Quantification of bread crust crispness including the effects of selected additives

By

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Abstract

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Bread crust crispness is one of the most important and desirable characteristics that express the level of freshness and quality for bread classified as 'crispy'. Several approaches have been used to determine food crispness; however no reliable objective method for bread crispness has been reported yet.

To understand and quantify bread crust crispness, standard procedures for both instrumental and sensory measurements should be developed. Therefore, the first part of this research aimed to investigate both mechanical and acoustic parameters that relate to bread crust crispness determination and correlate them with sensory evaluation using expert panels at 4, 24, 48 and 72 hours post baking. A texture analyser (TA-XT plus) fitted with an acoustic envelope detector was used to determine mechanical and acoustic parameters. Five different bread formulae were evaluated at 4 and 24 hours post-baking, predominantly for crust crispness

Two new experimental parameters were investigated in an attempt to standardise instrumental and sensory evaluations to improve consistency in the outcomes of the studies. Several mechanical and acoustic parameters either separately or in combination were tested and the results were compared with sensory evaluations. The ratio of sound pressure level and maximum force (SPL/Force$_{max)}$ along with the ratio the number of sound peaks and maximum force (AUX/Force$_{max}$) were chosen as instrumental crispness indicators due to their significant positive correlations with sensory evaluations at 4, 24, 48 and 72 hours post baking. SPL refers to sound pressure level (dB) which is the highest sound recorded during the fracture of the sample at a certain threshold, AUX refers to the number of sound peaks resulting from the pressure of the wedge probe on the surface of bread during the process of penetration, and the Forcemax is the maximum force (Kg) required during the fracture of the crust. Then the influence of selected additives on bread crispness and crumb firmness were studied. For crust crispness, both experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ were used as instrumental crust crispness, while crumb firmness was tested using compression test as reported by AACC (74-09).

Polydextrose, sodium alginate, and enzymes dough conditioner (EDC), citrus fiber and mono and di-glycerides (M&D-G) were used as additives to modify the bread formulation, each in three different ratios. The migration of water from wet crumb to dry crust is considered as the main reason of bread crust loss, therefore the main reason of choosing those additive was based on their highly water binding capacity.

The addition of 1% polydextrose, 0.25% and 0.5% sodium alginate and 1% enzymes dough conditioner (EDC) increased the sensory measures of crispness significantly above the control bread, and in most cases both SPL/$Force_{max}$ and AUX/$Force_{max}$ were also significantly higher than the control. Other concentrations were similar to the control or less crisp. The addition of M&D-G to the dough formulation did not show any effect on bread crust crispness. Neither did the addition of citrus fibre. Both experimental parameters showed high correlations with the sensory analysis when comparing bread of the same age, either 4 or 24 hours after baking. However conducting the sensory analysis at two different time points in the absence of score references lead to similarity in scores awarded at 4 and 24 hours, which did not fully reflect the loss of crispness occurring during this period. To allow the evaluation of both instrumental and sensory analysis at the same time, a follow on experiment was conducted using two different bread recipes at two different ages (4 and 24 hours) baked at the same time within two consecutive days.

In conclusion, this work demonstrated that both experimental parameters relatively corresponded with the sensory evaluations even when the time factor was compensated for. AUX/$Force_{max}$ showed more accuracy in reflecting the level of crispness than SPL/$Force_{max}$ while SPL/$Force_{max}$ seems to measure the of crust staling values. Polydextrose, sodium alginate and EDC in ratios of 1%, 0.25% and 1-2% respectively showed better enhancement both for bread crust crispness and crumb softness. Further work regarding the effects of polydextrose, sodium alginate and EDC was recommended to determine the optimal amount of these ingredients to ensure a better crispy product.

Declaration

I declare that the work and the contents of this thesis have composed by myself and have not been accepted in any previous application for a degree. The work and the information provided by others have been acknowledged by means of referencing.

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Dedication

I would like to dedicate this work to my parents, wife and children

(Ali, Ebtehal, Raghd and Jana Al-hebeil)

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List of Abbreviations

AACC = American Association of Cereal Chemists

AOAC = Association of Official Agricultural Chemists

TPA = Texture profile analysis

SPL = Sound pressure level

AED = Acoustic envelope detector

DSC= Differential scanning calorimetry

$\text{Force}_{\text{max}}$= Maximum force applied

AUX= Number of sound peaks

RH = Relative humidity

S.Cb. F= Sensory crumb firmness

S. Ct. C = Sensory crust crispness

S.Ct. H = Sensory crust hardness

F. peaks = Number of force peaks

I.Cb.F = Instrumental crumb firmness

I.Ct.F = Instrumental crust firmness

EDC = Enzymes dough conditioner

M&D-G = Mono & Di-Glycerides of fatty acids

S. alginate = Sodium alginate

C.T = Crust thickness

B.W = Bread weigh.

Chapter 1: General Introduction

1.1 Understanding of crispness

Crispness is one of the most important textural and organoleptically desirable qualities of dry crisp foods, and has been studied by many researchers. Different definitions and meanings of crispness, along with studies of instrumental measurement of crispness, and its importance will be described in this chapter. The acoustic envelope detector technique is presented as a potential method for the objective evaluation of crispness. The texture analyser TA-XT plus has also been used successfully in the food industry for many years for various purposes. The basic principles of acoustic envelope detection using the texture analyser and other applications are reviewed in this chapter.

In recent years, several researchers have worked on the various definitions and meanings of crispness (Table 1.1). The importance and attractiveness of crispness has increased and doubled research efforts to define and measure this feature (Szczesniak 2002).

Szczesniak (1998) attempted to describe crispness based on consumer descriptions and found that crispness was linked with brittleness, crackling, snapping, crunchiness and associated sound emission during eating (Castro-Prada, Luyten et al. 2007).

Several researchers have reported that crispness and crunchiness are associated sensations; however crunchiness is used more often to describe moist foods such as apples (De Belie, De Smedt et al. 2000). Moskowitz and Kapsalis (1974) applied regression analysis to investigate the correlations between different food attributes. They found that the sensation of crunchiness was similar to the sensation of crispness and the former was highly correlated with both crispness and hardness. For many products, crispness is the characteristic most appreciated by consumers and the majority agree that this property is perceived and evaluated by the behaviour of the fracture and the sound emitted during the process of fracture (Luyten, Plijter et al. 2004).

According to Duizer (2001a), acoustic theory and structural knowledge should combine with each other to optimise understanding of crispness. The crispness sensation can be better understood when fracture behaviour and acoustic emission analysis are evaluated simultaneously. Therefore, the related information between fracture and sound emission can explain the crispy/crunchy characteristics of a food product.

The definition, measurement and causes of crispness, as well as the related sensations such as crumbly and crunchy are very complex and imprecise. Vincent (1998), suggested that the crisp sensation should be converted to forms which can be described in a scientific way and this is through the use of sensory, mechanical and acoustic methods (Primo Martin, Beukelaer et al. 2008).

Table 1.1: Different definitions of crispness (Luyten et al., 2004)

Definition	Technique	Reference
Relative force required to bite through the food.	Biting with front teeth	Jeon et al., (1975)
Foods that produce a high pitched sound	Biting with front teeth	Vickers, (1984b)
First Bite: place the food between the incisors, bite through and evaluate the level of high pitched noise.	Biting with front teeth	Seymour and Hamman, (1988)
Firm and brittle, snaps easily, emitting a typical frequency of sound upon deformation.	N/A	Szczesniak, (1988)
The perceived relative force used by crunching food in the mouth.	Molars	Onwulata and Heymann, (1994)
The amount and pitch of sound generated when the sample is first bitten with the front teeth.	Front teeth bite	Harker et al., (1997)

1.2. Characterization and determination of bread crispness

The sensation of crispness detected from bread crust is one of the most important sensory characteristics on which consumers depend to express their appreciation of those types of bread characterised by crispy crust. Due to the rapid loss of the crispness property which starts immediately after baking through the migration of the water from the wet crumb to the dry crust, the latter converts from crispy dry to leathery resulting in decrease in its quality, desirability and shelf-life. Several ingredients have been suggested to be involved in the migration of water, but the main parameters are still inconclusive (Primo-Martin, Castro-Prada et al. 2008).

Hence it is important to investigate the relation between loss of crispness and parameters like ingredient composition, processing conditions and product morphology structure. This understanding might lead to development techniques to achieve the desired crispness of bread crust. Improving crispness retention of bread crust would enable the food industry to create longer shelf life crispy baked products that remain acceptable for the consumer (Van Nieuwenhuijzen, Meinders et al. 2008).

Although several methods using instrumental measurement of crispness in foods have been developed, a standard measurement method does not exist yet. The properties related to crispness are able to reveal the difficulties in defining crispness and its relation to other similar sensory attributes, such as brittleness, hardness and crunchiness (Castro-Prada, Luyten et al. 2006).

Various studies have been conducted on the fracture of brittle foods, however, Primo-Martain et al (2008) were the first researchers who studied bread crust crispness connected to and supported by multiple layers (whole bread).

