Rosenthal, Andrew J. and Share, Carmen (2014) Temporal dominance of sensations of peanuts and peanut products in relation to Hutchings and Lillford's "breakdown path". Food Quality and Preference, 32 (Part C). pp. 311-316. ISSN 0950-3293

Published as: Rosenthal, A. and C. Share (2014). "Temporal Dominance of Sensations of Peanuts and Peanut Products in relation to Hutchings and Lillford's "breakdown path"." Food Quality and Preference **32**(C): 311-316.

Temporal Dominance of Sensations of Peanuts and Peanut Products in relation to Hutchings and Lillford's "breakdown path"

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Abstract

Hutchings and Lillford's (Journal of Texture Studies, 19, 103-115, 1988) proposed a "breakdown path" whereby particle size reduction occurs through mastication in conjunction with the secretion of saliva to form a swallowable bolus. The swallowing trajectory of whole peanuts, peanut meal and peanut paste were studied with the temporal dominance of sensations technique. The sensations for whole peanuts progressed from hard, to crunchy, to chewy, to soft and ended compacted on teeth. Predictably peanut meal missed out the first two sensations, progressing from chewy, to soft and ending compacted on teeth. However peanut paste, which starts as a soft suspension with relatively little structure appears to thicken and stick to the palate during oral processing. We propose that the "hard to swallow" sensation elicited by peanut paste may be due to water absorption from the saliva as they mix in the mouth.

Highlights

- The oral trajectory for peanuts, peanut meal and peanut paste are described.

- Peanut butter appears to develop structure during oral processing.
- A term, "*hard to swallow oil seed pastes*" is coined.
- A mechanism for the difficulty in swallowing "*hard to swallow oils seed pastes*" is proposed.

Keywords

Breakdown path, Mastication, Oral Processing, Oral Trajectory, Peanut, Peanut Butter, Swallowing, TDS, Temporal Dominance of Sensation, Texture

1 Introduction

1.1 Texture of peanuts & their products

The peanut is the seeds of the legume *Arachis hypogaea*. Peanuts have a tradition of use as a snack food and are frequently processed in a variety of ways such as roasting and grinding to produce a range of products which are eaten in a variety of ways such as roasted salted snacks, sate sauce, peanut butter, etc.. Table 1 shows the proximate composition of various peanut products, revealing that they are a good source of protein, carbohydrate and fat, making them highly nutritious and a good source of energy. The low water content also helps to provide a long shelf life, limited only by the potential for fat oxidation.

As a popular and widely available food, peanuts (and their products) have been the subject of sensory evaluation studies. Using descriptive analysis, Gills and Resurreccion (2000) identified eight oral textural attributes for peanut butter, being the stickiness and graininess when first introduced to the mouth (prior to mastication), the hardness of the first bite as well as the adhesiveness, gumminess during mastication and residual sensations of: oiliness, mouthcoating and mouthdryness. Other researchers have studied oral food processing (mastication, bolus formation, swallowing, etc), for example electromyography has been used to study the muscle activity while chewing peanuts (Hanawa, Tsuboi, Watanabe, & Sasaki, 2008; Kohyama & Mioche, 2004; Kohyama, Mioche, & Martin, 2002) and the resultant particle size distribution evaluated by various techniques such as wet sieving or laser diffraction (Peyron, Mishellany, & Woda, 2004). Flynn et al looked at particle size distribution of peanuts prior to swallowing and postulated multiple compartments within the mouth during mastication (Flynn et al., 2011). While most researchers looked at single foods, Hutchings and colleagues embedded peanuts in gel matrices to investigate the particle break down dynamics (Hutchings et al., 2011, 2012). Several authors have looked at the importance of fluid and specifically saliva on bolus formation and swallowing of peanuts (Pereira, de Wijk, Gaviao, & van der Bilt, 2006; Pereira, Gaviao, Engelen, & Van der Bilt, 2007; van der Bilt, Engelen, Abbink, & Pereira, 2007). Hiiemae et al investigated bolus formation and its movement in the mouth for several foods including peanuts (Hiiemae, 2004; Hiiemae & Palmer, 1999). Once comminuted by the teeth, and formed into a bolus, the swallowing threshold for peanuts has been determined (Engelen, Fontijn-Tekamp, & van der Bilt, 2005).

