil temperature was measured by thermocouple in a position 5 mm below the chip edge.

**Moisture content and sorption/desorption**

Moisture content of fried samples was determined by drying samples overnight at 115°C (AOAC, 1980). Moisture was expressed as a percentage of sample total weight. Samples of 5g potato chips fried to either 2% or 8% moisture, were placed for 6 wk at 20°C over saturated salt solutions in evacuated desiccators (Motarjemi, 1988). Salts used were LiCl ($a_w=0.11$), CH$_3$COOK ($a_w=0.23$), and MgCl$_2$ ($a_w=0.33$).

**Texture measurement**

Texture analysis of chips was performed by using an Instron Universal Testing Machine (model 4442, Buckinghamshire, United Kingdom). Punch test was made on the chips, which were mounted over a 3-point-support, where the distance between points was 15 mm, and the punch diameter was 5.3 mm (Fig. 1B). The cross-head speed was 60 mm/min. Maximum breaking force and deformation were measured from the force-deformation curve (Fig 1A), which was recorded using a PC and LabView (for Windows 95) software.

**Results & Discussion**

**Thickness of potato chips**

The cutting process is important for potato texture studies (Smith, 1975). Weight of potato chips before frying was measured as an index of thickness. Chips were cut using the two kinds of slicing machines to the same nominal thickness. The average weight and standard deviation was 1.36g with 4% coefficient of variation with the industrial slicer, and 1.51g with 12% coefficient of variation for chips cut with the domestic slicer. The better reproducibility of the industrial slicer was also reflected in less variation in residual moisture (26% with 66% coefficient of variation), and breaking force results (3% with 5% coefficient of variation), after frying at 185°C for 120s. Slicing machine performance affected considerably the measurement reproducibility, as expected.

**Position of slice within tuber**

We found clear differences in post-frying moisture content of chips made from different positions in the tuber. Chips from the stem end had the highest moisture, up to 10%, vs typically 1.2% for the central slices. These results were not due to differences in initial moisture, which was not different in stem end and central slices. A large variability of texture was found, from 1 to 3.5N breaking force of chips made from bud end to the stem end, respectively. Observed variations showed no correlations with chip moisture before or after frying. Both variation of moisture and texture were attributed to anatomical heterogeneity of the potato tuber. It is known that starch content varies in the vascular and the stem area of potato tubers (Talburt et al., 1975). Higher texture variability within the tuber has been noted for cooked potatoes (Böhler et al., 1987). Good correlations between texture and starch content of cooked potatoes have been reported however no such studies were reported on fried potato products (Linehan and Hughes, 1969; Warren and Woodman, 1974). Variability of texture was reduced by a factor of 5 when only two slices were cut using the industrial slicing machine from the middle of each tuber with a given density.

**Moisture sorption and desorption at room temperature**

Chips fried to average 2% (“fully fried”) and average 8% moisture (“incompletely fried”) were kept for 6 wk in different controlled atmospheres, and their moisture and texture were measured (Fig. 2). “Fully fried” chips appeared to be close to glassy state, and did not equilibrate in 6 wk, as indicated by the same average moisture at 0.23 and 0.33 $a_w$. The large variations in individual chips were unexpected. These results were different from those reported by Katz and Labuza (1981), who found a direct correlation between moisture of chips and water.

The relationship between moisture and maximum force of break was complex (Fig. 3A-D). “Fully fried” chips kept at low moisture showed very reproducible force results (Fig. 3A). Room temperature drying of “incompletely fried” chips however made them weaker. The breaking force was proportional to the water content with very little random error (Fig. 3D).

“Fully fried” chips kept at higher moisture showed large variations and weak correlations between moisture and strength (Fig. 3B,C). Results indicated that fried potato chips could not be considered uniform in water sorption properties, and that sample processing and storage history would strongly affect texture measurement even at nominally identical moisture contents.

**Frying, time, temperature, and potato specific gravity effects**

During frying considerable water is removed, which is accompanied by fat uptake, resulting in textural changes in the fried potatoes and...
other properties such as appearance of the surface, and increased palatability (Lamberg, 1990; Bauman and Escher, 1995). In the frying process it is important to control the oil temperature and the time, but often, nominal, not exact oil temperatures are reported. The time-temperature conditions were summarized for our fryer for nominal 185°C (Fig. 4).

