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Possible Mechanism for Hard-to-Swallow Oil Seed Pastes

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Abstract

Roasted and crushed oil rich seeds such as sesame paste and peanut butter share both a common structure elicit and the apparent sensation of thickening in the mouth. Working with sesame paste, as an example, the force needed to compress water mixtures increased to about 25% added water. The adhesive force required to pull a plunger from the surface was bimodal with peaks around 15 and 25% hydration. It is postulated that when introduced to the mouth, water from the saliva is absorbed by the paste leading to a hard, adhesive material which sticks to the palate and the tongue, making these materials hard-to-swallow. We hypothesize that the shared hard-to-swallow behaviour exhibited by other oil seed pastes/butters is due to a similar hydration process in the mouth.

Keywords

Sesame paste, peanut butter, bolus, swallow, deglutition, hydration, oral processing

Application

The fact that some foods are hard-to-swallow may provide insights into the mechanisms of swallowing.

Introduction

Dried, roasted/toasted and ground seeds from peanuts, cashew, sunflower, hazelnuts, sesame are often used as spreads or ingredients in the cuisine of various cultures around the world. Products such as peanut butter, tahini, hazelnut butter, cashew nut butter, sunflower spread share a common structure, consisting of a fragments of cell debris suspended in oil. Anecdotal observations from people who eat these products, suggest that they appear to thicken in the mouth suggesting that they might be dilatant (shear thickening). This unusual property does occur in other concentrated suspensions such as starch granules in water and may be responsible for this unusual mouth feel.

We refer to this phenomenon as “anecdotal” because there have been relatively few scientific publications on the matter, however Chen and Lolivert (2011) who investigated the swallowing time of 28 liquid/paste like foods (their premise was that liquid foods would not require mastication for particle size reduction) found that the most difficult food to swallow food that they considered was smooth peanut butter with an average oral residence time of 7 (±1.7) seconds.

This paper seeks to investigate the mechanism behind this hard-to-swallow phenomenon using sesame paste as a model, with the hope that the findings may be transferable to the other similarly structured materials which seem to exhibit this hard-to-swallow phenomenon.

Sesame paste (Tahin, Tahina, Tehina, Tahini) is a widely used in middle eastern cuisine. Eaten on its own or as an ingredient in savoury dishes such as Humous (with chick peas, lemon juice and garlic), Babganoush (with aubergine, garlic), as well as sweet dishes like Halva (with syrups, honey or sugar). It is derived by grinding the dried, roasted, oil rich seed of *Sesamum indicum,* and it yields an oily, buff-brown coloured, opaque liquid consisting of a suspension of cell debris in expressed oil.

From its appearance one might expect this liquid to be easy to swallow, yet as mentioned above it exhibits the hard-to-swallow phenomenon when eaten on its own. The suggestion that sesame paste might be shear thickening may be discounted as several studies have looked at its rheology showing that it exhibits a strong shear thinning (pseudoplastic) behaviour (Abu-Jdayil, *et al*, 2002;Altay and Ak, 2005; Akbulut and Coklar, 2008) which is sometimes thixotropic (Ciftci *et al.*, 2008).

Another possibility is that the sesame paste is reacting with saliva in the mouth, resulting in changes in the rheological behaviour. Lindner and Kinsella (Lindner and Kinsella, 1991) investigated the hydration of sesame paste and showed a rise in viscosity as the water content rose to about 12%. Above 12% the consistency mixture starts to solidify and further viscosity measurements were not possible until the water content reached levels of 40% and above, when an oil-in-water emulsion is formed. This rise in viscosity not caused by shear but hydration may be partially responsible for the hard-to-swallow sensation, but no data exists for what happens between 12 and 40% hydration. This paper seeks to investigate the changes in rheological behaviour within this hydration range.

To monitor this change in viscoelastic behaviour we chose to undertake uniaxial compression of the mixture, by forcing a flat ended probe into the mixture while measuring the force needed to penetrate the surface. We also measured the adhesive force of the material by measuring the tack while withdrawing the probe after the compression (Rosenthal, 2010).