Since 1970s until the earlier of 1980 magnitude estimation technique was used to determine the property of crispness. In this technique one sample was determined first and is given arbitrary grade, then asked the panellists to evaluate and score other samples based on the score awarded to the first sample. This type of sensory analysis used for untrained panel of 20 – 25 panellists. After 1980 until current time descriptive analysis was used as reliable measurements for most sensory characteristics (Roudaut, Dacremont et al. 2002).

Mohsenin (1986) reported that there are two main approaches can be followed for evaluation of food crispness. Crispness can be evaluated either on the basis of scores given by the members of a sensory panel or on the basis of mechanical and acoustic properties of foods themselves. The former approach is known as sensory evaluation of food texture. Although this does offer acceptable results, effect of subjective human factors cannot be ruled out (Kilcast 1999).

On the other hand, sensory methods can be both expensive and time consuming (Boume 1994). Moreover, tested attributes are affected by physiological and psychological factors and therefore more information on individual preferences must be gathered before the results of sensory evaluation can be reasonably interpreted (Mohsenin 1986, Luyten 1992). Instrumental evaluation is the second approach in evaluation of food crispness. This method is more reliable and is mostly free from human factors (Mohsenin 1986).

1.2.1 Sensory aspects

Sensory analysis is a scientific approach for evaluation the properties of a product by using the human senses such as sight, smell, taste, touch and hearing (Kuti, Hegyi et al. 2004). The sensory properties of food are extremely important in addition to chemical and physical parameters, where these properties determine both consumer acceptance and the quality of the product. Sensory analysis is classified into two major categories, Qualitative and quantitative analysis. Quantitative analysis includes measurements which deal numbers, such as lengths, height, time, speed and temperature while qualitative methods are descriptive deal with description which meant that data can be observed not measured such as colours, smell and taste. Both of them are used in defining critical attributes of a product. Consumer preference and quantitative descriptive data provide worthy information during the improvement of new product (Murray, Delahunty et al. 2001).

Consumer preference data provide information on a product’s acceptance or consumer perception of its integrated attributes, but untrained consumers are not able to use words and numbers accurately to describe specific product characteristics that only a trained panel can provide (Noble 2006). Conversely, a trained panel provides a precise, reliable qualitative and quantitative description of the attributes of a product, but not its acceptance (Munoz and Chambers 1993). Many developments and advances in this area have been made since Methods for Sensory Evaluation of Food was published in 1967 (Elizabeth 1977). Research, product development, and quality control are the three main areas where sensory testing is utilized (Meilgaard 1999).

Several types of sensory tests exist. For example, quality difference tests are often used to evaluate in which quality the samples differ, while the affective sensory tests evaluate the consumer acceptance level of products. A triangle test is a type of discrimination tests to determine if there is a sensory difference between two products or to study the effect of changing a certain ingredient on the final product (Meilgaard 1999). The sensory test measures if any differences that have been detected are “real” by analysing the sensory data for statistical significance. After statistical analysis has been made, the researchers can make a meaningful interpretation from the results of the sensory data (Meilgaard, Civille et al. 2007). Sensory evaluation conducted at the lab research team and selected panel level is considered as the simplest approach either during the development of a new product or enhancing an existing product.

The evaluation of perceived characteristics of dry cellular food such as chips or derived cereal products are widely implemented by using sensory analysis and the findings are generally compared with physical measurements of crispness (Chaunier, Courcoux et al. 2005). It is a very difficult and complex process during sensory evaluation to differentiate some food products on the basis of their crispness, crunchiness and crackliness. These terms are difficult to differentiate as they may be used interchangeable even by trained examiners (Brown 1994, Guraya 1996).

The quantification of crispness by a sensory approach is not a simple process. The difference among sensory findings and their descriptions should be recognized. Therefore, the use of the same descriptor in different studies, particularly with trained panellists is not an assurance that the same sensory concept is measured. On the contrary, different descriptors might have been used to refer to the same concept. For example, ‘crunchy’ is used to characterize some products described as ‘crispy’ by other panels (Roudaut, Dacremont et al. 2002).

An exact definition of the meaning of the sensory characteristics crispness and crunchiness does not yet exist, but there is general agreement that both “crispy” and “crunchy” are sensations correlated to the rupture properties of food materials (Luyten, Plijter et al. 2004). Previous researches regarding food crispness determination were mainly depended on sensory evaluation due to the lack of instrumental method having the complexity, sensitivity and extent of mechanical motions as existing in the mouth (Bourne 2002).

1.2.2 Mechanical properties

The mechanical characteristics were considered to be the most significant in the evaluations of the textural properties of foods (Szczesniak and Torgeson 1965). Probably the most common objective measurement for crispness is a determination by using mechanical properties. The mechanical features are associated with the structural features of materials obtained by their ability to resist a compression of a blade or probe and to a tension which pulls the structure of food material regardless of using a universal testing machine such as Instron or a Texture Analyzer TA-XT.

Several modifications of jigs (probes) and tools can be used for objective investigations, such as the shear compression blade, the puncture probe, the Kramer shear-compression test cell, and the snap test cell (Antonova 2001). Generally the tests regarding food texture are dependent upon the nature of the products. Consequently, various mechanical tests have been reported for both low and high moisture foods (Vincent, Jeronimidis et al. 1991). The bite test was frequently used to determine some parameters such as bend deformation, fracture behaviour and firmness as reported by Vickers and Bourne (1976a). In addition, they found a strong correlation between those measurements and sensory crispness.

The number of force peaks detected by using a Warner-Bratzler shear force (WBS) test cell on dried food can be considered as one of crispness indicator in a certain fried food such as fried bacon (Voisey 1979). WBS is an imprecise predictor of beef tenderness characteristics determined by trained panellists (Caine, Aalhus et al. 2003). The crispness of biscuits was determined by using a fixed force rate showed a good correlation between sensory crispness and the ratio of work to fracture and total work (Vickers 1988). Despite the fact that mechanical tests are relatively rapid and easy to implement, they have not produced high enough degree of correlation with sensory crispness of bisects. Furthermore, these tests are not suitable for many types of crispy food due to their size and irregular shapes (Castro-Prada, Luyten et al. 2007).

Texture properties such as crispness of food are usually quantified by plotting the force required to deform or break samples against time or distance (Segnini S 1999). Szczesniak and Hall (1975) assessed potato chips with the General Foods Texturometer. They found that the height of the first peaks obtained using a two-bite compression was highly related to crispness. The two bite compression test was developed further into a standard texture profile analysis (TPA) (Hirte, Hamer et al. 2013).

Dagon (2005) evaluated the number of force peaks formed during the penetrating test using conical probe, however the limitation of this approach is that both the number of force peaks and maximum of force applied is related to toughness and hardness which in turn related to the crispness in some aspects, but not directly reflected the level of crispness.

The breakdown of food structure may produce small and many pieces, associated with sounds effects. The direct measurement of crispness has been suggested by Vincent (1998, 2004). He converted ‘‘crispness’’ into a form that is describable by materials science in order to measure independent parameters at the material and structural levels.

Mechanical parameters may reflect crispness of food. They are mainly associated with the structural properties derived from force-deformation of the tested food material. The mechanical approaches were performed for measuring crispness in different foods, such as biscuits and bread (Chen, Karlsson et al. 2005, Primo Martin, Beukelaer et al. 2008), potato chips (Katz and Labuza 1981), breakfast cereals (Sean 1997, Sanz, Primo-Martأ-n et al. 2007), and breaded shrimps (Tahnpoonsuk 1999).

1.2.3 Acoustic properties

One of the most important quality parameters for perceiving and determining the crispness is the sound emission during the fracture of a crisp food (Vickers 1976). The first study of ‘crunching sounds’ was made by Drake (1963). He found that the sounds emitted from crispy food are different from those of non-crispy food in their amplitude. Another study conducted by Darke (1965) showed that the correlation between sound amplitude and perceived loudness was high. After the leading role played by Drake (1963, 1965), Victers and Bourne (1976) set a hypothesis that the crispness sensation was produced by sounds. They postulated a model of the cellular structure to explain the generation of crisp sounds. As a crispy structure is penetrated, a series of sounds is emitted. Each sound event is produced from the fracture of a cell wall of dry food (Taniwaki, Hanada et al. 2006).

Due to the fact that the crushing of crispy or crunchy foods results in fracture and fragmentation, it appears that fracture and sound emission are associated (Tahnpoonsuk 1999). Sound propagated during either biting or compression of crispy food can be used as an indicator of their crispness level. Christensen and Vickers (1981) proposed that the perception of crispness occurred due to the vibrations produced by fracturing crisp foods.

The sound emitted during food breaking contains important information. It consists of different frequencies and also the loudness of the sound varies over these different frequencies. During biting or chewing of food a sound is emitted which can be detected by air conduction and by bone conduction. The auditory canal detects the sound waves that are produced by vibrating air molecules. The inner ear is the responsible part for perceiving loudness and pitch of sound (Duizer 2001).

