Hawthornethwaite, David and Ramjan, Yaneez and Rosenthal, Andrew J. (2015) Oral processing of low water content foods: a development to Hutchings and Lillford's breakdown path. Journal of Texture Studies, 46 (3). pp. 212-218. ISSN 1745-4603

Article published in *Journal of Texture Studies,* 46**,** 212-218, 2015

Oral processing of low water content foods – a development to Hutchings and Lillford's breakdown path

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Abstract

The "hard to swallow" phenomenon previously reported for peanut paste has been investigated for other oil seed butters. The Temporal Dominance of Sensations (TDS) technique showed similar findings, adding to the list of materials which do not follow Hutchings and Lillford's break down path (Journal of Texture Studies **19**: 103-115). From our data we propose a modification to the Hutchings and Lillford model which allows for initial hydration of dry foods. The model holds well for oil seed pastes and may also help to explain the behaviour of some dry, carbohydrate rich, foods previously constrained to fit extant models.

Since TDS does not measure the magnitude of an attribute, we undertook Time Intensity studies to assess stickiness of peanut pastes during oral processing. In the absence of another attribute becoming dominant, the intensity of sticky/cohesive sensations may remain paramount but diminish in intensity, prior to swallowing.

Keywords

Dry foods; Low water content; oral processing; Hutchings and Lillford's break down path; Temporal Dominance of Sensations; Hard to swallow oil seed paste

Practical application

Modelling oral processing may help us to understand the triggers for swallowing and thus assist people with swallowing difficulties (dysphagia). The much cited model developed by Hutchings and Lillford appears not to hold for all foods and exceptions necessarily require further investigation. This paper considers other published studies on oral processing of low water foods, offering an alternative interpretation to those previously given.

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Introduction

Hutchings and Lillford's (1988) model (HLM) for the breakdown path of foods is illustrated diagrammatically in figure 1. The three axes of "degree of structure", "lubrication" and "time" have two threshold planes corresponding to the degree of structure that can be swallowed and the degree of lubrication that can be swallowed. Where the two planes intersect is a "swallowing bar" where the two thresholds have been reached, and within which we can swallow the bolus. We can imagine various foods on this model which may well follow breakdown-lubrication trajectory with time in the mouth resulting from mastication and secretion of saliva until the bolus enters the "swallowing bar" at which point we can clear the bolus from the oral cavity.

In their original paper Hutchings and Lillford consider the swallowing trajectory of juicy steak, tough dry meat, dry sponge cake, oysters and liquids. They explain that juicy steak, tough dry meat and sponge cake appear to the left of the diagram with varying degree of structure and lubrication, they then follow curved trajectories towards the swallowing bar. Liquids start within the bar being already lubricated and without structure and can thus be cleared from the oral cavity without any mastication and some very moist foods of a relatively small sized foods, such as oysters may be swallowed without any mastication or further lubrication.

Since its creation in 1988 the HLM has been widely cited (183 times according the Science Citation Index, April 2015) to explain the oral trajectory. However, the oil seed pastes such as tahini (sesame paste) and peanut butter appear not to follow the model. Consider tahini for example, it is made by grinding roasted sesame seeds and consists of dry cellular debris suspended in sesame oil. When water is added it starts to thicken (Lindner. and Kinsella, 1991; Rosenthal and Yilmaz, 2015), to the extent that it no longer behaves as a liquid, but becomes a firm solid. Only on the addition of extensive amounts of water does it start to soften and then lead on towards an oil-in-water emulsion. In the case of peanut butter, the melting point of the suspending medium is lower and depending on ambient temperature it can exist as an oily suspension, verging on solid paste, consisting of dry peanut solids suspended in peanut oil. When introduced to the mouth the dominant sensations start as "chewy", becoming "soft" and then finishing with "sticks to the palate" (Rosenthal and Share, 2014). In terms of the HLM, one would expect that tahini (and depending on temperature peanut butter) to start with virtually no structure and with a high degree of lubrication due to the oil. Thus on the HLM we would expect it to sit within the swallowing bar, yet when introduced to the mouth both foods begin to thicken and develop structure as saliva is absorbed due to the hydration of the fat free dry solids (Rosenthal & Yilmaz, 2015).

