What is cohesiveness?

- a linguistic exploration of the food texture testing literature.

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Abstract

Cohesiveness is a widely used term in the food texture literature. Authors of this literature employ divergent methodologies, and can be divided into those who assess texture through sensory evaluation and those who use instrumental techniques. Within each of these disciplines there are some specialized uses of the word, creating discipline specific terms such as "cohesiveness of mass". The fact that many researchers attempt to (re)define cohesiveness, does suggest that the term is not universally understood. This blurring arises partly from the abstract nature of what it describes and also from ill matching measurements being used to quantify it. A widely agreed definition is that cohesiveness is "the strength of the internal bonds making up the body of the product", yet a challenge continues to be how we can measure it.

Using the Sketch Engine corpus analysis interface to examine a corpus of articles from the food texture literature in the period 2002-2017, the contexts in which the word stem 'cohes*' is used were explored. Collocation analysis suggests that in addition to considerable commonality in the way that 'cohesiveness' combines with other terms, differences reflect the foci of the disciplines with the instrumental community predominantly dealing with physical measurement while the sensory community relate 'cohesiveness' more to oral processing and texture perception.

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Introduction

'Cohesiveness' has a colloquial meaning, defined in the Oxford English Dictionary as "… the quality of forming a united whole", yet some words take on a specialised (jargon) meaning in certain contexts. Within the area of food texture studies its meaning is more complicated because texture professionals fall into two complementary scientific disciplines, the sensory scientists and those who deal with physical measurements.

For simplicity, in this paper, we will consider the meaning of cohesiveness in English only, though we recognize many authors have attempted to find equivalent terms in other languages (Drake 1989; Zannoni 1997; ISO 2009; Hayakawa 2015). Moreover, the concept of cohesiveness may not entirely come to mind in certain cultures and some authors do not even mention cohesiveness in their lexicons of texture terms (Yoshikawa *et al.* 1970).

In considering the definitions which different authors have used in an attempt to explain the meaning of cohesiveness we will first look at the definitions provided by scientists in the sensory community.

Szczesniak (1963) made no distinction between instrumental or sensory cohesiveness and defined it as "the strength of the internal bonds making up the body of the product"Later Civille and Szczesniak (1973) went on to conceptualize and refine their definition of cohesiveness as "the degree to which a component is fully compressed between teeth before rupturing"

Two years later Civille and Liska (1975) created a new and separate term 'cohesiveness of mass' which moved our focus from the properties of the food towards the properties of the bolus. These authors distinguish various terms involved in oral processing, explaining that

> *"…. the `number of chews to swallow' measures the time required to break down the product (hardness), hydrate it (moisture absorption), and disintegrate whatever mass might be formed with saliva (cohesiveness). The cohesiveness is the 'cohesiveness of the mass' and may not be related to the cohesiveness of the original cookie. It is conceivable that a crumbly (low in cohesiveness) cracker could mix with saliva to form a highly cohesive mass."*

This valuable distinction helps us remember that the oral trajectory transforms the properties of our food into a swallowable bolus, yet it means that from a sensory perspective we now have two types of cohesiveness to consider.

Some other authors have attempted to relate cohesiveness to oral processing with definitions such as … the "mechanical textural attribute related to the amount of work required to masticate a solid product into a state ready for swallowing" (Carbonell *et al.* 2003), or "the degree to which the chewed mass holds together" specifying it should be based on the perception after five chews (Çakir *et al.* 2012). An *in-vivo* physiological study of pharyngeal phase of swallowing, defined cohesiveness as a feeling of a cohesive bolus while swallowing (Funami *et al.* 2017). Despite these variations on the consistency of the chewed food, the definition and usage of 'cohesiveness of mass' seems to be most widely adopted for the way the bolus holds together.

Returning to cohesiveness of the food, Munoz(1986) refined Civille and Szczesniak's (1973) definition specifying that cohesiveness was the amount of deformation undergone by the material before rupture when biting completely through sample using the molars. She went on to identify a seven point reference scale with standards such as corn muffin, dried fruit and caramel intended to help sensory assessors be consistent in how they used the term.

Over a period of time some definitions have started to change, for example in a paper on the sensory properties of poultry meat cohesiveness is defined as the "amount the sample deforms rather than shears or cuts" and is measured by placing the sample between either the molars or the incisors and compressing fully (Rababah *et al.* 2005).

Of course we can perceive cohesiveness with our fingers and some researchers attribute it to the force to separate finger and thumb when the sample is between (Akissoe *et al.* 2006). In fact the current International Standards Organization definition (ISO 2009) does not mention teeth, but says that cohesiveness is the "mechanical textural attribute relating to the degree to which a substance can be deformed before it breaks". Such a definition seems rather close to elasticity and this has been noted by various authors with a variety of products (Akissoe *et al.* 2006; Scheuer *et al.* 2016).