Many studies have demonstrated that the hearing sensation has a great impact on crispness evaluation (Vickers 1976, Mohamed, Jowitt et al. 1982, Edmister 1985, Vickers 1987, Dunk 2002). Vickers and Bourne (1976) studied the acoustic properties by using a tape-recorder during the process of biting different types of dry and wet food. They found that crispy food consists of a sense of uneven and irregular noises and supposed that the repeated fraction and the process of chewing are responsible for the production of such acoustic properties. In addition, the amplitude time plots among the samples were different. Finally, they concluded that once the food was less crisp it produced less noise. A study by Christensen and Vickers (1981) to evaluate the loudness and crispness separately for 16 different food samples during the process of biting and chewing showed that the correlation among loudness and crispness was positive, which indicated that biting and chewing sounds were important for evaluating crispness (Zata M 1987). The effect of storage processes at different relative humidity on the sound emitted by crispy food was studied by Mohamed *et al.* (1982). The sound was recorded while the sample underwent a constant compression load, and the sound energy was significantly correlated with sensory crispness. The relationship between sensory crispness and different acoustical parameters for wet and dry crispy food were investigated by Edmister and Vickers (1985). They observed that the logarithm of the number of sounds emitted and the mean of their amplitude are the best indicators of perceived crispness (Taniwaki, Hanada et al. 2006).

Roudaut et al. (1998) claimed that sounds generated from a fractured by mechanical equipment were different from eating sounds and do not contain the related information for texture judgment. Lee et al. (1988) attempted to understand the fracture behaviour of potato chips and tortilla chips during a number of consecutive chews. The results showed that the intensity of the sound increased as the chews increased, while the high frequency of chewing decreased as the number of chews increased. These findings were in line with the psychoacoustical theory proposed by Vickers and Bourne (1976), which showed that crispness was characterised by a high tone. They concluded that the determination of crispness may depend more on the information obtained through the initial mastication. For more reliable information about food crispness, a Fourier transform method (FTM) was recommended by Peleg (1997). This method is concerned with the wavelength of the component giving the jagged outline to the strain-strain curve. Vincent (1998) reported that the latter method can be used only for data resulting from compression tests and not from penetration tests.

1.*2.4 Combinations between mechanical and acoustic parameters*

It has been reported by several researchers that crispness cannot be accurately determined depending only on acoustical parameters due to the excluding of the force applied on crispy material which caused that sound to be propagated. The combination between mechanical and acoustic measurements can provide better prediction for food crispness, where the combination appreciate both mechanical and acoustic parameters. (Mohamed, Jowitt et al. 1982, Vickers 1987, Vickers 1988). To study the sounds emitted during fracture, previous studies either analysed the amplitude-time plot of the acoustic signal, or the amplitude-frequency using Fast Fourier Transform, extracting parameters such as amplitude, mean height of peaks, number of sound peaks and mean sound pressure level (SPL). Most researchers were convinced that although some progress has been achieved regarding evaluation of crispy products, more remains unknown. In addition, the relation between the acoustic, mechanical and sensory properties of the food materials needed to be combined. It has been claimed that this combination should be able to reveal more information about crispness than the mechanical or acoustic methods alone (Chen, Karlsson et al. 2005). In contrast, other authors showed that for some foods, fracture or auditory sensations alone were sufficient to evaluate crispness (Primo Martin, Beukelaer et al. 2008).

The integration of an acoustic envelope detector (AED) to the Texture Analyser made it possible to measure force/displacement and acoustic signals simultaneously (Chen, Karlsson et al. 2005, Chen, Varela et al. 2006). Regarding this combination, a related study has been conducted by Chen et al, (2005). They used a second derivative of the force curve measurement with acoustical detection of food materials. An acoustic envelope detector (AED) was connected to a Texture Analyser and both the mechanical and acoustic parameters were simultaneously detected using a special microphone. The acoustic parameters were expressed in terms of maximum sound pressure level (SPL) and the number of acoustic events. Results from this study were highly encouraging where the ranking of acoustics gained from the instrumental assessment of the biscuits with regards to the number of acoustic events and amplitude of acoustic signal was in line with the sensory panel’s ranking of the biscuits from ‘‘highly crispy’ ’to ‘‘least crispy’(Chen, Karlsson et al. 2005).

The advantage of merging both mechanical and acoustic measurements has been demonstrated by several of texture scientists (Chen, Karlsson et al. 2005, Castro-Prada, Luyten et al. 2007, Primo-Martin, Castro-Prada et al. 2008).

1.2.5 Combination between objective and subjective approaches

The accuracy of an objective method to measure a quality attribute of food is only determined by its correlation to the sensory evaluation of that attribute (Kokini 1985). It has been reported that there are two main approaches to evaluate the relationships between crispness of food and sound. These approaches included both recording sound omitted during penetrating the texture of food to obtain quantitative information, and assessing the panellists perceptions (Drake 1965). Bashford and Hartung (1976) found good correlation between sensory and instrumental measures of bread (Carson and Sun 2001). It has long been reported by Drake (1963), that the sound emitted when crispy foods are bitten and masticated, and the extent of that sound reflect either the level of crispness or the crunchiness of these foods. This relationship between crispness and sound has been utilized to improve instrumental methods for food crispness evaluation. Several studies have studied acoustical measurements of food quality attributes and their relationship with food crispness (Drake 1963, Edmister 1985, Vickers 1987, Vickers 1988, Duizer, Campanella et al. 1998). The hypothesis of these studies was that, physical measurements of crushing sounds may be correlated with sensory evaluation of food texture (Ross 2009). Numerous experimental instrumental tests were developed to potentially correlate with sensory descriptors, however, instrumental measurements were not able to reflect the complexities which occurred during real mastication (Peleg 1994, Harker, Maindonald et al. 2002).

Edmister and Vickers (1985) successfully combined individual acoustic measurements into more complex parameters with the hope of characterizing crispness. They reported that sensory crispness of dry foods was positively correlated with the Logarithm of the number of sound peaks multiplied by the mean height of the peaks $R^2 = 0.66$ (Sean 1997).

Chen et al., (2006) attempted to create correlations between crispness and mechanical properties of food products, particularly the second derivative of force curve and the acoustic event. Even though this report showed positive correlations between acoustic parameters and the sensation of crispness, the exact interpretation of acoustic data is still difficult (Castro-Prada, Luyten et al. 2007). Stollman and Lundgren (1987) found a nonlinear negative correlation between hardness of the crumb (Instron measurement) and sensory softness of the crumb in the centre of the slice. The correlation between sensory crispness and loudness is well established (Vickers 1976, Edmister 1985). Bisschop (1995) and Boehnke (1996) by using a different methodology found crispness and loudness ratings to be highly correlated $r^2 = 0.93$.

Several possible reasons for a lack of correlation between instrumental and sensory data were described in different studies. One reason stated was the misleading similarity in language used by instrumentalists and panellists: they use the same words but measure different properties (Gambaro, Varela et al. 2002).

Psychophysical aspect had obvious contribution in the product developments and the design of the product. During the process of developing an existing product, the producers need to know the impression of the consumers (reactions) by determining the level of their acceptance by evaluating the sensory impressions when they steadily change ingredients or processes (Moskowitz 2005). When developing or creating new food products, the designer and the developers should be able to deal with the sensation threshold for the consumer in order to design a suitable formula ranged within the consumer’s sensorial perception. Hence, applying psychophysics to discover the relation between the products components and the consumers’ psychological sensation are necessary (Chang and Chiou 2006).

It has been reported since 19th-century that the discrepancy of the threshold between two stimuli was not an absolute amount, but an amount of relation to the intensity of the first stimulus. Weber’s law shows that the stronger the initial stimulus, the greater the additional intensity needed for the following stimulus to be apparent as difference (Chang and Chiou 2006). Power law as reported by Steven’s (1975) is the psychophysical power function that reflects the relationship between individuals’ psychological sensation and the intensity of physical stimuli. This law helped to know how consumers sense all of the ingredient adjustments of a certain food product (Meullenet, Lyon et al. 1998).

1.3 Bread

The first bread was made around 10,000 - 12,000 years ago, and was later improved through different experimentation by mixing the water, grain flour and rising agents such as sourdough. Egyptians were the pioneers who created the art of bread making throughout the world (Mondal and Datta 2008). Previous forms of bread were very different from how we see it in developed countries today and it would have been likely be similar to the modern flat breads of the Middle East. Bread has many types displaying different features such as shape, size, texture, colour and taste. The source of the variations might also be attributed to the different parts of the world where developed, for example, baguettes from France and flat breads from the Middle East (Cauvain 1998, Hoseney 1998).

Bread is the staple food for most of the world's population; it is made from dough of flour or meal and is usually raised with yeast or baking powder and then baked. In several countries, bread competes with different cereal products in being the main staple food of the country (Ridgwell 1986). There are many types of bread which differ according to the manufacturing process along with the purpose of use. Some types of bread such as toast bread require a crust (texture) which is soft and moist; bread crust crispness is preferred because its crust is crisp. The conventional Dutch loaf is known for its softness which reflects its storage in a plastic bag where the crispness is easily lost. However, the French baguette or a German “Kaiser brodchen” are known for their crispness (Baardseth, Kvaal et al. 2000). The quality of bread crust and the retention of the features that are characteristic is often unstable due to the moisture transfer from the crumb to crust of bread or by absorption of moisture from the atmosphere in the case of storage in unsuitable conditions, which both cause bread to lose its crispness (P.Cauvain 2000).