Exceptions to models are always awkward to deal with and these oil seed pastes seem not to fit to the HLM and have been coined "hard to swallow" oil seed pastes. A possible explanation of what is going on in these pastes might be the concept of bolus assembly. However, Hiiemae reminds us that: "boli from solid food are not formed in the oral cavity but in the oropharynx" (Hiiemae, 2004, p183), and the hard to swallow oral mixtures are definitely formed in the oral cavity. Moreover as boli are swallowable items, one might expect that bolus assembly would lead to a greater ease of swallowing, yet the behaviour exhibited by tahini and peanut butter in the mouth are quite the opposite of this, being cohesive and sticking to the palate and the tongue.

This paper aimed to identify other food materials which exhibit the hard-to-swallow phenomenon exhibited by peanut butter. We also attempted to quantify the sticky sensations implicated in peanut butter as the dominant sensation prior to deglution.

Materials and Methods

Ethical approval for both studies was obtained from the Coventry University ethics committee. Nineteen untrained, native English speaking students were recruited from Coventry University. Participants were all aged 18 or over, the had dental records absent of fractures and dentures. Participants were informed of all possible risks (such as nut allergies). Participation was on a voluntarily basis and no remuneration was given.

Temporal Dominance of Sensations studies

Almond butter, hazelnut butter, pumpkin seed butter and cashew nut butter all manufactured by Meridian Foods Ltd (Corwen, UK) were used. Jars were stored at room temperature. When opened the contents of each jar was mixed with a clean plastic knife to a homogeneous consistency. Five gram samples of each paste were levelled onto plastic desert spoons and placed on coded paper plates to present to the assessors in the same order.

TDS software (Morgenstern©, The New Zealand Institute for Plant & Food Research Limited) was used to collect data in this study. The TDS procedure described by Rosenthal & Share (2014) was followed. As assessors were untrained native English speakers, we did not create technical definitions of each attribute, but used terms with common meanings, being: 'compacted-to-teeth', 'granular', 'smooth', 'soft', 'sticky' and 'thick'. Assessors were introduced to the software on an individual basis and the first of each triplicate sample presentation was used as a training exercise to familiarize the assessors with the products, the descriptive terms, the software and the testing protocol. Only the results from the second and third replicates were included in the data set. The software also recorded the average chewing time, the average time to the first selection, the average number of swallows and the average number of attribute changes. Time was standardized by dividing the time from introducing food to the mouth until swallowing into 20 equal periods.

Assessors were provided with a plastic cup of bottled water. Each participant was asked to drink some water before each sample in order to cleanse their palate. The participants were instructed to take the full amount of paste from the spoon and begin to process the paste while they recorded the sensations they perceived as most prevalent using the TDS software.

Time Intensity studies

Lightly salted peanuts were purchased from a local shop (Holland and Barrett, Nuneaton, UK). The oil content was determined by Soxhlet extraction using 40-60 °C boiling fraction petroleum spirit. The peanuts were then blended in a food processor to yield a 52% oil paste. Addition of peanut oil (Sainsbury's, London, UK) allowed two further mixtures containing 57 and 62% oil to be prepared.

Four gram samples of each paste were levelled onto plastic desert spoons and placed on coded paper plates to present to the assessors. Duplicate samples of each paste were provided. The six samples were tested in a single session. Assessors were provided with sheets of paper onto which a series of unstructured 100 mm lines were drawn. Following initial ingestion of a sample, the assessors were asked to rate the subjective stickiness every three seconds on a different line

(Meilgaard, Civille & Carr, 2007). Between samples each assessor was asked to consume 50ml of water and wait for 5 minutes before commencing with the next sample.

Results

Figures 2 shows the TDS curves for almond butter, hazelnut butter, pumpkin seed butter and cashew nut butter. Pineau and co workers (2009) explain the calculation of a "random chance line" below which data can only be treated as arising by chance, they also advocate a 95% confidence line below which trends must be considered with less statistically certainty. In our case the random chance line was set to 0.14 and the 95% confidence line to 0.27. While the methodology was explained to each assessor, the low dominance rate exhibited probably reflects the fact that the assessors were naïve. This lack of experience also reflects in the delay before statistically significant dominant sensations arise. Despite the delay in the development of statistical significance, a general trend towards a sticky material (i.e. sticks to the palate or compacted on teeth) as oral processing continues.

Results of the time intensity study is shown in Figure 3. While there is considerable variation between the assessors, the degree of stickiness peaks at about 3 seconds and then progressively falls to the point of clearance at 15, 21 and 27 seconds for the 10%, 5% and 0% added oil mixtures.