Despite having been incorporated into a wide range of foods whose physical properties have been studied, whole peanuts and peanut meal have not themselves been characterized from a rheological point of view. Having said this, peanut butter is a viscous oily paste. Rheological studies on the flow behavior of peanut butter show that it is actually shear thinning with a yield stress (i.e. plastic behavior) (Citerne, Carreau, & Moan, 2001; De Man, 1990; Shakerardekani, Karim, Ghazali, & Chin, 2013).

1.2 Temporal Dominance of Sensation

The Temporal Dominance of Sensations (TDS) technique follows the oral breakdown trajectory of food from the assessors first bite to the point of clearance from the mouth. Throughout the process the assessor identifies the dominant sensation that are perceived and by comparing responses between the panel we are able to recognize patterns for particular foods by the group of subjects under test. TDS has been applied to a variety of liquid foods and drinks such as water (Teillet, Schlich, Urbano, Cordelle, & Guichard, 2010), espresso coffee (Barron et al., 2012), blackcurrant squash (Ng et al., 2012) wine (Meillon, Urbano, & Schlich, 2009; Sokolowsky & Fischer, 2012) and olive oil (Dinnella, Masi, Zoboli, & Monteleone, 2012). It has also been used to examine semi solid foods like yoghurt (Bruzzone, Ares, & Gimenez, 2013) and salmon-sauce combinations (Paulsen, Næs, Ueland, Rukke, & Hersleth, 2013). TDS is ideal to follow the breakdown of foods in the mouth using solid products including breakfast cereals (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009; Meyners, 2011, Sudre, 2012) and fish fingers (Albert, Salvador, Schlich, & Fiszman, 2012). In some cases it is changes in texture which are being measured, while in other situations the researchers are interested in flavor release of tastants such as salt (Teillet et al., 2010) or aroma release from candies (Deleris et al., 2011; Saint-Eve et al., 2011) or drinks (Déléris et al., 2011)

1.3 The breakdown path

The purpose of this research was to examine the breakdown path of peanuts and peanut products, and to put them in the context of Hutchings and Lillford (1988) model to illustrate the oral breakdown path (Figure 1). In this model, intact food enters the mouth towards the top left of the diagram (depending on its relative structure and moisture content). During mastication, the food structure is broken down, accompanied by an increase in degree of lubrication as saliva is secreted and mixed into the bolus. Of course the process is time dependent as both mastication and saliva production are gradual. As the oral processing proceeds, the food follows a trajectory from the top left towards the bottom right of the diagram until it enters the "swallowing bar" at which point an involuntarily swallow may occur.

By milling peanuts in a food processor we would expect to reduce the relative degree of structure, thus if milled foods are eaten we they should enter Figure 1 at a point lower on the vertical axis then the original food. According to the model it is then a matter of increasing lubrication through the mixing of saliva to form a bolus suitable to swallow.

2 Materials and methods

2.1 Sample preparation

Roasted peanuts (Love Life, Waitrose, Bracknell, UK) were purchased from local shops and then prepared into portions for mastication and swallowing as follows:

1. 4 g portions of whole or half peanuts were dispensed into 25 cm^3 clear plastic cups.
2. Peanuts meal was produced by finely chopping the peanuts with a Robot Chef food processor equipped with a rotating blade (Robot

Coupe, Vincennes, France). A particle size fraction (0.5 – 2 mm) was collected by feeding the milled peanuts onto a stack of two laboratory test sieves with rectangular holes (Endecotts, London, UK). The screen stack was gently shaken by hand. 4g portions of this size fraction were dispensed into 25 cm^3 clear plastic cups.

3. Using the same food processor used to produce the peanut meal, samples of peanuts were milled until a smooth paste was achieved. The paste was transferred to a glass bowl and a 4g portions were offered to assessors in the form of a level plastic teaspoon full.