Increasing the shelf life of bread can provide many advantages, for instance it can reduce the wastage of bread, and save production time as bread could be baked two times a day rather than three times or more (Baardseth, Kvaal et al. 2000, Clarke and Arendt 2005).

Since the structure of bread is formed from a combination of several components, as well as a different manufacturing process, any of those components and processes has a role and may contribute to the crispness attribute. So far, it is not known what the main component is which is responsible for crispness (Roudaut, Dacremont et al. 2002).

1.3.1 Basic ingredients of bread

1.3.1.1. Wheat grains and wheat flour

Wheat flour is the final product of the wheat grain milling process. Grains are dry products; classified as the one-seeded fruits of plants from the grass family *Gramineae* (Hoseney 1998). The kernel is surrounded by the pericarp within which the germ and the endosperm are protected. Roughly 5% of the wheat kernel is the pericarp, which is a high fibre component with high cellulose content. The embryo or germ includes about 3% of the kernel and is rich in protein, B vitamins and enzymes. Flour is mainly made up from the rest of the kernel, which consists of the starchy endosperm.

1.3.1.1.1. Starch

Starch makes up the biggest portion of the flour. Wheat flour at UK is considered as the main ingredient of bread and mainly consists of the starchy endosperm of a wheat kernel. Wheat flour contains about 75-80% starch. The size of starch granules is between 5 and 55 µm and it mainly contains of two different types of polymers: 30% amylose and 70% amylopectin. The former is α helix molecule and the latter is a branched molecule (Damodaran, Parkin et al. 2008). During the process of grinding wheat, damage can occur to the starch granules; this is known as damaged starch. Damaged starch is desirable in some manufacturing processes, but only up to a certain level. Increasing the level of damaged starch above this level may lead to undesirable results during the storage, as well as when being used to make bread. The optimal proportion of damaged starch to give the maximum bread volume is between 5 and 8%. Damaged starch improves water uptake of the flour and thus leads to additional water in the crumb after baking. However, too much water may lead to sticky dough that cannot be handled or processed. Damaged starch is easily accessible by enzymes like α and β amylases which will increase the amount of maltose and dextrins in the dough (Gambaro, Gimenez et al. 2006). This will in turn lead to more CO_2 and alcohol production by the yeast and more intense crust coloration due to caramelization and Maillard reaction. With an excess of water, gelatinization of the starch granules can take place upon heating. If not enough water is available gelatinization will not occur or only partly occur (Saxena and Rao 2000).

Gelatinization is caused when starch is heated to a particular temperature between 62˚C and 75˚C for most types of starch (Penfield and Campbell 1990). "Gelatinization refers loosely both to the loss of order, and also to the swelling of the granule" (Sharpe 2004). The alterations occurred in a starch granule during the gelatinization has an important role on the taste and texture of granule and make it easier to digest (Sharpe 2004).

1.3.1.1.2 Protein

The proteins present in wheat flour are about 10-15% of flour weight. These fractions mainly consist of glutenin and gliadin, and each of them has its own role. Gliadin offers extensibility and viscosity that gives the dough ability to extend during the fermentation process, while glutenin provide both the elasticity and the strength of the dough. Therefore, their contribution in dough gives unique properties for dough prepared form wheat flour. There has been consensus that the quality of flour is only determined by its content of gluten. Both the quantity and the quality of gluten are responsible in determining the usage of flour (Goesaert and Gebruers 2005).

The gluten proteins have heat-setting properties and tolerate cross linking reactions in the temperature range 70-160°C which contribute in the formation of crumb and crust (Kulp and Ponte 1981). The role of the gluten network in the formation and retention of the crispness of bread crust was studied using two different kinds of flour (Soissons and spring). It was found that limitation of water absorption by the crust (whether from the crumb or from the surrounding environment) along with modification of the proteins in the crust would be useful ways to maintain crispness of the crust for a longer period. Proteolysis results in a weaker, more open gluten network which helps bread retain its crust crispness (Primo-Martin, Pijpekamp et al. 2006). Products which are made mainly from wheat are dependent on the formation of the gluten network to build textural characteristics, this is because gluten is the component which is responsible for the retention of the gas from yeast fermentation due to its ability to expand when bubbles form in the dough (Cauvain and Young 2009).

1.3.1.2 Yeast

Saccharomyces cerevisiae is the scientific name for Bakers' yeast, which is widely used in the baking industry (Pyler 1988). It is a fermenting agent and is responsible of production carbon dioxide resulting in dough rise; it is also responsible for ethanol production in the fermentation stage.

Hoseney (1998) gives the following simplified chemical reaction for the action of yeast:

$C_6H_{12}O_6$ + Yeast $\longrightarrow$ $CH_3CH_2OH + CO_2$

The amount of yeast used in the bread recipe is linked inversely to the period of fermentation, longer fermentation systems usually employing somewhat lower levels of yeast and also lower dough temperatures. Carbon dioxide produced during the fermentation process is necessary for a loaf of bread to get both desired volume and a light crumb texture (Brown 1993). In addition to their role in producing carbon dioxide and ethanol, yeasts also contribute in the development of favour through producing flavour precursors (Chung 1997).

1.3.1.3 Salt

The salt level normally used in a bread formula is in the range of 1.5-2.0% of flour weight (Chung 1997). A basic function of salt in bread dough is not only to impart flavour, but also to increase dough strength. There is a strong relationship between the levels of salt and yeast in a recipe. Salt has a significant effect on the osmotic pressure of the yeast cell and so can be used to control the rate of fermentation. The more salt used in a recipe the more yeast will be needed to achieve a given proving time (Hoseney 1998, Cavella, Piazza et al. 2000).

Salt also influences the speed of fermentation in the dough by reducing the yeast activity at certain levels (Sluimer 2005). Addition of 1% salt on basis of weight flour reduces the yeast activity roughly 5-6%, 2% salt addition leads to a reduction of 15-20% and 4% salt decreases the yeast activity by about 65- 70%. Bread salt containing iodide was widely used in several countries to supplement an insufficient amount of iodide in the diet (Kent and Evers 1994, Hoseney 1998).

1.3.1.4 Water

Water is the second most significant ingredient in bread making after flour, but its importance is often disregarded (Cauvain and Young 2008). Water represents nearly 40% of the dough weight and 35% of baked bread (Brown 1993). It has a great importance for both quality and economic concerns. From a quality view, water plays two main roles. Firstly, water acts as a solvent during the dough formation period. When all the ingredients are mixed together for dough formation, water hydrates the flour proteins and forms the water phase, in which the soluble solids are dissolved and the yeast is dispersed (Shewry 1998). Secondly, water acts as a plasticiser during mixing and after baking (Cauvain and Young 2008). Consumers determine the freshness of baked bread by means of the 'squeeze test', therefore the higher the amount of water remaining in the bread, the softer and the more acceptable the bread (Gould 1998).

1.3.2 Non-basic ingredients

In addition to the four basic ingredients, several ingredients are also combined into the bread making process. Each of those ingredients has unique properties that it contributes to bread dough and the final quality of the bread.

1.3.*2*.1 Fat, emulsifiers and Shortening

Fat and shortening are minor ingredients of dough, and are used at levels around 2% of flour weight (Stampfli and Nersten 1995). Even though they only account for a fraction of the dough, they are essential in bread making. They contribute to the final texture of the baked product and also have an impact on the flavour and the mouth feel of a product (Cavella, Piazza et al. 2000). Emulsifiers provide a positive effect to improve dough properties and bread quality as well. For that reason emulsifiers remain as important additives in bread making, regardless of increasing other additives such as enzymes (Stampfli and Nersten 1995).

Emulsifiers are fatty substances that have the properties of both hydrophilic and lipophilic molecules and belong to the compounds called surface active agents. They have the capability to reduce the surface tension between two immiscible phases.

The characteristics needed by the baking industry as mentioned by Potgieter (1992), Kamel and Ponte (1993) are increased shelf-life of bread; enhanced gas retention resulting in lower yeast requirements; improved slicing characteristics of bread; enhanced crumb structure; improved rate of hydration and water absorption and finally enhanced dough handling including greater dough strength (Stampfli and Nersten 1995).

The desired properties in bread making require emulsifiers to be divided into two types, the first types are dough strengtheners and the second types are crumb softeners, although some emulsifiers provide properties for both crumb softening and strengthening. The ability to enhance bread volume and produce longer crumb freshness by using emulsifiers can be reached by adding shortening. In the baking industry shortening is a term using to describe either compounds or their derivatives such as fats, oils. The combination of them that enhance bread quality can also be considered as shortening (Stauffer 2000).