Discussion

Considering the similarities in manufacturing method and structure of the nut butters used in this study, it is unsurprising that they exhibit the same progressive increase in the TDS attribute "sticks to palate" as was seen in peanut butter (Rosenthal and Share, 2014). This is to say that when introduced to the mouth all these nut butters start to become cohesive and stick to the oral surfaces – namely the tongue, the palate and the teeth. Presumably the absorption of water from the saliva is causing some structure to form in the suspension as the dry fat free solids start to absorb water and stick together. This behaviour is consistent with findings from sesame paste (Rosenthal and Yilmaz, 2015).

Part of the elegance of the HLM is its ability to bring the dimensions of structure, lubrication and time together in a three dimensional representation. Having said this, representing a three dimensional model on a two dimensional surface requires perspective and inevitably some distortion. While it is relatively easy to draw trajectories in 3D perspective for the break down paths of foods which start at the top left and curve down to the bottom right, it becomes more challenging to unambiguously represent materials that start with little structure in the middle of the diagram, before developing structure and losing lubrication before starting to decrease in structure as the lubrication rises again. For this reason, the authors of this paper have attempted to re-present the HLM by undertaking two graphical steps. Initially we rotate the HLM through 90º on the vertical axis (figure 4a). Nothing has changed, but we see the model differently, because instead of the "swallowing bar" being parallel to the x axis, it is positioned at the right hand end, becoming the common destination of all foods. The model still works, but the fixed point of reference is no longer when the food enters the mouth, but when we are ready to swallow. Taking this concept a step further, our second graphical step is to view the model side on, looking directly at the x and y axes. The z axis, time, disappears orthogonally into the page (Figure 4b). The visible axes are the "degree of structure" and "degree of lubrication". The threshold planes in Figure 4a, become threshold lines in Figure 4b. Similarly, the swallowing bar in the 3D view, becomes a swallowing box. The notion of time still exists, though it is now implied by the length of the trajectory.

We can use this modified model to examine the break down paths of the foods which Hutchings and Lillford considered in their original discussion paper. Figure 4C shows, liquids such as soup or coffee, located within the swallowing box at point A. Small highly lubricated solids, such as oysters, sit just above the swallowing box at point B. Point C represents the juicy steak and the solid line towards the swallowing box is its oral trajectory. These examples are classic HLM behaviour. However, to accommodate dry foods we have stretched the horizontal axis to create a new region. Point D represents an oil seed paste and the dotted line depicts the oral trajectory initially absorbing water from the mouth to create a cohesive mass, after which the material behaves as any other food in terms of the HLM, finally crossing the two thresholds and entering the swallowing box.

The flaw in this model, is the concept of lubrication, for as Hutchings and Lillford say:

> "….We might have used the word 'juiciness' instead of 'lubrication' as many foods depend upon a moisture/water continuous phase for lubrication. However, we decided that the word 'juiciness' may not have been seen to apply to fat-containing foods." (Hutchings and Lillford, 1988, p106)

By definition, oil seed pastes used in this study are all high fat foods, and on the face of it they should be highly lubricated, yet the effect of the oil lubrication is overshadowed by the hydration of the dry fat free solids (point D in Figure 4c). For this reason in our modified model we are reinstating Hutchings and Lillford's original idea of water based juiciness by adopting the "degree of hydration" as the x axis.

We use models to help us understand what is going on in reality. When a widely accepted model is vogue, researchers may feel constrained to interpret their results in the context of that model. The fact that oil seed pastes start as a liquid or plastic solid and thicken in the mouth is a clear example that does not fit the HLM. With this in mind we might look at other low water, carbohydrate rich foods for whom, once the gross structure is lost during the first few bites, they will absorb saliva to form a cohesive mass.

Lenfant and co-workers (2009) used the Temporal Dominance of Sensations technique to identify the most dominant sensation perceived at any particular time during the oral processing of various dry breakfast cereals. The "first bite" characteristics of crispness, hardness and brittleness, ultimately gave way to stickiness towards the end of the mastication period.

Pereira (2006) studied the effects of added fluids to the oral perception of solid foods. They separated out the first bite characteristics from those experienced during chewing. With Melba toast and cake, added fluid had a major influence on the number of chewing cycles. The characteristics during chewing which they termed "drying" – denoting the absorbance of saliva from the mouth was significant for both products ($p<=0.01$) as was the "gooey" sensation. Both of these suggest absorption of water leading to a cohesive mass.