In defining sensory cohesiveness some authors have considered opposites thereby creating scales of magnitude with word anchors at each end. For example, in the context of pork sausages, there was an inverse relation between tenderness and cohesiveness (Leheska *et al.* 2006) or in the case of particulate quinoa, cohesiveness was placed as an anchor point at one end of a scale, the other end being labelled 'separate' (Wu *et al.* 2017). Working with high protein nutrition bars sensory cohesiveness was set as an opposite to sensory crumbliness and placed as opposite ends of a common scale (Banach, Clark and Lamsal 2016). Thus opposite terms for cohesiveness include 'tender', 'separate' and 'crumbly' – each in different contexts. The product dependence of the use

of a word is noted by Nishinari's group (2008) who recognize different terms are associated with varying magnitudes of a common parameter.

Just as the sensory science researchers have several definitions of cohesiveness, the physical testing community also have differences in their use of the word.

When studying powders the term cohesiveness relates to the flowability and is often measured with an annular shear cell (Ricks, Barringer and Fitzpatrick 2002). Powder cohesiveness may be described in terms of Hausner ratio, which may be defined as the ratio of tap density to the loose bulk density (Geldart, Harnby and Wong 1984). Some workers have related cohesiveness to the water content of a powder, wetter powders being more cohesive and difficult to flow (Teunou, Fitzpatrick and Synnott 1999). Powder particle shape and their ability to entangle with each other also affects the cohesiveness (Toniazzo *et al.* 2017).

One of the more widely used definitions of cohesiveness in the food science community is that proposed by Friedmann, Whitney and Sczcesniak (1963) when they developed their texture testing protocol, Texture Profile Analysis (TPA). In TPA, a food sample undergoes a cyclic double compression and the resisting force is progressively measured. The ratio of the areas under the force:time curve of the second bite compared to the first was used as a calculation (and definition) of 'cohesiveness'. They attributed this value to Szczesniak's (1963) definition of cohesiveness, "the strength of the internal bonds making up the body of the product". The strength of bonds would presumably be measured as a force and as such have units of Newtons, yet dimensional analysis tells us that cohesiveness as defined in TPA is dimensionless, so clearly there is a mismatch in terms of the quantities being equated to each other.

The popularity of the use of TPA can be gauged from a dataset of citations which found over 500 published studies from 1972 - 2009 (Rosenthal 2017). Perhaps its attraction stems from the idea of a simple, easily undertaken, universal test to determine multiple texture parameters for food materials. Yet it is doubtful whether the definition given for cohesiveness matches the quantity being measured (Nishinari, Fang and Rosenthal 2019; Peleg 2019). Moreover, many researchers have modified the original protocol and others have introduced additional terms such as 'cohesion energy' and 'cohesion force' (Nitcheu Ngemakwe, Le Roes-Hill and Jideani 2016).

When TPA was conceived the authors created standard rating scales of food products. The intention was to correlate instrumental and sensory values which encompass the range of each defined term, (Szczesniak, Brandt and Friedman 1963). Correlations were performed for 'Hardness', 'Brittleness', 'Adhesiveness', 'Chewiness' and 'Gumminess' (the latter two terms being derived mathematically from cohesiveness), yet they did not

create a standard rating scale for cohesiveness itself. This may be in part due to ambiguity in attributing the ratio of two areas to the term cohesiveness. It is perhaps little wonder, that some researchers found a negative correlations between sensory and TPA cohesiveness (Wu *et al.* 2017) while others found no correlation at all (Di Monaco, Cavella and Masi 2008).

Several authors talk about cohesiveness as having elastic behaviour or being associated with elasticity. In the case of waxes and solid fats cohesiveness/elasticity is measured by the ability to flow under compression (Wang and Wang 2007; Liu *et al.* 2016). Similar terminology is used for bread (Scheuer *et al.* 2016). Another approach to measuring cohesion is to measure cohesive fracture forces by cutting the food with a wire (Wu *et al.* 2015). Cohesiveness has also been ascribed to the resistance as an immersed plunger is pulled out of a sample of sunflower butter (Lima and Guraya 2005). In their review of adhesiveness, Fiszman and Damásio (2000) describe cohesiveness as 'internal adhesiveness' which provides a tangible image of the resistance to pulling a material apart.

Some works choose to define the term 'cohesion' or the adjective 'cohesive' rather than the nominal 'cohesiveness'. For example Adhikari and co-workers (2001) when talking about forces on particles that stick together say that "cohesion is an internal property of material and a measure of force holding two similar particles/surfaces together"- a definition not dissimilar to that of Szczesniak (1963). Other researchers use cohesive to describe material failure, for example when undertaking a tack test where two parallel surfaces sandwiching a sample are pulled apart. The sample may either detach at one of the two surfaces (adhesive failure) or may start to neck prior to breaking in its middle (cohesive failure) (Dunnewind *et al.* 2004).