All samples were stored at room temperature and consumed within one week of preparation.

2.2 Sensory testing

TDS software (Morgenstern©, The New Zealand Institute for Plant & Food Research Limited) was used to collect data in this study. Initially the authors considered the three foods and discussed the range of sensations that they perceived during chewing and swallowing each. A focus group of 6 students (Oxford Brookes University) undertook TDS with the samples, they then discussed and narrowed the list of terms helping to remove redundant words (such as oily and greasy). The final mix of sensation descriptors were: "Hard"; "Crunchy"; "Chewy"; "Soft"; "Compacted on teeth"; and, "Sticks to palate".

Fifteen, untrained, native English speaking, participants were recruited in accordance with the ethics procedures laid down at Oxford Brookes University. Participants were warned that the test foods contained peanuts and were advised that if they knew of any intolerance/allergy they should not participate.

Participants were invited to attend a single tasting session in which the procedures were explained. Participants were asked to complete the Sydney Swallowing Questionnaire (Wallace, Middleton, & Cook, 2000) and then they were given two replicates, each of the three samples. The order of sample presentation was not randomized, as the samples were distinctive and could not be disguised, that order was in all cases: Whole nuts (replicate 1), Meal (replicate 1), Paste (replicate 1), Whole nuts (replicate 2), Meal (replicate 2), Paste (replicate 2).

3 Results and Discussions

The Sydney Swallowing Questionnaire was designed to gauge levels of swallowing difficulty of dysphagic patients. None of the subjects in this study reported any habitual difficulty in swallowing. Thus we were confident that differences in the swallowing times were likely to be due to the oral processing of the foods being investigated and not a physiological anomaly of individual assessors.

Of course the outcome of TDS is directed to a great extent by the choice of attributes available to the assessors who participate in a study. Unlike this study, when subtle changes in flavor and texture are being gathered, a trained panel is normally used, however we were more interested in gross changes which might be perceived by healthy members of the general population, and therefore we sought a vocabulary which we thought described the distinctive oral sensations that could be understood and related to by untrained healthy assessors.

In order that we provide a simple unambiguous vocabulary, the authors discussed the attributes that they perceived when chewing peanuts, peanut meal and peanut butter between themselves. The attributes of stickiness and graininess as defined by Gills and Resurreccion (2000) were not perceived during normal eating and thus not included in the list. Having said this, adhesive, sticky sensations were identified during eating, these took the form of samples sticking to the palate and tongue or becoming compacted and stuck to the teeth. Overall seven attributes were identified, being: hard, crunchy, chewy, soft, oily/greasy, "compacted on teeth" and "sticks to the palate". To refine this list further, a focus group of students from Oxford Brookes University, agreed to consider the terms in relation to the samples. While the group understood the concept of an "oily/greasy" sensation, they did not perceive it to be dominant at any time during oral processing and we thus removed it from the list.

Had the study focused on subtle flavors or taints then allowing two individuals to identify the vocabulary would have been wholly inappropriate as key nuances might have been missed in creating the list of terms. However, the textural attributes of interest in this study were neither subtle nor unusual. Thus the terms identified would have been meaningful to all regardless of training or sensory acuity and to this end the terms should allow the reader to identify with the sensations involved. Since our intention was to work with untrained lay assessors, the running a focus group would have introduced exposure and hence an element of training to those individuals. Thus we invited a second group of assessors who had no knowledge of the products, the focus group or its participants to collect the TDS data for this study.

The TDS software used in this study allowed participants to note each time they swallowed as well as the point at which the sample was cleared from the mouth. For each sample type, matched t-test showed no difference in the time to the first swallow or the time to clear the samples from the mouth between first and second replicates. This suggests that no "learning" went on from the first to the second replicates. This consistency in response between the two replicates of any one product and their ability to discriminate between samples, suggests that the untrained assessors involved in this study coped with the test protocol.

