AN OBJECTIVE AND SUBJECTIVE CHARACTERIZATION OF THE ORAL PROCESSING OF SIX SOLID FOODS

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The aim of this work was to carry out a comprehensive study of the texture of six solid foods (banana, apple, carrot, cured ham, peanut and potato chips). Firstly, mechanical properties of foods were measured using a miniature Kramer cell. In carrot, peanut and potato chips, acoustic properties were also recorded. Secondly, dynamic rheological properties of the six bolus counterparts were measured. Thirdly, a sensory evaluation focused on the texture perception of six foods was performed by an untrained panel, which also involved objective measures of eating behaviors. Finally, Pearson correlations were established to find out links between food and bolus mechanical properties, texture perception and oral processing.

Experimental

➤ Solid food items

➤ Mechanical properties of solid foods and boluses

➤ Sensory evaluation

A sensory methodology was developed for evaluating during oral processing the dynamic texture perception of the six solid foods together other drivers of choice and preference. Thirty-nine participants with good dental health and no chewing difficulties performed the sensory evaluation (ages ranging between 21 and 65 years old). Each participant completed several trials of the six foods corresponding to four different stages of oral processing. Testing was carried out in a sensory laboratory equipped with eight individual booths.

➤ Participants were asked to look at, smell and even touch the foods, and then to arrange them according to preferred order for consumption.

➤ Participants selected from a list given the drivers of product choice and preference that had influenced in chosen orders.

➤ For each food item, participants selected from a list given the expected textural attributes (texture expectations).

➤ On the same serving foods, participants were asked to bite normally each food item in the preferred order, and then to spit-out each bitten piece.

➤ They ordered the foods, in decreasing order, according to their perceptions of force required at first bite and degree of loudness.

➤ Weighed portions of each food were dispensed to participants. Saliva incorporation was determined by gravimetric difference, weighing each spat-out bolus.

➤ Participants recorded the chewing duration and the chews number required before spitting-out each bolus. Chew rate and average eating rate were also calculated [2].

➤ Participants ordered foods, in decreasing order, according to perceptions of force exerted to chew down and degree of loudness. They selected for each food item the textural attributes perceived during chewing.

➤ Boluses were collected after normal *in vivo* mastication, and the participants ordered them, decreasingly, according to perceived degrees of both consistency and adhesiveness.

Non-oral evaluation

1

First bite

2

Chewing process

3

Bolus characterization

4

➤ Kramer mechanical properties of solid foods Results and Discussion ➤ SAOS rheological properties of food boluses

Fig. 1. Typical Kramer force-distance curves and SPL-distance curves of solid foods. A. Banana. B. Apple. C. Carrot. D. Cured ham. E. Peanut. F. Potato chips.

Potato chips were preferred to be eaten in first place. Main drivers of product choice were lifestyle, time of the day, appearance and expected oral sensations. However, the texture had little influence on foods choices before tasting. At first bite, carrot and banana were scored with the highest and the lowest perceived force and loudness degree, respectively. Saliva incorporation was estimated by subtraction between weight of bolus after mastication and that of food sample. In banana and apple, with higher water content, had no saliva incorporation (data not shown), whereas the contrary was true in carrot, cured ham, peanut and potato chips. Potato chips bolus had the highest saliva incorporation. Chewing time and chews number were longer and higher in carrot and cured ham. Banana and apple were the faster foods, while cured ham was the slowest one.

By considering the six foods together, correlations ranging between $r = 0.823$ (for expected and perceived hardness) and $r = 0.993$ (for expected and perceived gumminess) were found. On the other hand, carrot bolus was perceived as the least consistent and adhesive, whereas banana and cured ham boluses had the highest degrees of adhesiveness and consistency, respectively.