Obviously adding water to a dry material suspended in a water immiscible liquid will not dilute the dispersion. As would be expected the initial effect is for the dry cell debris to become hydrated while still suspended in oil. In order that we could gauge the interaction of the water and the sesame paste constituents, we also examined the water activity of the mixtures – thus giving a sense of how added water associates with the diverse mixture materials likely to be present in the cell debris.

The objective of this study was to fill gaps in the physical data previously collected on the hydration properties of tahini and to relate this to anecdotal reports of the oral behaviour of sesame paste and other similar products formed by crushing toasted oil rich seeds.

Methodology

Sesame paste (Al Taj, Riyadh, Kingdom of Saudi Arabia) was stirred to ensure a homogeneous composition. For the water activity and uniaxial compression, mixtures of sesame paste and distilled water were prepared on a weight-weight basis to achieve the following percentages of water: 0, 2, 4, 5, 6, 8, 10, 12, 14, 15, 16, 18, 20, 22, 24, 25, 26, 28, 30, 32, 34, 35, 36, 38, 40 and 50% water. The mixtures were mixed well with a spatula and about 10 g of each mixture was placed into three separate water activity dishes (Novasania, Switzerland), the surface of the mixture was smoothed out to fill the dish with an plane surface, lidded and left in the dark at room temperature for two days in order that the water distribution equilibrate (the 40 and 50% added water samples were stored at 4^{o}C to prevent mould growth and then warmed to room temperature prior to further testing).

A water activity meter (Novasania TH200) was calibrated by according to the manufacturers recommended procedure with saturated solutions of known relative humidity (RH). The following freshly prepared calibration standards were used: Lithium Chloride (11% RH), Magnesium Chloride (33% RH), Magnesium Nitrate (53% RH), Sodium Chloride (75% RH) and Barium Chloride (90% RH). When samples were introduced to the water activity meter, the dish was de-lidded and swiftly placed into the meter which was sealed. Readings were taken when the reading was steady (± 0.005 water activity unit for 5 minutes). All determinations were done at 25^{o}C. Following water activity determinations, the sample dishes were lidded prior to being used for the uniaxial compression.

Uniaxial compression was determined using a LFRA texture analyser model LFRA1500 (Brookfield Viscometers, Harlow, UK). The sample still in the water activity dish (40 mm diameter) was placed on the instrument base plate and a 10 mm diameter round acrylic probe was used with a speed of 5 mm s^{-1}. The instrument triggered at 1 g resistance and then compressed the sample to a depth of 2 mm. After compression the probe was removed at 5 mm s^{-1}. The force required both to force the probe into the sample and to pull it out were measured. Taking account of the probe contact area, forces were converted to stresses and recorded in Pa.

Results and Discussion

Lindner and Kinsella (1991) made a variety of tahini water mixtures and found them to behave as liquids at water content below 12% and greater than 40%. However, in the range of 14-24% they reported that the rotor of their controlled stress viscometer slipped and in the range of 24-35% the material became inhomogeneous – with the separation of oil. Figure 1 shows the changes in water activity which we measured with addition of water to the sesame paste. The initial water activity (A_w) of the sesame paste was around 0.58 (±0.01). Gradual addition of water barely raised the A_w until about 4% was present, further addition led to a gradual rise reaching an A_w of 0.90 at about 12%, which corresponds to Lindner and Kinsella's lower limit of viscous behaviour. Subsequent addition of water results in a more gradual rise in the A_w until at 28% water where the A_w plateaus out at about 0.99 (±0.01) which corresponds to Lindner and Kinsella's return to viscous behaviour.

Using uniaxial compression we are able to see how the consistency of the mixtures vary with the addition of water. Figure 2 shows the force needed to push the 10 mm diameter probe just 2 mm into the surface. The error bars are standard deviations of triplicate determinations. Obviously at the extremes of hydration (i.e. <12% and >35%) the mixtures behave as liquids and the concept of hardness is inappropriate as the material flows when the probe penetrates the surface, but clearly in the added water range from 12-35% a solid material exists with a peak of solidity around 25%.