This review of the food texture literature has demonstrated that there is a range of understandings of what 'cohesiveness' is and how it can be measured. In the following sections we report on a study in which we examined whether the two research communities, the sensory researchers and the instrumental researchers, use the term cohesiveness in the same way, or whether they are distinct in their conceptualisations of 'cohesiveness'.

The approach taken in this study derives from a branch of linguistics called 'corpus linguistics'. In linguistics, a corpus is a collection of machine-readable texts that has been created for linguistic research purposes, and corpus linguistics makes use of such collections (called a *corpus*, plural *corpora*) for linguistic analyses. The approach is similar to that used in searching literature using abstracting databases, but a corpus linguist looks at entire articles, not just the title, abstract and keywords, and retrieves all

the instances of a word or phrase in the collection of texts. For our purpose, this allows us not only to identify the parts of texts where an author explicitly defines a term, but also to see how the term is used. As we observed above, terms are sometimes understood through a relationship of opposition ('tenderness' and 'cohesiveness', for example) and sometimes through the contexts in which the words appear, in what linguists refer to as 'collocation'. A word is described as being a 'collocate' of another word if the two words have a tendency to cooccur (to be found close to each other, usually set at 3-5 words in either direction) within the corpus (see, for example Hunston (2002)). The approach allows us to look at the frequencies with which the words 'cohesiveness', 'cohesive' and 'cohesion' occur, to see which words they tend to cooccur with and then determine different tendencies within the dataset.

Methodology

Sketch Engine® (Kilgarriff *et al.* 2004) (https://www.sketchengine.eu/) is a web-based corpus management and search tool which allows the researcher to find individual words or roots of words within an entire corpus, or sections of a corpus. The Concordance tool retrieves instances of a search item and presents these in a sortable concordance display (see Figure 1) to examine the contexts in which each word is being used, and the Collocations tool also provides lists of collocates for the search term.

um content are significant (P ≤ 0.01), indicating that good	**cohesiveness**	can be achieved for parboiled rice doughs with a
ofibrillar spaces of CGC flesh demonstrated that a greater	**cohesiveness**	and resilience than GC flesh. Effects of the myof
ral observation that sticky samples usually yield a greater	**cohesiveness**	of mass. These results demonstrate the potentia
and freeze-dried), bread clearly demonstrated the greater	**cohesiveness**	of crumb compared with the control bread. The c
of moin-moin made from cowpea flour having the greatest	**cohesiveness**	ratio (0.28) compared with imbibed cowpea seec
ration distance indicates sensory cohesiveness (hereafter	**cohesiveness**	) (Lanier and others 1985). Ten specimens were
that was not too firm or chewy, and liked medium to high	**cohesiveness**	. The lower sweetness of the boiled samples, co
th small particle size, high charge-to-mass ratio, and high	**cohesiveness**	resulted in high transfer efficiency and adhesion
mportant. Choosing powders with small particle size, high	**cohesiveness**	and high-powder resistivity, and using electrostat
amples that show high values of C2, C4 and A4 had high	**cohesiveness**	). C2 represents the amount of stress at peak of
fore a low Force 2 and a bar with low crumbliness or high	**cohesiveness**	will have a high Force 2. Also, crumbliness is a p
ing the internal cohesion of the material. Breads with high	**cohesiveness**	values are desirable as they allow a bolus to be

Figure 1: Screenshot of a sample of concordance lines for 'cohesiveness' in Sketch Engine, sorted by the first word to the left of the search term.

The first step was to create a corpus of food texture studies in which 'cohesiveness' was considered. Using the Food Science and Technology Abstracts database, we searched the following journal titles in the period 2002 to 2017: *Appetite*; *Food Quality and Preference*; *Journal of Food Science*; *Journal of Sensory Studies* and *Journal of Texture Studies*. We then undertook a second search for: cohesiveness OR cohesive OR cohesion

OR stickiness OR adhesive OR adhesiveness OR tack, before combining these two searches with an AND operator. Some topics identified by the search use 'adhesion' in relation to microbes sticking to surfaces and these were removed as they do not relate to food texture. On the basis of a reading of the abstracts, we then classified the papers as being predominantly "sensory", "instrumental" or "blended" (a balanced combination of the two). The papers were saved as text files (in UTF-8 encoding), all figures and tables removed, and then the files were uploaded as a corpus into Sketch Engine.

The corpus contains 257 papers (two from *Appetite*, 10 from *Food Quality and Preference*, 14 *from Journal of Sensory Science*, 136 *Journal of Food Science* and 105 from *Journal of Texture Studies*).