Table 2 shows the overall average times (i.e. both replicates combined) to the first swallow and clearance of the samples from the mouth (along with standard deviations). While no difference exists between the replicate of any one sample, paired t-tests show significant differences ($p<0.02$) between the different sample types. Unsurprisingly, there is a decreasing progression in time to process the whole nut, the meal and the paste.

Figure 2 show the normalized TDS curves for whole peanuts (A), milled peanuts (B) and peanut paste (C) as perceived by this second group of students.

Of course with untrained assessors there is likely show a greater delay in entering a response to the computer as they are unfamiliar with the technique and the software. Thus each of the curves on Figure 2 has a short lag at the beginning before responses begin to show. Even after the curves appear they are all below the two horizontal lines. These two lines horizontal lines correspond to the chance occurrence of selecting any of the six attributes (i.e. 0.17), while the higher line shows the 95% confidence level, that is the level at which we are confident ($p\leqslant0.05$) that the assessors are behaving as a consistently with each other (in this case 0.28) (Pineau et al, 2009). It would be foolish to consider data below the "chance" line, yet for certainty it is better to only consider curves in excess of the 95% probability line, even if this adds to the lag at the start of the mastication.

The vertical axis (dominance rate) is auto-scaled by the TDS software and it is notable that the magnitude of this axis is around 60% for whole peanuts, 70% for peanut meal and 80% for the peanut paste – this suggests less inter-assessor variation in choice of dominant sensation as the peanuts are commiunted both in the food processor (i.e. producing different products) and in the mouth during oral processing.   This is substantiated when we look at the detail of the different curves, with the whole peanuts five of the six sensations are dominant to some extent over the period of oral processing (Hard → Crunchy → Chewy → Soft → Compacted on teeth), whereas the peanut meal only exhibits three of the sensations (Chewy → Soft → Compacted on teeth), while the peanut paste elicits just two dominant sensations (soft → sticks to palate).   It is not unsurprising that comminuted products should lose their "hardness" and "crunchiness", but what does seem odd is how the three curves proceed as the food passes along the oral trajectory.

It is necessary to distinguish between the forces involved in the oral processing of peanuts in the mouth and through mechanical size reduction undertaken in our laboratory.   A rotating cutting blade effectively slices through the peanuts. The sharp blade introduces a notch at the surface of the nut and a crack rapidly propagates through the tissues slicing the particle into two (Dobraszczyk & Vincent, 1999). Short bursts of chopping result in a meal of varying particle size. While there is presumably some cell damage, the overall meal is perceived to be composed of intact kibbles of nut. Extended chopping results in extensive size reduction and the level of cellular damage is presumably increased, with the liberation of oil and other cell constituents which result in a paste. Most peanut butter mills, compared with our food processor, apply compressive and shear forces to the nuts resulting in crushing and attrition with the creation of a paste with a similar consistency to that produced by our extended chopping. The forces involved in mastication of the whole peanuts and the peanut meal are primarily compressive and shearing (Chen, 2009), which would result in the deformation of the solid nuts on the surface of the teeth leading to cellular damage, liberation of oil and compaction of the nut debris on the molar surfaces.

The swallowing trajectory of the whole peanuts as observed by TDS can be seen to follow the pattern described above. Initially the peanuts are perceived as hard and then during mastication their crunchiness is overtaken by chewiness as the particle size is reduced and saliva imbibed. The chewiness leads to sensations of softness, prior to swallowing with residues compacted on the teeth (Figures 2 and 3 curve A). While the peanut meal enters figure 3 with less structure, it follows a similar process to the whole peanuts.

The sensation of moistness must not be confused with water content. While water content can cause the sensation of moistness, it is well known that the moistness of many food products (e.g. cake) is due in part to the fat or oil content. The moist appearance of peanut butter and peanut paste results primarily from the oil in the mixture, we know from Table 1 that the oil content of peanut products is high and water content low.