In some respects a single penetration uniaxial compression test is similar to the first cycle of the widely used, empirical test protocol, "Texture Profile Analysis" (TPA) which is said to mimic what goes on during the first two bites in the mouth during chewing. In terms of TPA terminology the compressive force in Figure 1 is akin to "hardness" (Rosenthal, 2010).

Removing a flat probe from a sample sandwiched between that probe and a parallel surface is often referred to as a tack test. In TPA terminology this is the "adhesiveness". Figure 3 shows changes in tack as a function of added water.

While there is considerable variation between replicate tests, Figure 3 seems to show two distinctive peaks of adhesiveness occurring as water is added to sesame paste. It is as though different components of the mixture are separately hydrated. At early stages of hydration the components coalesce and to adhere to surfaces on which they contact. It is only when they become fully hydrated that they lose their adhesive capacity. The first of these adhesive peaks occurs at 12-14% added water (when the A_w is about 0.90) and the second peak at a maximum at 25% added water (with an A_w of 0.97). The fact that the A_w is less than one in both adhesive peaks suggests that the substances present have further capacity to bind to water.   From a botanical point of view, it makes perfect sense that cell wall and polysaccharide materials should hydrate at a lower A_w than enzymes, membranes and their constituent proteins thus allowing carbohydrate substrates to be available for metabolism prior to processes such as germination, when enzymes first become functional.

Whatever the constituents and mechanism causing these adhesive events to occur, the overall effect of adding water to this suspension of cell debris in oil, is to initially raise the viscosity of the solution as the suspended particles start to adsorb water. The mixture gradually hardens while reaching a peak of stickiness at about 12-14% water. Further hydration leads to a second, and higher, peak of stickiness which coincides both with a maximum hardness of the mixture at 25% added water. We corroborate Linder and Kinsella's observation of phase separation and liberation of oil at such water contents. Addition of further water results in the formation of an oil in water emulsion (phase inversion) along with softening of the material as the water activity tends towards one.

Water activity has been widely seen as a measure interaction between water and other components, whereby the water sorption isotherm illustrates the tenacity with which water present is bound to other materials. In the case of these water and sesame paste mixtures, the physical state of mixtures up to 12% water are essentially oil based suspensions of particles with low water activity. In this region further small additions of water become absorbed into the particles which remain separate allowing viscosity measurements to be undertaken (Kinsella and Lindner, 1991).

With further addition of water the particles begin to form a network, the adhesive force between particles is apparent at a rheological level with a small increases in tack. Viscosity measurements are no longer possible, but with increasing water addition, solidity develops with the increasing forces needed to compress the mixture and a second peak in the tack. Within this region there is an expulsion of oil as the inter-particle network becomes more established into a coherent mass.

Finally, at high water levels, the mixture is essentially an oil in water emulsion which is thinned by addition of further water and which exhibits an A_w close on maximum suggesting all other macromolecules have become saturated with water and excess water is unassociated in the in the continuous phase.

In terms of oral processing – the source of hydration is predominantly saliva and the low A_w of the sesame paste provides a high water binding capacity able to absorb water from the palate, sucking water from the mouth. In his review of oral food processing, Chen (2009) examines the role of saliva in swallowing. He points out that when stimulated the flow of saliva can reach as much as 4.15 $cm^3\ min^{-1}$, thus a typical 5 g portion of sesame paste would need to remain in the mouth for about 20 s to acquire enough saliva to lubricate it to 30% at which point it starts to behave more like a liquid.