Using Sketch Engine's Concordance tool, we searched for the root 'cohes*' (where the asterisk is a wild card character, capturing any number of letters following the root term 'cohes'). We also filtered the output using the Collocations function to find the commonest terms/characters within three adjacent words of the root (cohes). This returned 2182 hits, with 1772 instances of 'cohesiveness', 293 of 'cohesive', 110 of 'cohesion' and 7 of 'cohesivity'.

Results and discussion

Definitions

When 'cohesiveness' either starts a sentence or is followed by the word 'is' we often have a definition, such as "Cohesiveness is determined as the degree to which a substance is compressed between the teeth before it breaks…"(Renuka, Prakash and Prapulla 2010) which is very similar to that of Murphy et al (2005) though physiological as opposed to instrumental, or "Cohesiveness is an indication of how the sample holds together during cooking" (Majzoobi, Ostovan and Farahnaky 2011), which is perhaps a little vague. Ten percent of these definitions relate to the TPA definition of areas under curves and four percent relate to cohesiveness of mass. However only two papers (<1%) use Szczesniak's (2002) instrumental definition while only one paper uses her sensory definition and only four use Civille's definition. Having eliminated the standard definitions we can now examine the less standard ones.

A number of authors define cohesiveness as a measure of the difficulty to break the internal structure (Luechapattanaporn *et al.* 2005; Yang *et al.* 2007; Yang *et al.* 2007) which is related to Szczesniak's (1963) definition, and others describe it as the limit of deformation before the material breaks (Murphy *et al.* 2005; Chevanan *et al.* 2006; Siegwein, Vodovotz and Fisher 2011; Martínez, Marcos and Gómez 2013). Some other

authors rather than define cohesiveness say it is an "indication of": structural integrity (Kamali and Farahnaky 2015) or how the sample holds together (Majzoobi, Ostovan and Farahnaky) or how the sample sticks to itself (Salehi *et al.* 2016) and the degree to which particles stick together (Cui *et al.* 2011).

Other physical testing approaches have related cohesiveness to elastic behaviour (Scheuer *et al.* 2016) and some authors suggest that it is the work needed to compress a sample (Liu *et al.* 2016), while others push a probe into a material and define cohesiveness as the force needed to withdraw that probe (Lima and Guraya 2005) and more recently (after the dates of our corpus) (Chetachukwu, Thongraung and Yupanqui 2018)

Of course, oral processing of solid foods leads to bolus formation prior to swallowing and it is widely agreed that during this process the degree of perceived cohesiveness increases monotonically (Funami *et al.* 2017).

Another approach to locate definitions within the corpus is to seek strings of alternative words and opposites. The use of a slash ("/") immediately before or after cohesiveness is a useful way to identify potential alternatives/opposites, and then each line has to be read carefully to gauge the sense from the context. We offer three observations:

- Cohesiveness is treated as one end of a scale. A common partner to cohesiveness in this context is crumbliness and certainly recognizing the opposite does help in defining, for example "…altered cohesiveness/crumbliness" (Banach, Clark and Lamsal 2016) as well as (Imtiaz, Kuhn-Sherlock and Campbell 2012; Banach, Clark and Lamsal 2017). Wu, Ross, Morris and Murphy (2017) give another example when they define a lexicon of terms for cooked quinoa and include "Separate/cohesive".
- Amongst synonyms or closely related terms, the commonest such term associated with cohesiveness is adhesiveness. Many authors have linked the terms for example Hawthornthwaite, Ramjan and Rosenthal (2015) say "..the intensity of sticky/cohesive sensations..". Other authors also make this association including Wu(2015), Tunick(2003), Çakir(2012), Wada(2017) and more recently beyond the dates of our corpus (Mayhew *et al.* 2018; Maleki *et al.* 2020). While some similarity exists between adhesiveness and cohesiveness, some papers distinguish them by the way in which they fail – with cohesive failure in tension exhibiting necking of a sample followed by breakage within the sample itself as opposed to adhesive failure in which little or no necking occurs, yet failure occurs leaving a clean surface (Dunnewind *et al.* 2004).

- A slash can indicate a quotient and in the case of powder cohesion, the Hausner ratio is sometimes cited as a measure of how closely packed the particles are, where Hausner ratio is the tapped density divided by the freely settled bulk density (Toniazzo *et al.* 2017). Another widely used quotient in the context of cohesiveness is its definition within TPA and some authors merely refer to areas within a sketched graph such as "Cohesiveness=(Area 1:2+Area 2:3)/(Area 5:6+Area 6:7)" (Ginés *et al.* 2004).