Compared to the whole peanuts and the peanut meal, peanut paste has relatively little structure, thus positioning it towards the bottom of figure 3. Moreover, as an oil suspension we might expect peanut paste to be well lubricated and as such sit towards the right of the diagram. These two criteria probably put peanut paste either within, or very close to the "swallowing bar". However, while the time to the first swallow and time to clear the mouth are less than those for whole peanuts or peanut meal, they are by no means instant and the TDS curve seems to show softness leading to stickiness as oral processing proceeds, as though structure is actually forming in the mouth (Figures 2 and 3 curve C).

Peanut paste is a concentrated suspensions of cellular debris in oil. Other concentrated suspensions such as starch granules are reported to exhibit dilatant (shear thickening) flow behaviour (Kim et al, 2002), whereby high shear rates result in aggregation of the particles and an increase in viscosity of the suspension. One explanation of the final oral sensation of peanut paste would be that the particles aggregate during oral processing due to shear forces exerted on the paste between the tongue and the palate. However, as stated in section 1.1, peanut pastes have been shown to be exhibit plastic behaviour whereby they start to flow once a yield stress has been overcome and then progressively thin with increasing shear (Citerne, Carreau, & Moan, 2001; De Man, 1990; Shakerardekani, Karim, Ghazali, & Chin, 2013).

We propose that the explanation for the sticky sensation and apparent difficulty to swallow peanut paste is due to the solid matter suspended within the oil becoming hydrated by the saliva during oral processing. Using the instrumental technique, texture profile analysis, Abegaz and Kerr (2006) showed that small amounts of added water increase the instrumental hardness, adhesiveness and chewiness of peanut paste. Presumably the cellular debris in peanut paste hydrates and sticks to the surfaces on which it is in contact - namely the tongue and the palate. While the hydration of the cellular debris from the mastication of whole and milled nuts occurs on the dental surface, resulting in sensations of stickiness and compaction into the molars.

It is interesting that Lenfant and colleagues (2009) showed that dry breakfast cereals followed an oral trajectory from "hard", "crisp" and "crackly", towards a sensation of "dryness" and then on to "stickiness" prior to clearance, suggesting that maybe stickiness is a trigger for swallowing. Our data would corroborate this inasmuch as compaction on the teeth and sticking to the palate and tongue are the dominant sensations towards the end of oral processing, however as with their data, the sticky sensations are dominant for some time prior to clearance. Perhaps it is the progressive lubrication of the sticky bolus resulting in a gradual loss of stickiness that allows swallowing to occur.

Peanut butter shares its structure with other oil based seed/nut products, for example tahini (sesame paste), cashew nut butter, hazelnut butter, almond butter, Brazil nut butter and sunflower spread. All of these are manufactured in a similar way, whereby the dried roasted nut/seed is ground to produce a suspension of solid particles in a continuous phase of liberated oil. Like peanut butter, these products are all low in water content and all elicit the same sticky "hard to swallow" sensation in the mouth.

4 Conclusion

TDS has been used to study the oral trajectory of whole peanuts, peanut meal and peanut paste. Whole peanuts are initially perceived as hard, then becoming crunchy, chewy, sticky and finally compacted on the teeth. While omitting the first two of these sensations, peanut meal follows the same pattern. In contrast the peanut paste, appears to thicken in the mouth with the apparent creation of solidity. Whereas we would intuitively think that a paste would be easier to swallow than a more highly structured solid, it seems that the peanut paste sticks to the palate becoming difficult to clear.

Having discounted rheopectic and dilatant rheological behaviours due to literature reports of shear thinning with a yield stress (i.e. plastic) properties, the authors speculate that it is the absorption of water from the saliva that gives rise to a sticky mass which coats the tongue and the palate. The authors have observed a similar behaviour with other oil seed suspensions such as tahini and cashew nut butter, and have coined the phrase "*hard to swallow oil seed pastes*" to describe the behaviour, further studies are needed to corroborate this phenomenon.

5 Acknowledgements

We are grateful to Marco Morgenstern of The New Zealand Institute for Plant & Food Research Limited for valuable discussion and encouragement, and for providing the TDS software used in this study.