1.3.1.2. Enzymes

1.3.1.2.1 Alpha Amylase

α-amylase exists naturally in wheat flour and is activated during the germination process. It is normally present in low concentrations in the grain (Bcenas, Haros et al. 2003, Cindy 2007). α-amylase works mainly on damaged starch. It converts the long starch chain into a number of smaller chains including dextrins by hydrolyzing the α-1, 4 glycosidic bonds randomly within the starch molecule. The dextrins are converted to maltose through the action of β-amylase present in flour (Matz 1989, Williams 1998).

The supplementation of wheat flour with alpha amylase has become common practice through adding a portion of malt flour as a source of alpha amylase. (Catteral 1998, Cindy 2007).

For the past few decades, the tendency of using fungal α-amylase became more preferable than cereal α-amylase due to lower heat inactivation needed for the former, therefore even added in higher level the crumb of bread would not be sticky (Hoseney 1998, Brown 1993).

Bacterial α-amylase is classified as a heat stable enzyme, thus its use in the baking industry is limited for certain products such as malt breads. This is because the bacterial α-amylase continues to be active and is able to produce dextrins even after baking and cooling (Matz 1989, Williams 1998). α-amylase has been used as an agent to retard the staling in bakery products through its effect on both amylose and amylopectin. Due to changes occurring in the baking industry, enzymes have gained greater importance in the manufacture of bread recipes, replacing additives such as oxidizing agents or emulsifiers (Mathewson 2000). Addition of amylases results in a higher level of fermentable sugars in the dough and therefore, improves the loaf volume.

1.3.1.2.2 Beta Amylase

β -amylase, is also known as the saccharifying enzyme, because it produces sugar in the form of maltose. After the random hydrolysis of the starch molecule by α-amylase, β-amylase attacks α-1, 4-glycosidic bond from the non-reducing end of the starch molecule to yield maltose molecules. β-amylase is inactivated during baking process at a temperature around 55-60^{o}C (Catteral 1998). Together, α- and β-amylase convert starch chain into simple compounds more rapidly, than either would do alone (Hoseney 1986). The levels of β-amylase in flour are normally sufficient as opposed to α-amylase levels, which normally have to be added from other sources (Cindy 2007).

A dough conditioner containing alpha amylase (EDC) as a functional ingredient was selected on the basis of the known effect of alpha amylase on bread qualities such as bread crumb softness and bread volume as reported by Primo Martin, et al. (2008), while its effect on bread crust quality has only been studied by few researchers.

1.3.1.3 Dietary fibre and hydrocolloids

The desirability of using dietary fibre in the food industry is not only due to its nutritional value but also because of its technical and functional properties (Elleuch, Bedigian et al. 2011).

1.3.1.3.1 Polydextrose

Polydextrose is a synthetic product made by polymerization of glucose in the presence of citric acid as a catalyst and sorbitol as plasticizer agent. The chain of polydextrose is randomly branched through 1, 6-glyco-sidic linkage as shown in Figure 1.1. the molecule is also characterised with high molecular weight (162-20,000) (Craig 1998).

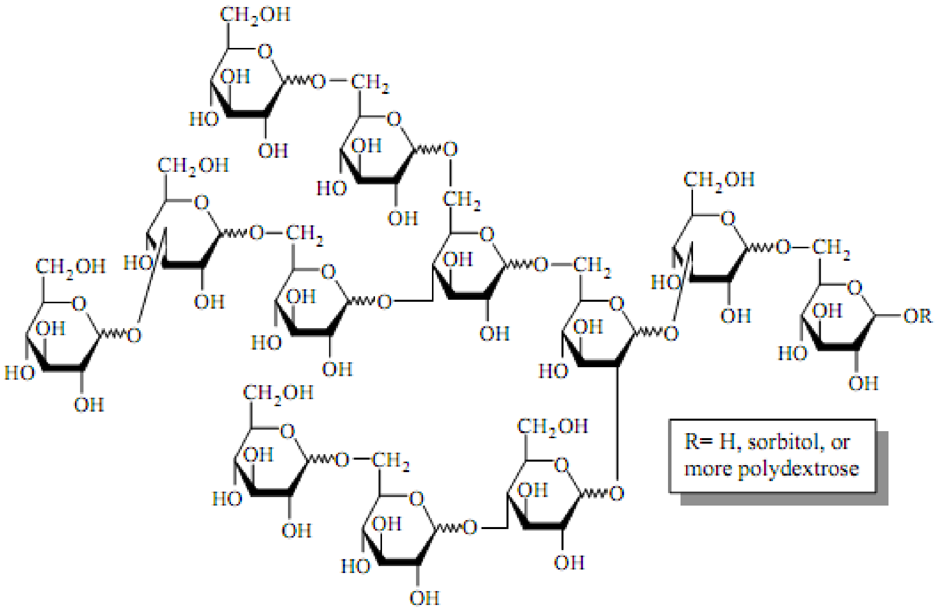

Figure 1.1 Representative structure for polydextrose (Craig 1998, Craig, Holden et al. 1999).

Polydextrose has been widely used due to its versatility as a bulking agent and texture improver. Furthermore, polydextrose has an important role in increasing the number of some useful types of bacteria (Wang and Gibson 1993). As shown in another study, the results showed linear decrease of *Clostridium perfringens* in faeces of adult dogs as the amount of polydextrose increased (Endo K 1991).

It has also been found that polydextrose has the capability of reducing the levels of certain carcinogenic substances produced by bacterial fermentation (Kilibwa and Niantic 2004). In food manufacturing, polydextrose is widely used as humectant due to its ability to prevent or delay wet products losing their moisture or absorption of water from surrounding air (Craig 1998). It has been claimed that the role of polydextrose in adjusting water absorption and moisture loss is depended on several factors such as recipe, storage conditions and packing (Esteller, Amaral et al. 2004). It has been demonstrated that when polydextrose is used in combination with fibre, the products were less sticky, and crumb freshness was enhanced (Kilibwa and Niantic 2004).

Polydextrose has a higher water absorption capacity and thus increases the content of soluble carbohydrates. It is though that the primary effect of polydextrose in reducing the rate of staling in baked products is to dilute the starch components thus reducing the available starch fractions for crystallization (Kilibwa and Niantic 2004).

The use of polydextrose in combination with flour alone or in combination with certain emulsifier and enzymes showed improvement in anti-staling properties and bread crumb structure for both bread and other baked goods. These improvement are generally achieved without adverse effect upon organoleptic characteristics of baked products (Kilibwa and Niantic 2004). It has been found that dough contained polydextrose in ratios between (1 – 5%) showed better handling than Control, while the final baked products was slightly better than those bread baked without polydextrose (Craig, Holden et al. 2000). Despite the lack of information about the applications of polydextrose on food crispness, related study reported that the addition of polydextrose to shortcrust pastry increased the crispness (Sibel Roller 1996).

1.3.1.3.2 Citrus fibre

Citrus fibre is derived from the peel of the orange, not from the fruit itself. Several studies have been conducted using citrus fibre offering positive attributes when added to bakery products without affecting or compromising taste (Elleuch, Bedigian et al. 2011). Those attributes include: managing moisture migration, increasing dietary fibre and extending the shelf life of the product (McKee and Latner 2000). Oranges, lemons, grapefruits and mandarins represent about 98% of the entire industrialised crop, approximately 82% of the total production was assigned to oranges (Nassar, AbdEl-Hamied et al. 2008).

Citrus fibre produced from orange juice cells was reported to contain 54% insoluble fibre and 22% soluble fibre (Fernández-Ginés, Fernández-López et al. 2004). Citrus fibre has water holding capacity of 11:1 and a fat absorption capacity of 3 to 4 times its weight. Organoleptic characteristics of the citrus fibre do not adversely affect food properties. Suggested applications include drinks, fruit juices, baby food, soups, desserts and milk products (McKee and Latner 2000).

Previous studies have shown that citrus peel fibre has a big effect on bread weight due its role in increasing water absorption (Nassar 2008). On the other hand, Miller (2011) reported that bread containing citrus peel fibre had decreased loaf volume but crumb firmness was similar to control loaves.

1.3.1.3.3 Alginates

Alginates are natural polysaccharides extracted from brown seaweed and are a family of non-branched binary copolymers of (1→4)-linked β-D-mannuronic acid (M) and α-L-guluronic acid (G) residues (Figure 1.2) (Nussinovitch 1997, Draget 2001).

Figure 1.2 Chemical structures of β-D-mannuronic acid (M) and α-L-guluronic acid (G) (de Vos, Faas et al. 2006).

Alginate can be considered as a source of dietary fiber because it is classified as an indigestible polysaccharide (Brownlee, Seal et al. 2009). It has been known that alginates have a high affinity for water (200-300 times of their weight) and that they readily form lumps when they are added in water.

The consumption of the alginate has widely been increased in Western world; however studies concerning of its use as bread improver are relatively few. (Guarda, Rosell et al. 2004). Alginates used as additives in some food industries due its useful effect in modifying the rheology and texture of aqueous suspensions.

These properties were utilized in the food industry in some products like custard creams and restructured food. They are also used as a stabiliser and thickener in a variety of beverages, ice-creams, emulsions and sauces (Lee 2002, Guarda, Rosell et al. 2004). It has been reported that an improvement in wheat dough stability during proving can be obtained by the addition of sodium alginate (Rojas 1999). Bekaert (1996) reported that the use of sodium alginate for improving the fresh bread quality resulted in softening the final product due to its high water retention capacity or by hindering the gluten–starch interactions.