A number of workers have looked at the oral processing of whole nuts. Unlike the oils seed pastes which arise when whole nuts are milled, the surface to volume ratio is small, preventing rapid hydration of particles. However when chewed in the mouth the particles that result from mastication, hydrate and stick to the crushing surfaces of the teeth, being the wet surface in immediate contact at the time of structural breakdown (Rosenthal and Share, 2014). Interestingly, "granular" was the initial dominant sensation of the hazelnut butter in this study before moving to "compacted on teeth", maybe suggesting a larger particle size of this material compared with the other nut butters, and requiring further mastication during oral processing instead of just hydration.

Another high carbohydrate dry food is the potato crisp. *In-vitro* studies show that ground crisps absorb moisture from a step addition of buffer solution leading to a clear rise in G', suggesting an increase in the cohesive nature of the paste (Boehm *et al*, 2014).

Young and co-workers (2013) examined the structural changes of biscuits during chewing. Again TDS shows a move from hard/crumbly to crunchy/crispy to dry and finally sticky sensations. This research group went on to study the addition of saliva during mastication and concluded that the fractured particles agglomerate, leading to the formation of a single cohesive bolus (Rodrigues et al., 2014). Even after all the biscuit is deconstructed, saliva absorption continues to bind the particles. We would suggest that before this time, the particles are being hydrated and after this point we enter the classic HLM where the cohesive sticky sensation lessens with added saliva to the point of swallow.

When Hutchins and Lillford created the HLM, they used "dry sponge cake" as one of their example foods to illustrate the model. We speculate that point E in figure 4c would represent sponge cake (along with the other solid dry foods mentioned above). Such foods would follow the oral trajectory depicted by the broken line whereby after the rapid destruction of gross structure, the uptake of saliva would lead to a cohesive mass at which point it enters the HLM. The mouth drying capacity of such foods may prompt the consumer to imbibe additional fluid to moisten their palate and hydrate the food which otherwise sucks water from the mouth drying the palate.

While TDS tells us the dominant sensation at any particular time, it does not give us any sense of magnitude. For this reason we undertook time intensity studies on nut pastes, for while previous work (Hutchings et al, 2014; Rosenthal & Share, 2014) had shown that with time oil seed pastes became sticky in the mouth, the degree of stickiness could be diminishing even if it was still dominant over other sensations. Figure 3 shows the average intensity of oral stickiness for peanut pastes and clearly the degree of stickiness does change with time, initially rising to a peak after three seconds and then gradually falling away. Roasted peanuts are typically about 50% oil and 1% water, thus the fat free dry matter is in the region of 49%. If we increase the oil content by 5 and 10% then the dry fat free matter falls accordingly. As it is the fat free dry matter that is binding water in the mouth, it is not surprising that the magnitude of peaks and the time to swallow is also reduced, as the amount of oil increases and the fat free dry matter is reduced.

Conclusions

We have transposed the HLM to a two dimensional format, retaining the degree of structure on the vertical axis, but replacing the lubrication axis one of hydration. The sense of time is implied by the length of the oral trajectory with the point of swallow being the only fixed reference point common to all foods and where all trajectories converge. The point of entry for any particular food and its subsequent breakdown path depends on the initial hydration and degree of structure. Moist foods continue to be described well by the HLM, however dry foods require an initial extension where the water necessary to hydrate the dry solids is taken up before entering the HLM. While TDS shows that many dry foods tend towards a cohesive and sticky texture as the final dominant sensation, we note that TDS does not measure intensity and in the absence of other dominant sensations the degree of stickiness will decrease with time to the point of swallow.

Acknowledgments

We are grateful for the valuable insights and discussion from Jianshe Chen, Marco Morgenstern and other delegates at the 3rd Oral Food Processing Conference, Wageningen, Netherlands, 29 June – 2nd July 2014.

Captions to Figures

Figure 1: Schematic to illustrate the Hutchings and Lillford Model.

Figure 2: Temporal Dominance of Sensations curves for Hazelnut butter, Almond butter, Cashew nut butter and Pumpkin seed butter.

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Legend: thick ——; soft ——; smooth ——; granular ——; compacted on teeth ——; sticks to palate ——.

Figure 3: Average Intensity of Stickiness During Oral Processing of Peanut Paste with added Oil, error bars are one standard deviation. Legend: no added oil —♦—; 5% extra oil --■--; 10% extra oil •••▲•••.