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	Water	Protein	Carbohydrate	Fat
Plain Peanuts	6.3	25.8	12.5	46.0
Dry Roasted	1.8	25.7	10.3	49.8
Roasted Salted	1.9	24.7	7.1	53.0
Wholegrain Peanut Butter (peanuts, oil & salt only)	0.7	24.9	7.7	53.1
Peanut Butter (smooth)	1.1	22.8	13.1	51.8

Table 1: Percentage Composition of Peanut Products based on McCance & Widdowson's The Composition of Foods Integrated Data Set (Food Standards Agency, 2002)

Time (s) to	Whole nut	Meal	Paste
1st swallow	36.8 ±13.9	27.8 ±11.3	20.8 ±14.6
Clearance	49.1 ±17.9	36.5 ±13.9	29.6 ±15.9

Table 2: Mean time (seconds) ±standard deviation, to first swallow and clearance.

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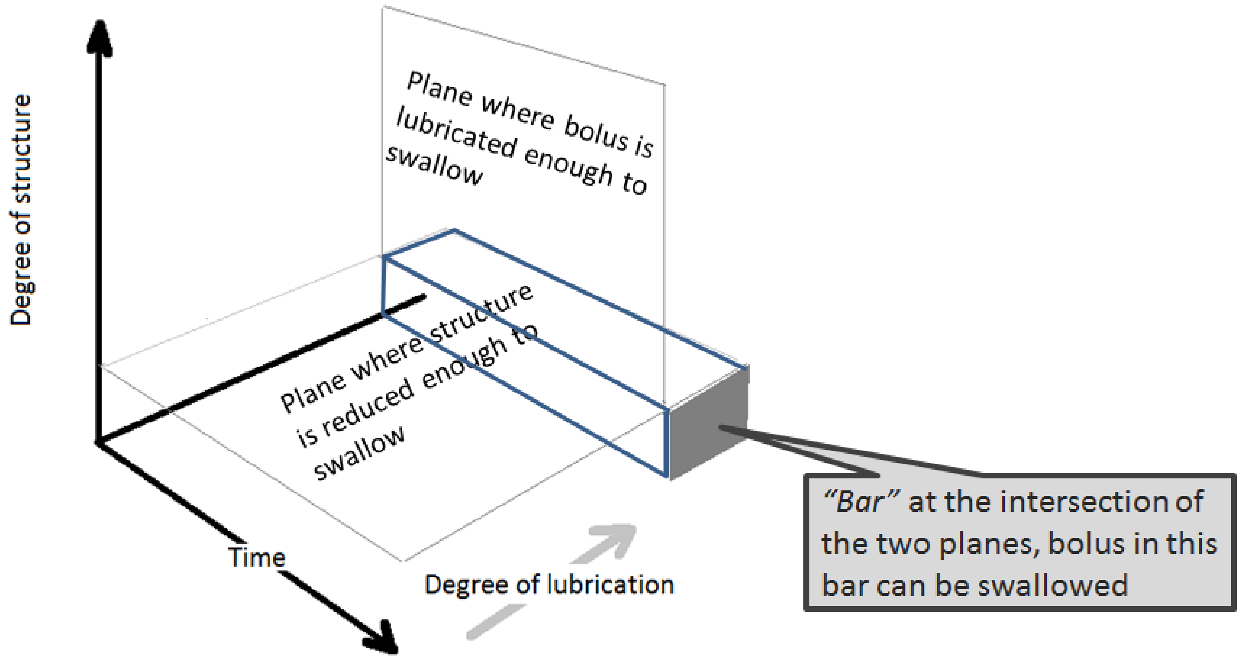

Figure 1 Schematic to illustrate Hutchings and Lillford's "breakdown path"