Collocations

Sketch Engine provides a number of statistics by which to examine the frequency of co-occurring terms. The Dice score (Dice 1945), originally used to measure ecological association between species, can be used to compare the association between independent words (Rychlý 2008). It is defined as

$$Dice = \frac{2 \times fAB}{fA + fB}$$

Where *fAB* is the frequency of the collocated terms, while *fA* and *fB* are the frequencies of the individual terms anywhere in the corpus.

Table 1 shows the strongest collocates within three words of the key word in context (KWIC) 'cohes*' and sorted by the log of the Dice score. The collocations are shown for each of the three categories: sensory, blended and instrumental. We have only included collocations which occur in more than two citing papers in order to eliminate idiosyncrasies (that is, unusual terms which are used in one or two papers). By way of example, Liu and co-workers (2016) in their paper "A novel method of determining wax cohesiveness by a texture analyser" understandably collocate the words 'wax' and cohesiveness 19 times producing a logDice score of 9.7, yet this is the only paper which collocates wax and cohesiveness, and therefore the collocation was excluded.

Table 1: Ten highest logDice scores for collocations of words with cohes for the three sub-corpora (number of papers counted with this collocation in brackets)*

Sensory	LogDice	**Blended**	LogDice	**Instrumental**	LogDice
mass	12.1 (14)	springiness	11.0 (18)	springiness	11.9 (53)
adhesiveness	11.1 (18)	hardness	10.7 (21)	hardness	11.2 (53)
hardness	10.1 (12)	mass	10.7 (9)	resilience	10.8 (13)
springiness	9.8 (8)	adhesiveness	10.5 (18)	adhesiveness	10.5 (28)
sticky	9.5 (4)	chewiness	10.4 (12)	chewiness	10.2 (25)
adhesive	9.4 (7)	crumbliness	10.3 (4)	gumminess	10.0 (14)
less	9.4 (5)	and	9.9 (27)	firmness	9.9 (6)
negatively	9.4 (4)	"	9.9 (4)	and	9.3 (44)
bolus	9.2 (5)	more	9.4 (10)	Force	9.2 (4)

and	9.1 (40)	increased	9.4 (10)	more	9.1 (14)

Our first observation is that commonly used texture attributes/characteristics such as 'hardness', 'springiness', and 'adhesiveness' collocate relatively highly in all three corpora. They often cooccur repeatedly in arrays of text such as "..depends on hardness, cohesiveness and springiness" (Chevanan *et al.* 2006) where the authors discuss contributions of multiple textural attributes concurrently. The sensory corpus has both 'adhesiveness' and 'adhesive'; authors either collocate the nouns or the adjectives together, i.e. 'adhesiveness' with 'cohesiveness', and 'cohesive' with 'adhesive', as is the more colloquial term 'sticky'.

We have already mentioned 'crumbliness' as a possible antonym to cohesiveness while discussing definitions and understandably it shows up in the blended corpus.

Both the blended and instrumental collocations include the terms associated with TPA, such as 'chewiness', 'resilience' and 'gumminess' (occurring in position 14 in the blended corpus). In fact, 'TPA' itself appears in the collocation lists of all three corpora, though the relative position is 17 for the blended corpus while sensory and instrumental are 58 and 88, respectively. The position reflects the relative importance of TPA for each community of researchers.

As has been already stated, the 'cohesiveness of mass' is a discipline specific term and understandably crops up in the blended as well as the sensory corpora. Another notable and related term in the sensory corpus is 'bolus', for both relate to changes in the food during mastication while the instrumental corpus is devoid of both 'mass' and 'bolus'. At the other end of the texture professional continuum, instrumental authors collocate 'resilience' with 'cohesiveness'. Resilience does not show up at all in our sensory corpus, yet bizarrely from a texture point of view it was originally defined in the context of a sensory property being akin to bounciness or the "extent to which a sample returns to its original shape (elasticity)" (Civille and Liska 1975, p26). While resilience was not one of the original measurements obtained from TPA, it is like cohesiveness, a ratio of two areas obtained from texture analysers output. Some of the resilience-cohesiveness collocations provide their own definitions such as "cohesion energy and cohesion force" (Nitcheu Ngemakwe, Le Roes-Hill and Jideani 2016).

Figure 2 presents a visual representation of the collocates of 'cohesiveness', grouped by their grammatical relation to the search word (using LogDice scores). In the upper half of each circle, we can see the nouns that congregate together in 'and/or' relations (usually within a listing of attributes), and bottom right, the nouns that modify 'cohesiveness' (in Sketch Engine this means that the noun precedes the word

'cohesiveness'), and these are broadly similar. ‘Hardness’, ‘springiness, ‘adhesiveness’ and ‘chewiness’ are all closely associated with ‘cohesiveness’ in all three groups, but ‘gumminess’ does not feature in the Sensory subcorpus, and ‘resilience’ is particular to the Instrumental corpus. ‘Irregularity’ and ‘release’ are particular to the Sensory corpus. As for verbs, the majority in all three categories relate to measurement (‘increase’, ‘decrease’, ‘calculate’, etc) and the Sensory articles are particular in the use of the verbs ‘differentiate’, ‘rank’, ‘perceive’ and ‘score’.