The specific gravity of potatoes is used as a rapid industrial index to grade potatoes. It is essentially a measure of starch content. It predicts mealliness of French fries and yields of dehydrated potatoes and potato chips (Smith, 1975). HSG and LSG potatoes were at two different oil temperatures. The moisture of potato chips was a function of time of frying for different potato densities and oil temperatures (Fig. 5). A simple model was adequate to describe the drying process at this level of moisture data accuracy. We assumed that first, the chip was brought to 100°C with no drying, and then the drying rate was only dependent on the available temperature difference (T oil − 100°C), and the amount of available water.

\[ M_f = M_0 e^{-K(t - t_{lag})/T_{oil - 100}} \]

Here \( t > t_{lag} \), and \( M_0 \) is the initial moisture content, \( K \) would include chip geometry and the external heat transfer coefficient. \( T_{oil} \) is the oil temperature and the \( t_{lag} \) is the lag time, assumed to be indirectly proportional to mean logarithmic difference of temperatures between oil and chip up to 100°C.

\[ t_{lag} = K_2 / DT \log \]

This model has two fitting parameters, \( K_1 \) and \( K_2 \), and fits the data quite well (\( R^2 = 0.9895 \)). In reality however, heat transfer outside the chip would vary considerably with bubbling rate (Costa et al., 1997).

Sensorial acceptable potato chips (2–3% moisture) were prepared after 60 and 150s of frying at 180°C and 140°C respectively. Some effect of specific gravity on moisture content was observed, most clearly towards the end of drying, as the water content dropped below 10%, e.g. at 180°C after 50s frying. HSG had lower moisture content than the LSG potatoes, as expected, as they contained about 2–3% less water.

The formation of crispness in potato chips occurs at the end of frying (Smith, 1975). Therefore, texture analysis as a function of frying time was studied at the end of frying. The maximum breaking forces for potato chips fried at the two different temperatures (180°C and 140°C) were compared (Fig. 7) using the two potato densities. There was a clear difference between maximum breaking force of potato with low (1.0914−1.0954) and high specific gravity (1.1028–1.1068), except at the final product (105s of frying) when they were fried at 180°C (Fig. 7A). This difference was more obvious when the chips were fried at 140°C (Fig. 7B). Also, there was a tendency of the maximum force of break to decrease for the longest frying times, i.e. at <2% moisture.

**Moisture as an indicator or predictor of texture**

Correlations were found (Fig. 8) between the maximum breaking force and the moisture using the pooled data from the experiments on frying. An optimal moisture point was observed, where the maximum breaking force of the chips was the highest. This point corresponded to 2.5% moisture content. Before that point the maximum breaking force was proportional to moisture content, and after that point the maximum force of break had a tendency to decrease when moisture increased (Fig. 8A, B). We observed that chips with the same moisture content had different maximum breaking forces depending on specific gravity of the raw potatoes. The maximum breaking force was higher for HSG than for LSG chips, especially at 1–5% moisture content (Fig. 8A, B). These differences in maximum breaking force were clearer when the chips were fried at 140°C. We hypothesize that the difference was caused by the higher starch content. There was around 2-3% more dry matter in the HSG potatoes. Since strength of a plate is related to thickness squared (Pilkey, 1998), then if the increased total solids was related linearly to final thickness, with no change in porosity, we would expect an increase of 20-30% in maximum force of break. However, porosity, which we did not measure, is probably also affected.

**CONCLUSIONS**

*We proposed use of maximum breaking force in the punch test with 3-point support to quantify texture of potato chips.*
variability of individual measurements was reduced considerably by such use. Residual variability of moisture and texture of potato chips might be attributed to the heterogeneous distribution of starch and other compounds and to the tissue structure after frying. For chips of different moisture contents, the relationship between moisture content and maximum breaking force passed through a maximum. This relationship was not identical in chips fried and those subsequently equilibrated at room temperature to a different moisture content. Chips from higher starch (higher density) potatoes were stronger at the same moisture content.

**REFERENCE**


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