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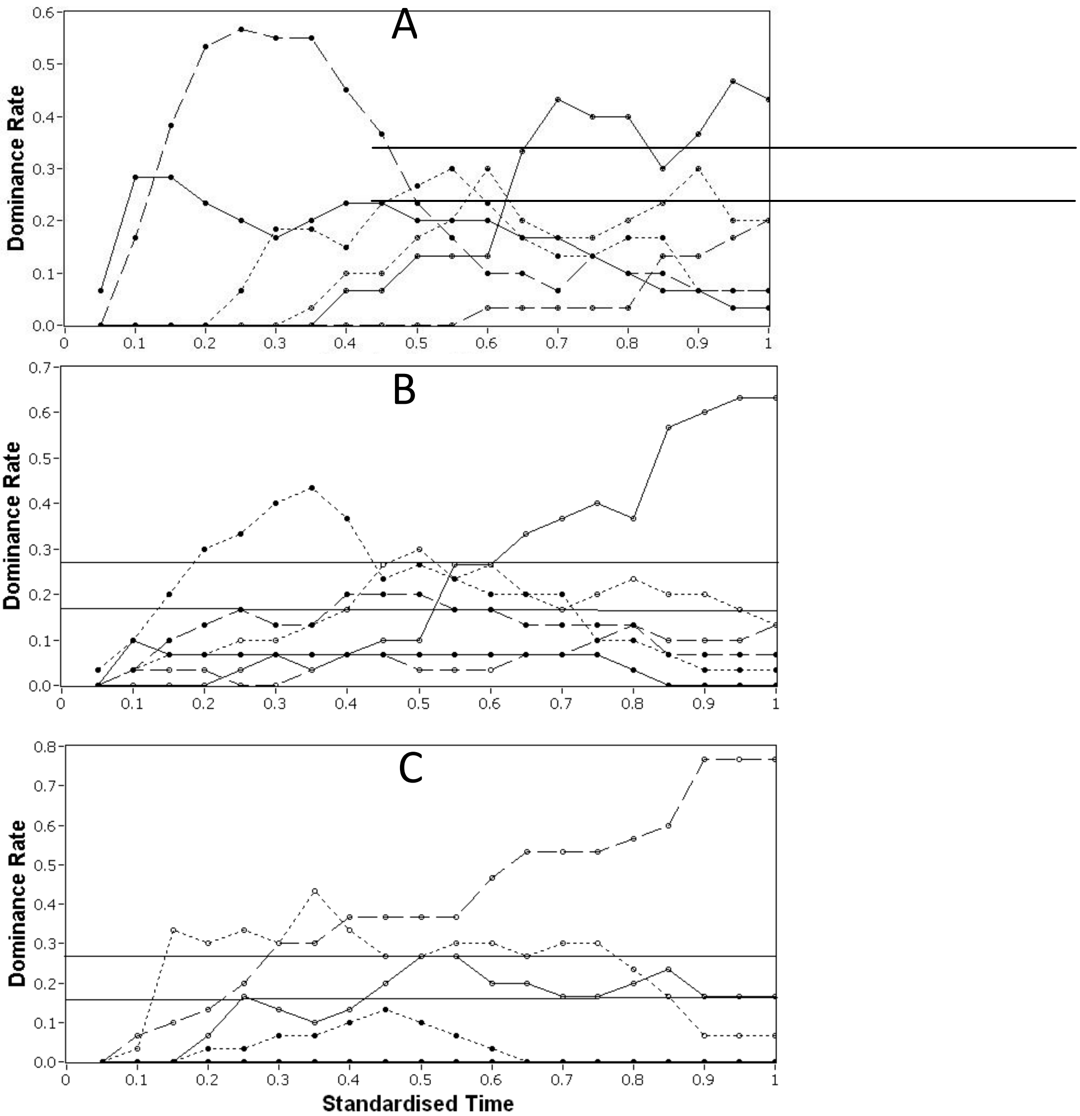

Figure 2: TDS curve for (**A**) whole peanuts; (**B**) Peanut meal; and (**C**) Peanut paste. Hard ●—●, Crunchy ●– – –●, Chewy ●····●, Soft ○····○ Compacted on teeth○—○ sticks to palate ○– – –○.