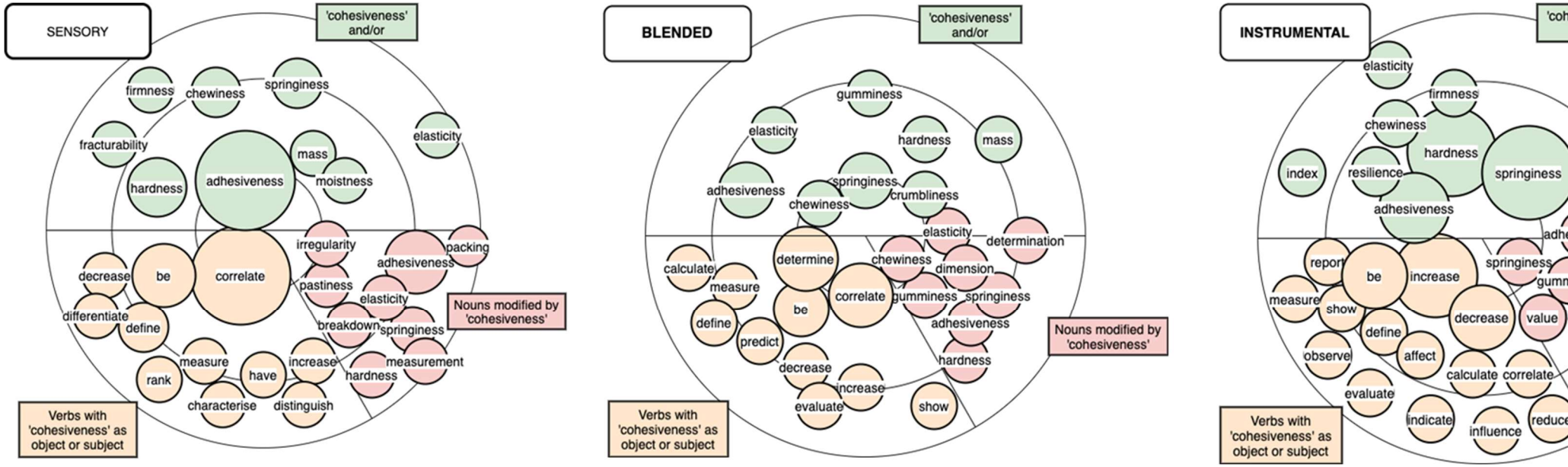

Figure 2: Collocates of ‘cohesiveness’ in the three sub-corpora, grouped by words that are in ‘and/or’ relationship with ‘cohesiveness’ (top), verbs that have ‘cohesiveness’ as a subject or as an object (bottom left), and nouns that are by cohesiveness (bottom right). Words towards the centre of the circle have a stronger collocational relationship to ‘cohesiveness’ [adapted from a visualization created by Sketch Engine]