Hutchings and Lillford (1988) created a model to explain how the bolus develops during mastication. They identified three factors: *time in the mouth*; *degree of structure*; and, *degree of lubrication.* They plotted these factors orthogonally (Figure 4a) and postulated that there was a level of material structure above which we could not swallow the bolus. They represented this cut off as a plane across the *degree of structure* axis, whereby foods which existed above this threshold would need to be masticated until the particle size was small enough to swallow (e.g. Peyron et al., 2004). Similarly they suggested that a minimum level of lubrication was necessary to swallow the bolus and again they represented this threshold as a plane across the *degree of lubrication* axis. The intersection of these two planes forms a solid bar shape (in 3D – the third axis being time) outside of which the bolus needs further oral processing to lubricate or disintegrate, but inside of which the bolus can be cleared. Figure 4b shows two example foods which Hutchings and Lillford refer to:

- Liquids start with no structure to break down and have adequate lubrication, it is just a matter of time to enjoy the food before it is swallowed.
- A piece of sponge cake which starts both dry and while friable it does have considerable structure – in the case of sponge cake there is a need for structural breakdown through mastication and

moistening through secretion of saliva. The trajectory line shows how these two factors interact with time

Figure 4c, sesame paste seems to break the rules, while it starts as a lubricated unstructured liquid it rapidly absorbs moisture from the saliva, both drying the mouth and creating structure within itself. Thus it becomes impossible to swallow. Furthermore, it sticks to the palate and tongue, becoming inaccessible to the teeth – thus preventing mastication. It is only with time that enough saliva is secreted or if the subject drinks additional liquid, that it can return to the swallowing bar and be cleared.

Bearing in mind the origin, composition, processing and structural similarity of sesame paste, peanut butter, cashew nut butter and other oil seed pastes, it is difficult to dismiss the hard-to-swallow behaviour in the mouth as being unrelated. Clearly further work needs to be done to verify the similarity, however we hypothesise that the same mechanism of cell debris hydration is responsible for the hard-to-swallow sensation produced by these products in the mouth.

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Captions

Figure 1: Water Activity (A_w) as a function of added water (error bars are one standard deviation).

Figure 2: Compressive force as a function of added water (error bars are one standard deviation).

Figure 3 Tack as a function of added water (error bars are one standard deviation).

Figure 4a Hutichings and Lillford's model of swallowing based on level of lubrication and structural integrity. 4b Swallowing trajectory of two common foods. 4c Swallowing trajectory of sesame paste