Table 1. Kramer mechanical properties of solid foods and AED parameters

Food item	Maximum force (N)	Average force (N)	Work (J)	SPL _{max} (dB)	Average drop off (dB)
Banana	23.4d (1.53)	8.08c (0.591)	0.195e (0.017)	-	-
Apple	83.8d (4.87)	31.1c (0.450)	0.779d (0.011)	-	-
Carrot	725a (42.3)	377a (24.5)	5.65a (0.368)	90.0a (5.50)	7.94a (0.814)
Cured ham	554b (71.4)	201b (21.0)	5.03b (0.525)	-	-
Peanut	574b (16.0)	200b (23.8)	2.48c (0.310)	80.6b (3.97)	6.11b (0.823)
Potato chips	244c (0.091)	36.8c (3.63)	0.921d (0.091)	86.9a,b (1.75)	7.25a,b (0.450)

Great differences were observed in the shape of the Kramer force-distance curves depending on the food tested (Fig. 1). Carrot had significantly ($P < 0.05$) the highest Kramer forces, followed by peanut and cured ham, potato chips, apple and banana, in that order (Table 1). Carrot also required the highest work, and both carrot and potato chips had similar SPL_{max} and average drop off values.

Fig. 6. Frequency of occurrence of the textural attributes selected for each food by the participants of the sensory evaluation before and after mastication (expected and perceived texture).

Conclusions

1. Kramer work would appear to be the best mechanical property for measuring the initial degree of structuring of the six foods studied.
2. The critical stress (σ_{max}), representing bolus crosslink density, was highly correlated with Kramer mechanical properties, reflecting that a higher degree of structure in food is associated with a higher bolus network density.
3. Higher foods mechanical properties are linked to longer chewing duration, greater chews number and slower eating rate.
4. Perceived hardness had positive correlations with both Kramer forces, σ_{max} , G^*_{max} , G' and G'' , and negative correlation with bolus adhesiveness, reflecting the interplay between texture perception, oral physiology and food properties.

Figs. 2-5. Amplitude and frequency sweeps of boluses collected after normal *in vivo* mastication. Figs. 2, 4: Banana, Apple and Potato chips. Figs. 3, 5: Carrot, Cured ham and Peanut.

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Carrot bolus had the highest critical shear stress (σ_{max}) and complex modulus (G^*_{max}), and the lowest shear strain amplitude (γ_{max}) (Table 2), reflecting a denser with higher rigidity but less flexible physical network. On the contrary, cured ham bolus had the highest conformational flexibility (γ_{max} value) and the lowest structural complexity ($\tan \delta$ value closer to 1). Boluses studied all exhibited weak gel properties, but the gel structure was weaker in banana and cured ham boluses.

Table 2. Viscoelastic properties of boluses (limit values of LVE range and at 1 Hz)

Food item	σ_{max} (kPa)	γ_{max} (%)	G^*_{max} (kPa)	$\tan \delta$ (-)	G' (kPa)	G'' (kPa)
Banana	0.006e (0.001)	0.251c (0.001)	2.44c (0.548)	0.285a,b (0.016)	2.63d (0.140)	0.657d (0.040)
Apple	0.029e (0.006)	0.159d (0.001)	18.2c (3.58)	0.177d (0.010)	44.3b,c (6.31)	7.19b,c (0.920)
Carrot	0.222a (0.008)	0.100e (0.001)	222a (9.45)	0.197c,d (0.005)	166a (13.5)	28.7a (3.94)
Cured ham	0.135c (0.005)	1.00a (0.001)	13.4c (0.550)	0.292a (0.023)	10.7d (1.19)	2.65c,d (0.254)
Peanut	0.175b (0.021)	0.158d (0.000)	111b (12.9)	0.216c (0.002)	61.9b (5.21)	10.9b (1.34)
Potato chips	0.080d (0.010)	0.395b (0.000)	20.2c (2.45)	0.255b (0.004)	32.6c (3.44)	6.33b,c (0.593)

Kramer test, performed with a miniature cell, could be very appropriate to establish an instrumental standardized approach of texture evaluation, from the solid food up to the bolus counterpart, enables to understand how mechanical properties change during dynamic oral. This study is a first step towards a more consistent understanding of the texture of solid foods to be able to select more suitable foods for disadvantaged people and to establish a safer and more efficient diet for them.