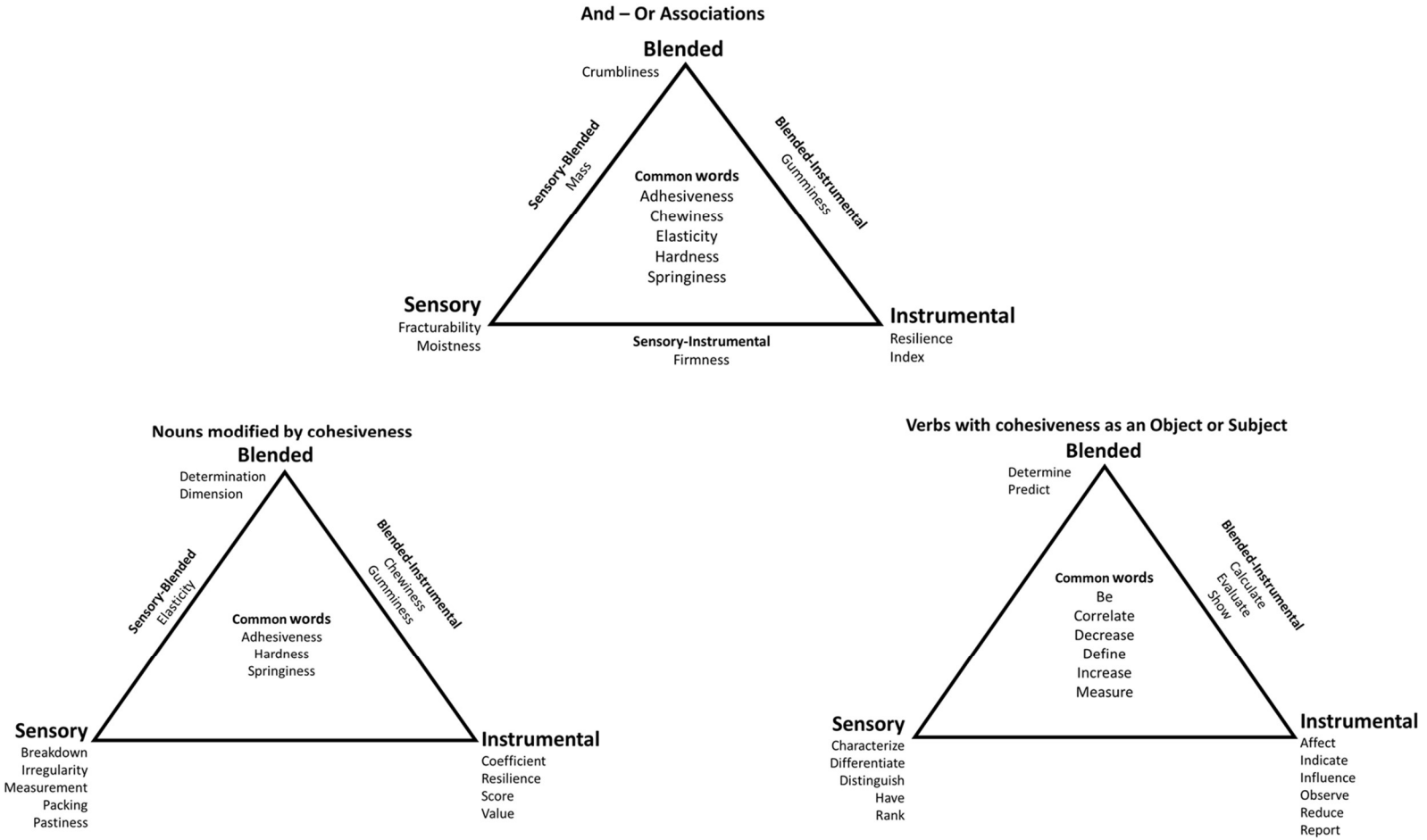

Figure 3

Collocates of ‘cohesiveness’ showing commonality between the three sub-corpora, grouped by words that are in ‘and/or’ relationship with ‘cohesiveness’ (centre), nouns that are modified by ‘cohesiveness’ (left), verbs that take ‘cohesiveness’ as an object or as a subject (right)

Figure 3 is extracted from Figure 2 which is a visual re-presentation of the collocates of ‘cohesiveness’ grouped by grammatical relationships to the search word (using LogDice scores). Of course Figure 3 reflects many of the terms in Table 1, yet it helps us to see similarities and differences between the three corpora. ‘Cohesiveness’ naturally links to other texture terms through and/or associations (Figure 3 top left). Such terms are often common to all three corpora, for example ‘adhesiveness’, ‘chewiness’, ‘hardness’ and ‘springiness’. When reading the literature, there is a sense that these nouns are linked formulaically, such that when one is mentioned, others must be included. In this respect they sometimes lose their individual meaning – becoming a mishmash of what we call texture. Yet Figure 3 also shows us where the corpora differ from each other in the way researchers refer to ‘cohesiveness’ and some of the disciplines have particular jargon terms such as ‘resilience’ (specific to TPA and associated only in the instrumental corpora) or as discussed previously we find ‘mass’ (in the context of ‘cohesiveness of mass’) being used in both the sensory and blended corpora.

The sensory literature does stand apart from the instrumental and blended papers when we consider nouns modified by ‘cohesiveness’ (Figure 3 centre). Here the blended and instrumental documents focus on measurement terms such as ‘determination’, ‘dimension’, ‘coefficient’, ‘value’ and ‘score’, whereas the sensory papers are more to do with mouthfeel and oral processing with terms like ‘breakdown’, ‘pastiness’, ‘irregularity’ and ‘packing’ (as in tooth packing).

The three corpora seem to vary in the verbs that take ‘cohesiveness’ directly as a subject or as an object (this excludes instances such as 'the intensity of cohesiveness was highest' but includes 'crumb cohesiveness decreased').

The blended corpus understandably contains verbs used by both or either the sensory and instrumental corpora, with verbs like ‘correlate’, ‘measure’, 'increase' and ‘decrease’ shared across all three. The verb 'determine' stands out, but closer inspection of the data reveals that 18 out of the 20 instances in which this verb appears with 'cohesiveness' come from a single paper, Liu (2016).