Figure 4: Stepwise graphical modification of Hutchings and Lillford's model.
4a is a vertical rotation through 90°;
4b transformation to two dimensions.

4c modified model with dry food extension, showing oral trajectories for liquids (A), oysters (B), juicy steak (C & —), oil seed paste (D &••••), and dry solid foods (E & - - - -).

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Figure 1

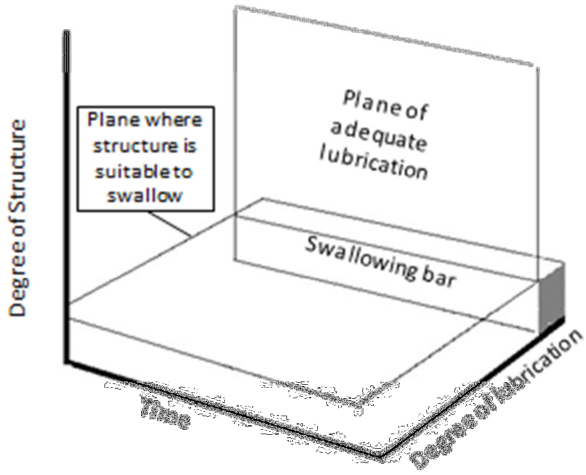

Figure 2

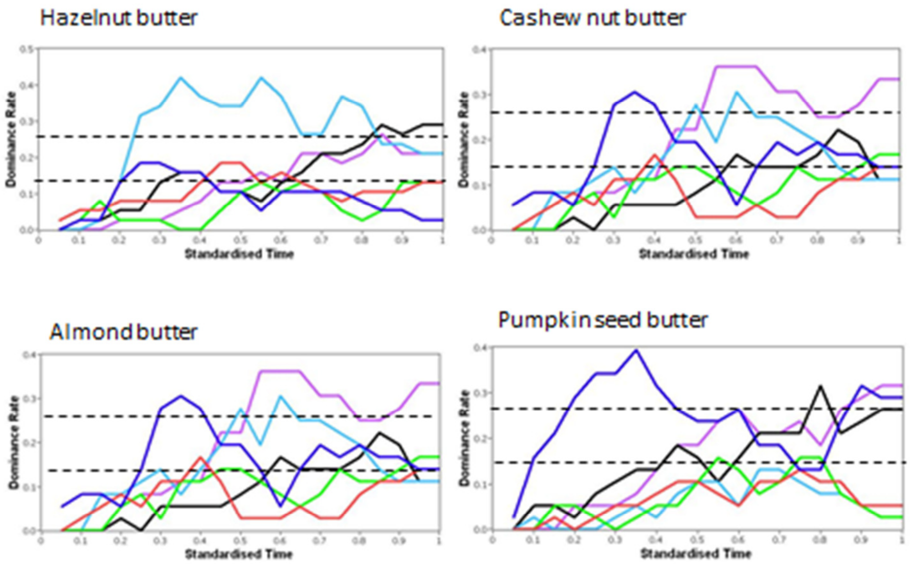

Figure 4

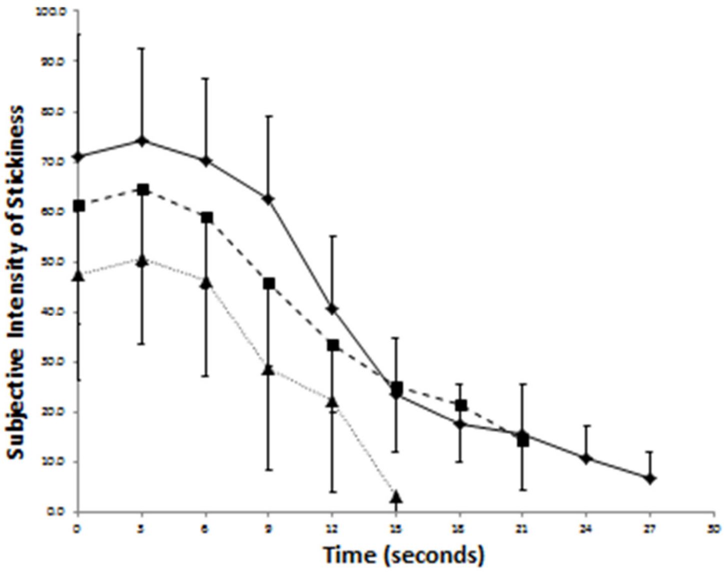

Figure 5