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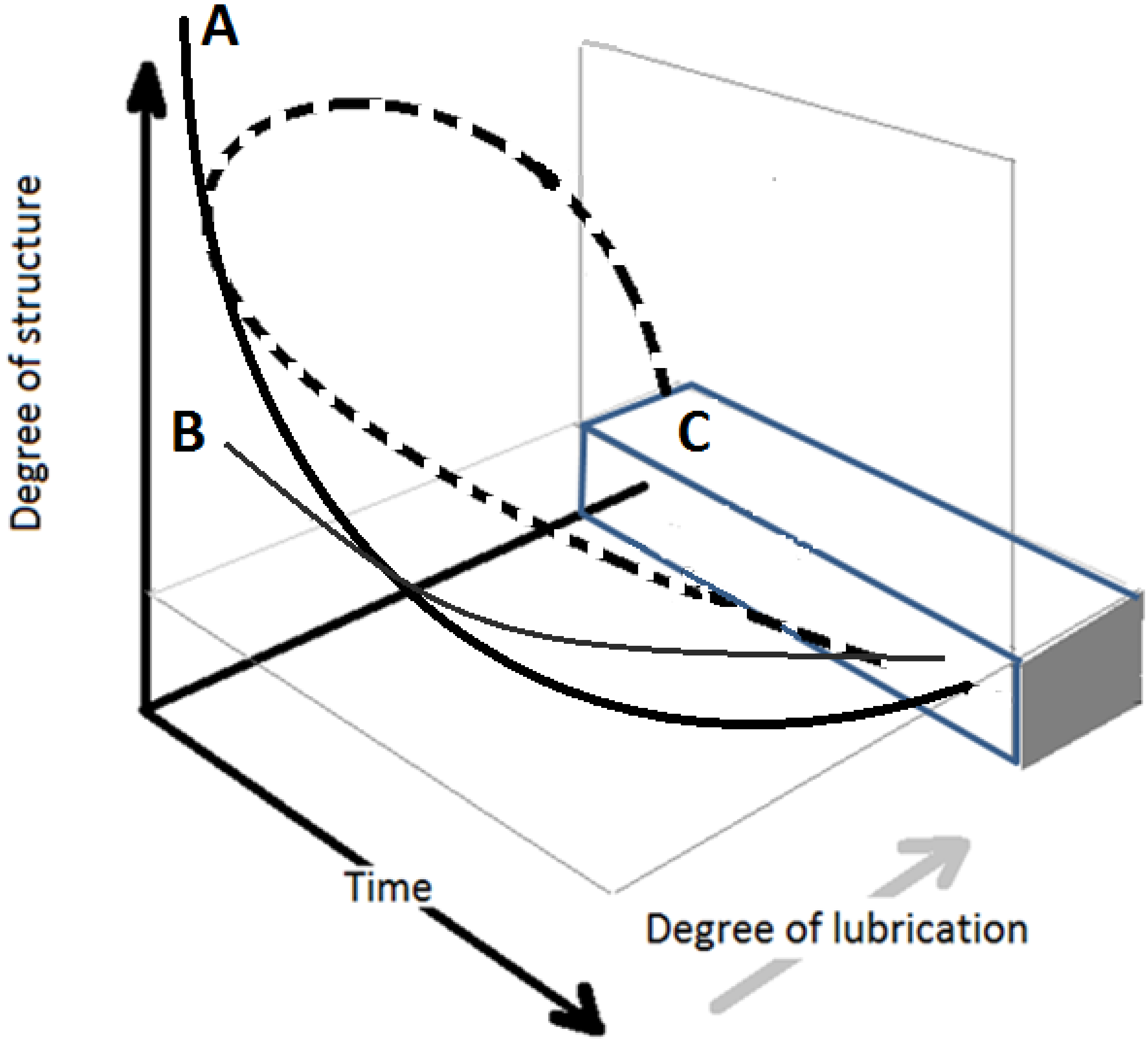

Figure 3: Supposed oral trajectory for (A) Whole peanuts; (B) Peanut meal; and (C) Peanut paste. All superimposed on Hutchings and Lillford's "breakdown path".