Our analysis of the verb collocation data indicates that there is both commonality and difference in the verbs used. All three feature 'correlate', 'increase' and 'decrease' but the incidence of 'correlate' is far higher in the sensory data, whereas the latter two are more common in the instrumental. Broadly speaking, the instrumental corpus appears more factual and numerical with terms like ‘correct’, ‘increase’, ‘multiply’ and ‘calculate’ (shared with the blended corpus). In contrast the sensory corpus is more about feeling and perception with words like ‘differentiate’, ‘distinguish’, ‘have’ and ‘characterise’. It

should not surprise us that the choice of nouns and verbs where 'cohesiveness' is the object are more about physical method and measurement in the instrumental corpus, while authors of work that make up the sensory corpus deal more with differentiation, feeling and breakdown [in the mouth].

The blended corpus contains characteristics of both the sensory and instrumental communities, sharing verbs and nouns with both. Yet with the exception of words that are shared by all three corpora, no verbs or nouns associated with 'cohesiveness' are shared between the sensory and the instrumental corpora. It is as though their researchers are discussing 'cohesiveness' in different ways.

Without doubt one limitation of this study has been the breadth of coverage of the literature in developing the corpus and the classification of whether articles are sensory, instrumental or a blended mix of the two approaches. We have also sought to restrict the corpus to a fixed time scale, and clearly our understanding of language continues to change as does our understanding of 'cohesiveness'. What is reassuring of our classification of papers into sensory, blended and instrumental is how they do consistently behave in similar ways within each of the sub-corpora. Thus papers with collocations to mass and bolus seem to be classified in a similar way and feature in the sensory and blended corpora.

Figure 3 does not allow us to gauge the strength of the collocations, yet the proximity of a term to the centre of the circles in figure 2 gives us this information. Thus for example the and/or term 'mass' is strongly associated with 'cohesiveness' in the sensory corpus, but less strongly associated in the blended corpus. Similarly some of the terms common to all three corpora vary in the strength of their association between the literature of the disciplines, for example 'springiness' has an and/or association with 'cohesiveness' in all three corpora, yet figure 2 shows a range of loci away from the centre and this is further confirmed with the LogDice scores in table 1 (11.9 for instrumental, 11.0 for blended and 9.8 for sensory).

If we were to look at the collocates of the words which collocate with 'cohesiveness', we find that the terms which relate to the relative position (e.g. more & less) are used most commonly with 'cohesiveness' compared to other textural attributes (e.g. 'hardness', 'springiness', etc) this suggests that 'cohesiveness' is used as a comparative term as opposed to an absolute value, perhaps implying that it is not fully understood.

The authors of this paper began their study with the hypothesis that the instrumental and sensory communities use 'cohesiveness' in different ways and if we merely look at

LogDice scores of collocations we would conclude that their hypothesis is disproven. Yet if we consider the grammatical structures which associate 'cohesiveness' with other words we start to see that the instrumental community focus on absolute values and scores, while the sensory community relates 'cohesiveness' with mouthfeel and oral processing.

Some of the older texts on texture talk of instrumental tests being objective, with the implication that sensory evaluation is subjective (this is something which the authors of this article have fought to allay, as modern sensory testing techniques can be highly objective). In fact what seems to come out of this study is that the sensory community recognize 'cohesiveness' as an experience derived through eating, starting with whole foods, each with their own textural properties, and which gradually change through oral processing, starting with the first bite, then mastication and bolus formation. The sensations experienced during these steps are real to the individual and reproducible across the population. Such sensations seem better defined and understood than the instrumental concepts which do not command a consensus but which have been adopted by many within the instrumental community, following suggestions by influential authors.

Moreover the instrumental definitions of cohesiveness have at times (e.g. TPA) been based on ill thought through measurements. Researchers who define cohesiveness through TPA should be cognisant of the technique's limitations and susceptibility of results to operating conditions (Nishinari, Fang and Rosenthal 2019). Whilst Szczesniak's (1963) definition of cohesiveness as "the strength of the internal bonds making up the body of the product" does make sense, the challenge, particularly for the instrumental community, is how to measure it - for TPA is certainly not the answer.

Conclusions

In conclusion, 'cohesiveness' is a widely used term in the food texture testing literature. A variety of definitions and way of measuring it have been put forward, though some measurements do not tally with the definitions used.

While some of the definitions for 'cohesiveness' used in the literature are more tangible than others, definitions and ways of measuring the phenomenon do not always align with each other.

Collocation analysis of journals that deal with food texture during the fifteen years up to 2017 indicate a number of common terms between the instrumental and sensory (and blended) research communities. Differences in the use of 'cohesiveness' tend to reflect

the focus of the disciplines with the sensory science researchers delving more into perception and changes during oral processing. In contrast the instrumental community deal more with physical measurement and calculation.

Ethical Statement

The authors declare that they do not have any conflict of interest. This study does not involve any human or animal testing.

Data availability statement

The corpus that supports the findings of this study are openly available in SearchEngine.

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