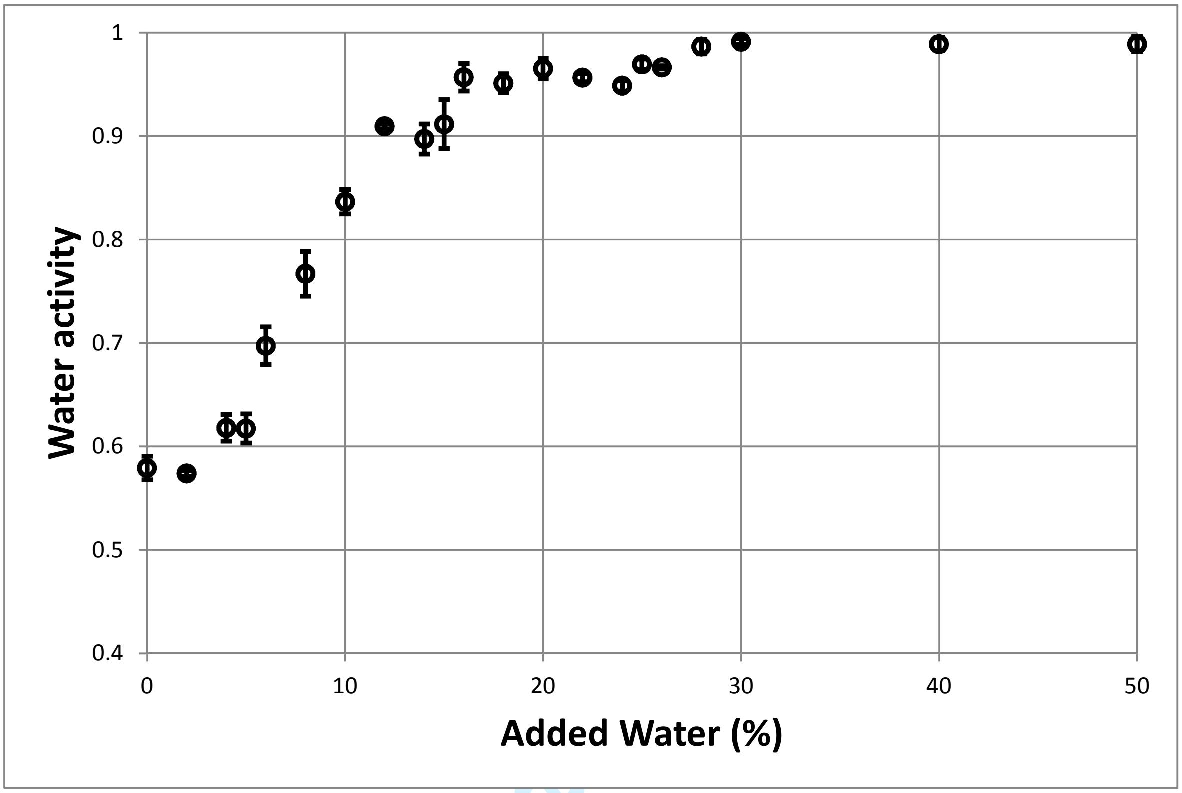


Figure 1

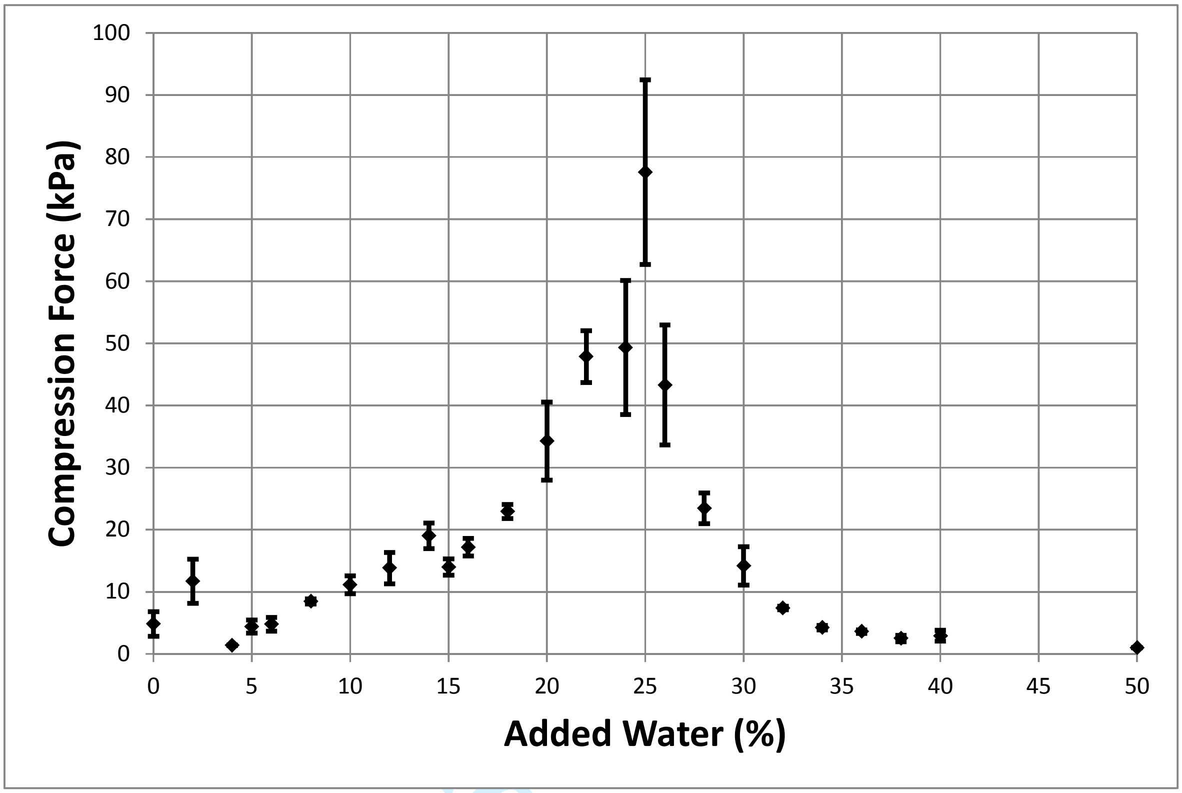
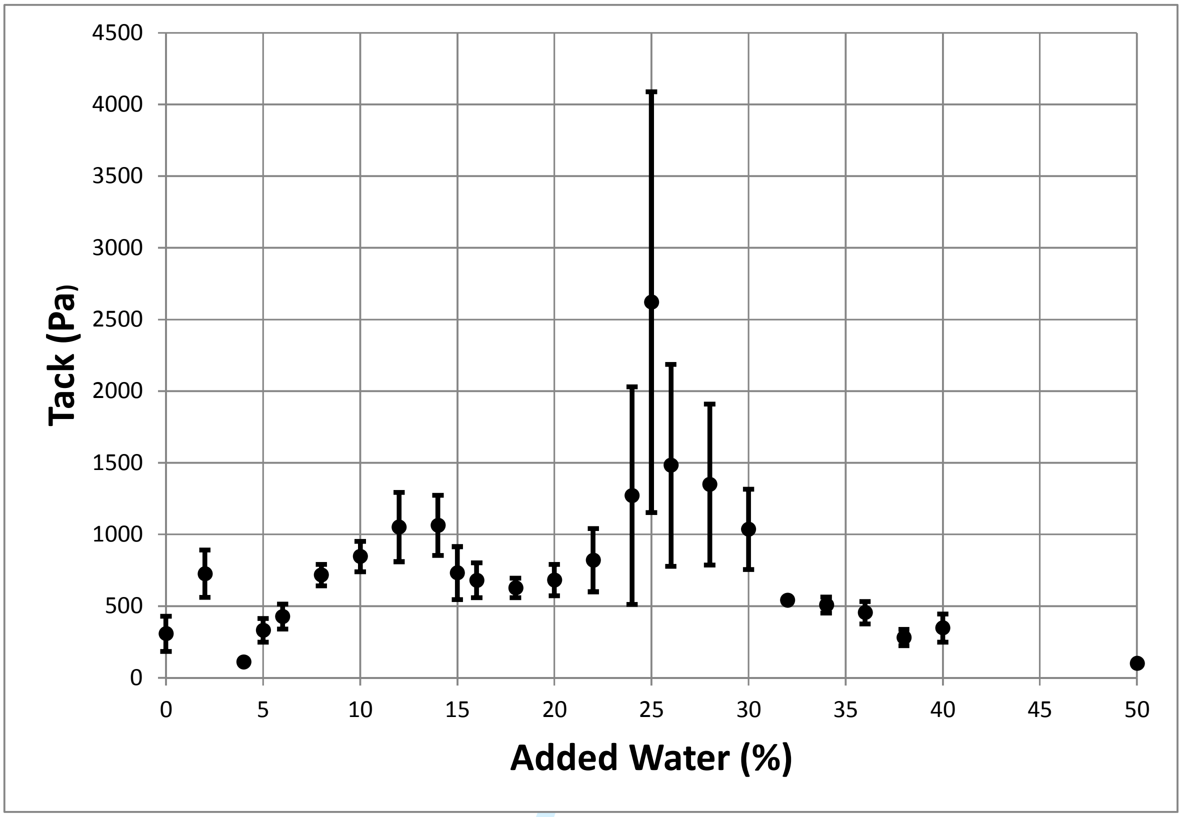

Compression Force (kPa)
Added Water (%)
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
50

Figure 2



Tack (Pa)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
40
45
50
Added Water (%)