Alginates have various industrial uses as stabilisers, gel-forming and water-binding agents. The common use of alginates in bakery creams is to provide the cream with stability and reduction of separation among solid and liquid components (Brownlee, Allen et al. 2005). Alginates are used in mixture with other hydrocolloids to enhance the thickness and the stability of the ice cream. In addition, it also increases heat-shock resistance and gives ice cream desired melting characteristics (Brownlee, Seal et al. 2009). It has been reported that the presence of sodium alginate in certain amounts 0.1-0.5% of flour weight resulted in increased moisture content in bread (Guarda, Rosell et al. 2004). Sodium alginate can retard staling caused by a decrease in the retrogradation of the amylopectin (Barcenas 2003). According to Mandala et al. (2008), bread containing hydrocolloids showed a decrease in crumb firmness level during the storage period due to a reduction of gluten– starch interactions. The effect of alginate on the activity of α - amylase was assessed by several researchers. They found that amylases have an attraction for alginate which leads to decrease the effect of α - amylase on starch. This act also had an effect on yeast by effecting the amount of maltose needed to be consumed to produce carbon dioxide (V.O. Selomulyo 2007).

1.4 Bread manufacture

Bread is made by several procedures. The procedure used depends upon many factors, including tradition, the cost and type of energy available, the type of the flour available, the kind of bread wanted, and the time between baking and eating. There are numerous bread making procedures that are used in different countries (Kaur 2008).

1.4.1 Straight dough bulk fermentation

Straight dough bulk fermentation can be regarded as the most traditional method in the breadmaking process. Figure 1.3 is a simplified flow diagram of the straight dough process, as described by Hoseney (1998). This method was considered as the simplest procedure where the entire ingredients are combined and mixed together in low and high speed for a certain time for each speed, and then allowed to ferment for a specific time.

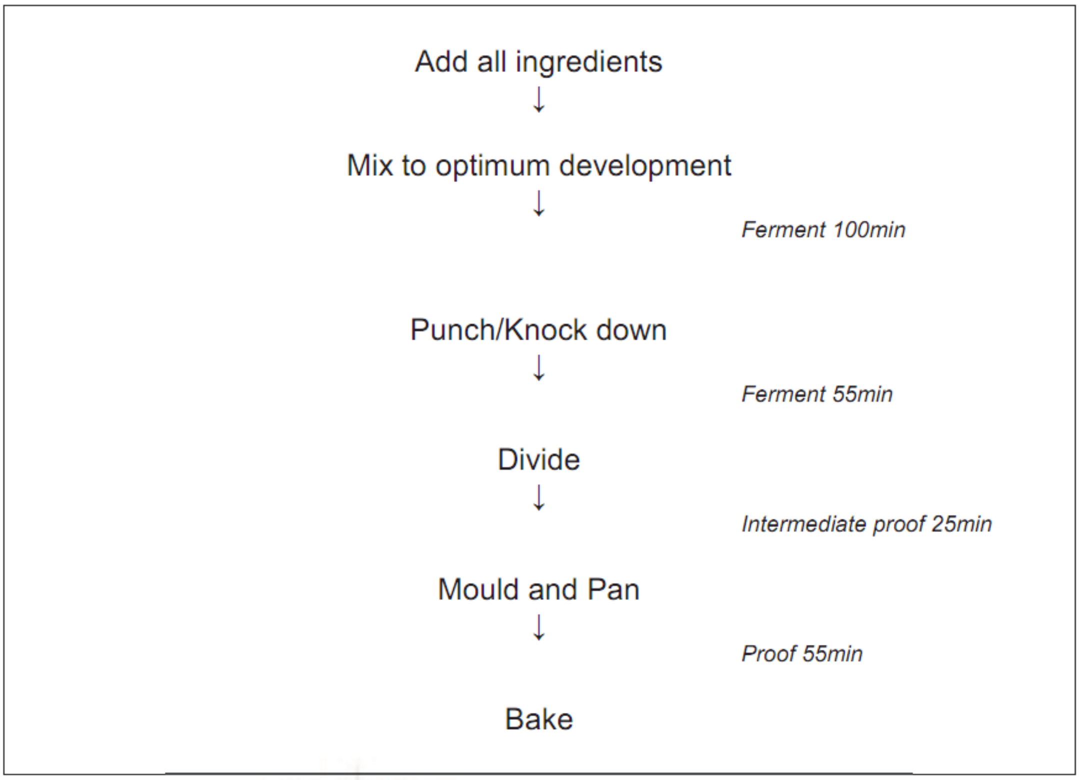

Figure 1.3 Straight dough baking process (Hoseney, 1998)

1.4.2 Sponge and liquid sponge dough

In the United States the sponge dough procedure is preferred choice in preparing bread. This procedure is similar to straight dough bulk fermentation; they are only different in the fermentation step, where two steps are needed to prepare sponge dough. In the first step, only parts of the ingredients are used in the fermentation to form the sponge. After fermentation, the rest of the ingredients are mixed in with the sponge initially prepared to form homogenous dough.

Two of the main advantages of using sponge dough are its contribution to enhancing bread flavour and the modification of the rheological properties (Cauvain and Young 2007).

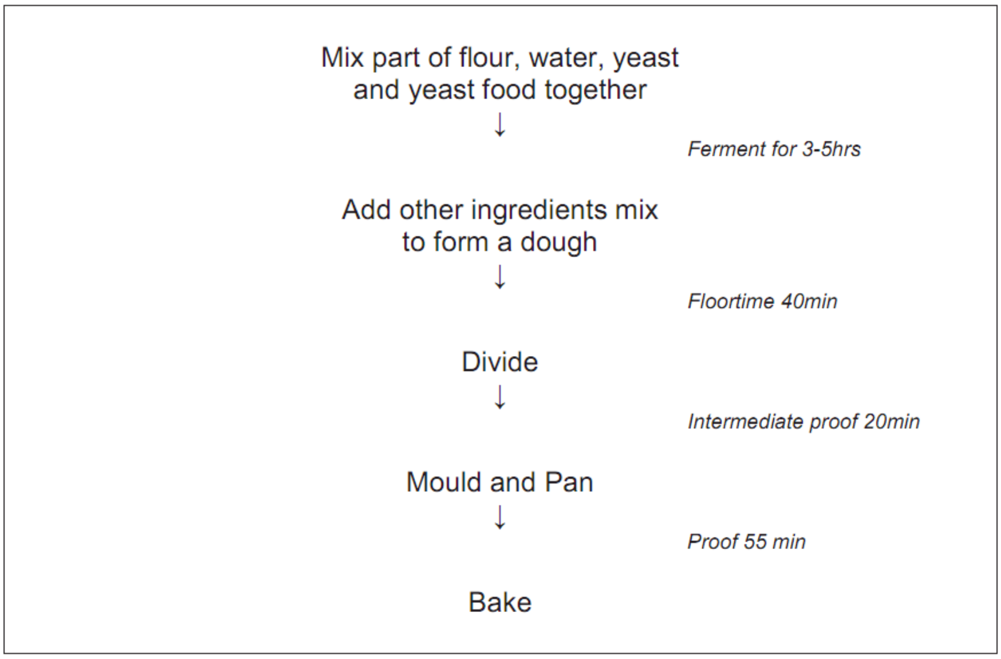

Figure 1.4 Sponge and dough baking process (Hoseney, 1998)

Liquid sponge dough is roughly similar to the sponge dough. It only differs in the amount of the water to prepare the fermented dough. Liquid sponge dough needs more water than sponge dough, as a result of that sponge dough is a hard dough while Liquid sponge dough is a liquid (Cauvain and Young 2009).

1.4.3 Baking of bread

Baking is the last but the most important step in the bread-making process (Mondal and Datta 2008). To see a dough come out of the oven in the form of bread seems to be a very simple process, however it is not so easy to understand how dough is converted or transferred into bread. Several characteristic changes occur in dough before becoming bread (Gray and Bemiller 2003). These changes are primarily due to physical and chemical reactions that take place during baking.

Baking is a heating process in which many reactions occur at different rates. These reactions are:

1. expansion of the gas cells, melting of fat crystals and their incorporation on the surface of air cells and gas cells that rupture (Brooker 1996).
2. Coagulation of gluten and gelatinization of starch. Both operations occur at the same temperature of 60-85˚C resulting in change from dough to crumb (Mondal and Datta 2008).
3. Crust formation which acts as a barrier towards weight loss during baking and is considered as one of the limiting factors restricting the expansion of the dough during baking (Zhang 2007) .
4. The formation of crust and browning during baking are the primary contributors to the creation of bread flavour. The browning is mainly the result of the Maillard reaction and takes place when the temperature is greater than 110˚C. The Maillard reaction is an important reaction to form the colour and aroma in the bread crust (Zanoni 1995).