Figure 3

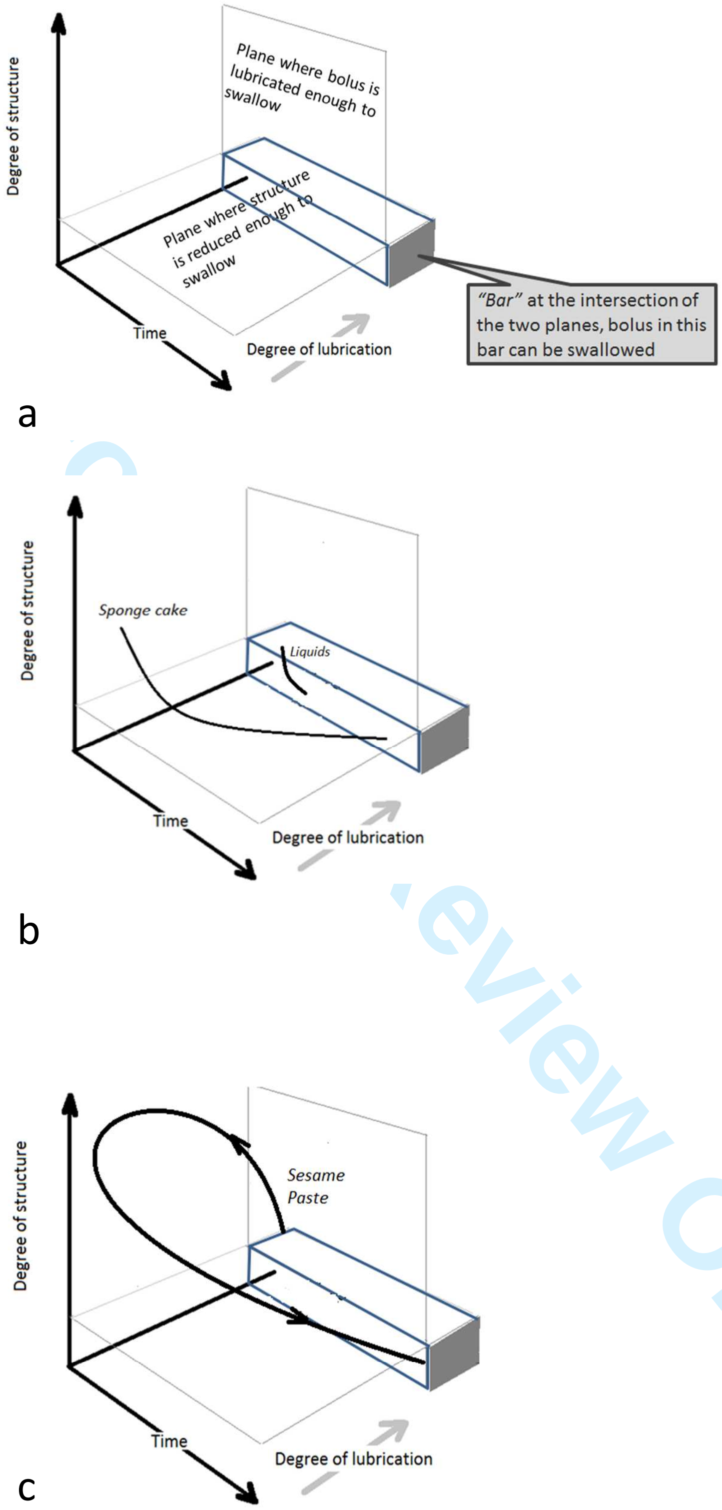

Degree of structure
Plane where bolus is lubricated enough to swallow
Plane where structure is reduced enough to swallow
"Bar" at the intersection of the two planes, bolus in this bar can be swallowed
Time
Degree of lubrication
a
Degree of structure
Sponge cake
Liquids
Time
Degree of lubrication
b
Degree of structure
Sesame Paste
Time
Degree of lubrication
c

Figure 4