1.5 Staling of bread

Bread staling has been studied for a long time, but the precise mechanism is not fully understood yet. The staling of bread is defined as an indicator of the decrease of product acceptability by a consumer which is mainly caused by changes in both crumb and crust more than changes resulting of spoilage organisms. Bread staling has been divided into two categories, i.e. the staling of crust and the staling of crumb. The staling of crust is generally caused by moisture transfer from the crumb (core) to the crust, resulting in a soft, leathery crust, and it is generally more acceptable than crumb staling (Lin and Lineback 1990). Crumb staling is more complex and more important in affecting acceptability than crust staling, but less well understood (Gray 2003). Figure 1.5 illustrates a schematic picture of a slice of bread with directions of water transfer. A crust of fresh bread contains around 12% water and the crumb of fresh bread around 46% water (Primo-Martin, Pijpekamp et al. 2006).

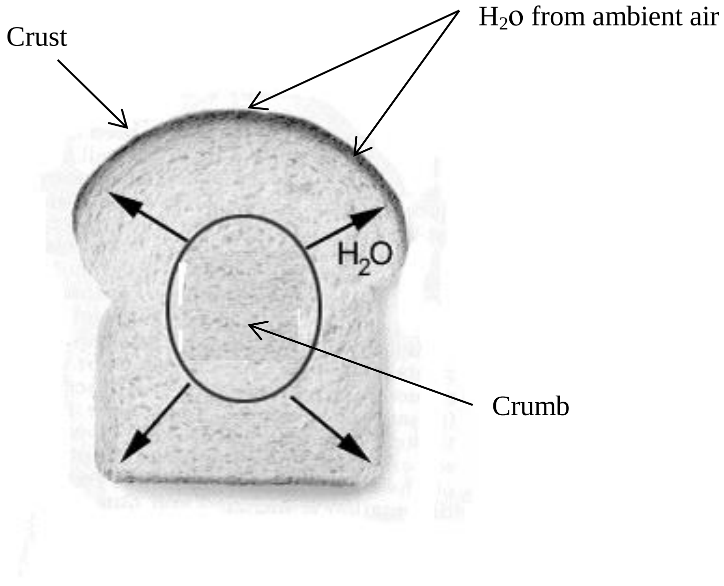

Figure 1.5 Schematic picture of a slice of bread. The directions of the transport of the water after baking are indicated with arrows.

It has long been revealed that starch retrogradation is the main reason for bread staling. Several studies have focused on starch gelatinization and retrogradation (Willhoft 1973, Kim and D'Appolonia 1977, Cauvain 1998). Zobel and Kuple (1996) proposed a model which predominantly attributed staling to the stiffness for starch, Figure (1.6). The mechanisms of staling assumed so far have taken this model into account.

The staling of bread crumb is not only due to loss the moisture from crumb, but also the slow changes that occurs in starch which is known as starch retrogradition. This retrogradition occurs during bread storage, where the starch converts from an amorphous form to a crystalline form which reduces water mobility. These changes will lead to changes in bread properties such as increasing firmness, leathery crust, loss of flavour, increase the opacity of crumb, migration of water from crumb to crust, shrinkage of starch granules from the structure of gluten and finally fragmentation of the crumb (Hoseney,1986).

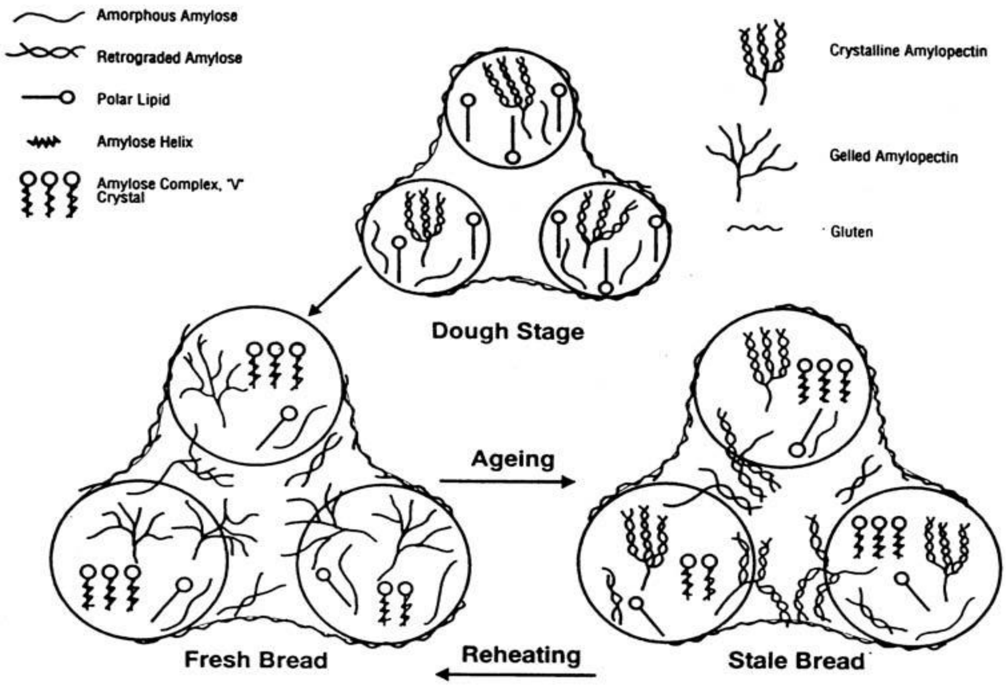

Figure 1.6 Starch retrogradation model (Zobel and Kulp 1996).

Since the 1950s it has been demonstrated that protein (gluten) has an essential function in bread firming. Since then, several researchers have addressed the importance of protein (Erlander and Erlander 1969). Several studies were conducted to compare bread made from white flour and other bread made from whole meal flour at different percentages of protein. Results showed that the bread containing a higher percentage of protein showed softer crumb than the lower protein bread after eight days. They concluded that the protein inhibits or hinders starch retrogradation process through the creation of a complex between protein and starch. They also mentioned that the amide group of glutamine in protein interacted with a glucose unit either in amylose or amylopectin series (Primo-Martin, Pijpekamp et al. 2006). Several approaches have been conducted to determine the degree of the staling such as differential scanning calorimetry (DSC), however the increase in crumb firmness measurement remains the most widely used indicator of staling (Gray 2003).

Most approaches measure the force applied by compressing a sample to a specific distance. AACC Approved Method 74-09 (AACC 2000) uses the Instron Universal Testing Machine to determine the degree of firmness in white pan bread crumb. A 25% compression depth (as specified in the AACC Approved Method 74-09) was confirmed to be the most effective method for detecting significant differences in bread firmness due to staling (Baker A. E. and Walker C. E. 1988). Other methods used for measuring the degree of staling include, thermal analysis, near NIR spectroscopy, nuclear magnetic resonance spectroscopy, X-ray crystallography, microscopy and sensory/organoleptic tests (Gray 2003).

1.6 The aims of this study are:

1. To determine which, if any, mechanical and acoustic parameters best characterise bread crust crispness.
2. To determine the correlation between sensory crust crispness scores obtained using expert panels with physical (mechanical and acoustic) parameters in order to determine the most effective instrumental parameters for the prediction of bread crust crispness at 4, 24, 48 and 72 hours post baking.
3. Investigation of the usefulness of using the experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$, through evaluation of the effect of five different selected additives predominately on bread crust crispness.
4. To examine the effect of several addition ingredients, in different amounts on bread crust predominately on its crispness and other relative quality attributes such as: bread crumb softness, crust water content, bread weight, crust thickness and finally on attributes. To relates the effects of ingredients on crust crispness to their effects on other properties such as water content.

Chapter 2: Quantification of bread crust crispness

2.1 Abstract

Crispness is one of the most important and desirable textural characteristics that signify freshness and high quality in many types of bread. For bread to be classified as ‘crispy’, its crust should fracture in a brittle way and the sound must propagate while being eaten or when penetrated by a probe (Saeleaw and Schleining 2011). Crusty white bread with crisp crust strongly preferred and demanded by consumers due to the unique and desirable characteristics of a soft and moist interior with an outer crispy crust. Although many approaches to instrumental measurement of crispness have been conducted, there is no reliable method available that can accurately measure and quantify crispness in bread crust and therefore optimal measurement conditions have not been determined (Primo-Martín, Beukelaer et al. 2008). To understand and evaluate the property of crispness, a standard procedure for both instrumental and sensory measurements is needed.

New parameters have been developed in an attempt to standardise instrumental and sensory evaluations to improve consistency in the outcomes of the studies. This was in response to the need for development of instrumental determinations of food texture particularly bread crust crispness, together with a strong correlation to sensory evaluation.

Two newly experimental parameters, the ratio of SPL/Force$_{max}$ and the ratio AUX/Force$_{max}$, are presented in the current study to quantify bread crust crispness. They are based on recording the maximum force required to fracture the crust (Force$_{max}$), sound pressure level (SPL) and number of sound peaks (AUX).

Five different bread formulae (Pre-ferment, Overnight sponge, Overnight liquid sponge, Panarome and White bloomer bread (standard)) were evaluated at 4 and 24 hours post-baking, predominantly for crust crispness. Results were compared with sensory evaluations conducted by sensory panel expert in the field of bakery products. Panellists scored crispness on a unstructured 15cm scale (Thybo, Bechmann et al. 2005).

A texture analyser (TA-XT plus) fitted with an acoustic envelope detector was used to determine mechanical and acoustic parameters (Chen, Karlsson et al. 2005).

Good correlations between sensory crispness and developed instrumental parameters were observed. The results showed that the correlations between instrumental crispness represented by SPL/Force$_{max}$ and sensory crispness were R^2 = 0.88, *P* = 0.052 and R^2= 0.90, *P* = 0.036, at 4 and 24 hours respectively. Regarding AUX/Force$_{max}$ the correlations were R^2 = 0.80, *P* = 0.104 and R^2 = 0.93, *P* = 0.024, at 4 and 24 hours respectively. This indicates that sensory crispness could be reasonably well predicted by the experimental parameters, in particular for the 24 hours age of bread that is most important for the industry.

2.2 Introduction

Bread crust properties such as crispness, hardness and softness are significantly influenced by dough ingredients, baking process, and preservation conditions such as temperature and relative humidity (RH) (Al Chakra, Allaf et al. 1996). Dry crisp foods are cellular foods that contain air within the cells, foods such as bread crust and biscuits contain air filled cavities with brittle walls. Cellular structure of several types of dray food such as bread were characterised by their crispness. Several methods were suggested to measure the property of crispness, however the investigation of both mechanical and acoustic parameters was considered as the best and direct method. Brittle fracture and low force required to accomplish that fracture were the main attributes characterised to crispy products. Sound propagated during the fracture is a significant parameter for crispness perception (Drake 1963, Luyten, Plijter et al. 2004, van Vliet, Visser et al. 2007).

Since 1960s, the evaluation of sound emission was used as an indicator for a brittle structure and therefore as an objective measurement to determine crispness. This sound can easily be produced by applying a certain force on food structure causing fracture of product cell wall which in turn release of energy in form of sound (Drake 1963). This released energy would then be transported through the air as acoustic waves to be available to detect and record. (Vincent 1998). Each type of food structure needs a certain amount of force to break; this amount is dependent on several factors such as water content and thickness (Duizer 2001). Peleg and Normand (1995) reported that jaggedness of the force–deformation curves (force peaks) was the key characteristic that correlated with crispness. Accordingly, both acoustic and force–deformation parameters have been determined using Texture analyser TA-XT plus along with acoustic envelope detector and then related to sensory crispness. Previous researches into food crispness determination were dependent on sensory evaluation. This was due to the lack of an instrument that can accurately simulate such complexity, sensitivity and mechanical motions existing in the mouth (Bourne 2002).

It is reported in the literature that the number of sound peaks and the sound pressure level are related to crispness (Mohamed, Jowitt et al. 1982, Zobel and Kulp 1996, Luyten, Plijter et al. 2004). If these two parameters are higher, the product is also rated as crispier by sensory analysis. Determination of a number of mechanical and acoustic events has been proposed to be a good approach to quantify crispness (Roudaut, Dacremont et al. 2002).

Crispness is an important textural attribute that indicates crust freshness and quality level in bread quality. Development of new parameters based on existing mechanical and acoustic parameters that can be correlated to sensory crispness analysis might offer new opportunities for product improvement.

The hypothesis for this stage is that the combination of the Stable MicroSystems Texture analyser (TA-XT plus) with an Acoustic Envelope Detector (AED) technique can reliably quantify crispness of bread crust supported by a much softer and moist crumb.

The aims of this stage are:

5. To determine which, if any, mechanical and acoustic parameters best characterise bread crust crispness.
6. To determine the correlation between sensory crust crispness scores obtained using expert panels with physical (mechanical and acoustic) parameters in order to determine the most effective instrumental parameters for the prediction of bread crust crispness at 4, 24, 48 and 72 hours.

It is hope that the results from this work could enhance our understanding of acoustic and mechanical properties of crispness and help to establish a reliable and simple method for determining and improving of bread crust crispness.

2.3 Materials and Methods

Five different formulas of white crusty wheat flour bread were prepared from white flour of one wheat cultivar, Soissons, supplied by ADM Milling Sovereign (UK, EU).

Compressed yeast and salt were supplied by Pinnacle, (British salt). Delta 2 bread improver as a source of ascorbic acid and extra fresh bread improvers as a source of enzymes were supplied by Cereform (UK, manufactured in UK from Canadian soya beans) and Cereform (UK, Germany and Malaysia) respectively. Gluten was supplied by Rank Hovis, UK. Bread emulsifier was supplied by Cereform (EU, UK and Spain) and fluid shortening as a main emulsifier (mono and di glycerides) was supplied by Cereform (EU, Malaysia, UK, and Indonesia). Panarome as flavour agent was kindly provided by Puratos Ltd and pre-fermented liquid was provided by Greggs plc.

2.3.1 Preparation of crusty white bread with a crisp crust

Five different bread formulae were prepared in this stage. Different processing methods were used although the amount of dough at the final step was nearly similar (Table 2.1). Details related to these formulae will further discussed in this chapter.

Table 2.1 Bread recipes for five different bread formulae in Kg

Ingredients	Bread formulae				
	Pre-ferment	Overnight sponge	Overnight Liquid sponge	Panarome	White Bloomer
Bread Flour	9.600	9.600	9.600	9.600	9.600
Salt	0.135	0.135	0.135	0.135	0.135
Delta	0.094	0.094	0.094	0.094	0.094
Extra fresh	0.094	0.094	0.094	0.094	0.094
Gluten	0.148	0.148	0.148	0.148	0.148
Crumb soft	0.045	0.045	0.045	0.045	0.045
Fluid shortening	0.045	0.045	0.045	0.045	0.045
Pre-ferment 5%	0.480				
Water	5.548	5.100	4.686	5.548	5.567
Yeast	0.220	0.220	0.220	0.220	0.220
Sponge 25% of flour weight		2.400			
L. Sponge 25% to flour weight			2.400		
Panarome				0.171	
Total	16.496	17.881	17.467	16.217	15.948

2.3.1.1 White bloomer bread

White bloomer (white extra-bite) which represents standard bread was prepared by the straight dough method which is the simplest mixing method. This consists of just one step as shown in Figure 2.1. The dough was given only a few minutes rest before being scaled and made up. The dough is generally divided within 10 to 20 minutes after mixing. All further processing is the same as for other doughs. The advantage of this method is that it is easy to perform as all steps can be done on the same day with no need to prepare anything in advance. The major disadvantage of the straight dough method is that the fermentation is hard to control because of fluctuations in temperature and other factors if used for large batches. Therefore, the straight dough method is usually only used for small-scale productions (Hsi-Mei and Tze-Ching 2005).

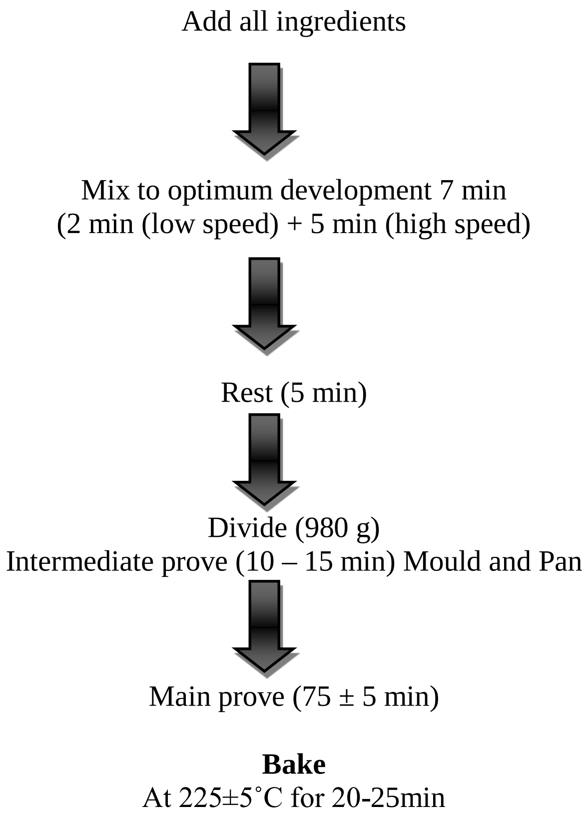

Figure 2.1 Outline diagram of the straight dough method

2.3.1.2 Overnight sponge bread (O.N. Sponge)

In this method, part of the flour (roughly 65.9%), part of the water (32.95%), the yeast (0.49%) and the salt (0.66%) are mixed just enough to produce hard dough (sponge) as shown in Figure 2.2. The sponge is allowed to ferment for up to 18-20 hours. Then it is combined with the rest of the ingredients at a rate of 25% to flour weight and mixed into developed dough. After being mixed, the dough is given an intermediate proving of 5- 10 min so that it can relax, and then is divided, moulded, and proofed as is done in the straight-dough method. It has been suggested that sponge and liquid sponge dough can also have positive effect on bread flavour particularly to those consumers who prefer yeasty flavour (Hoseney 1998).

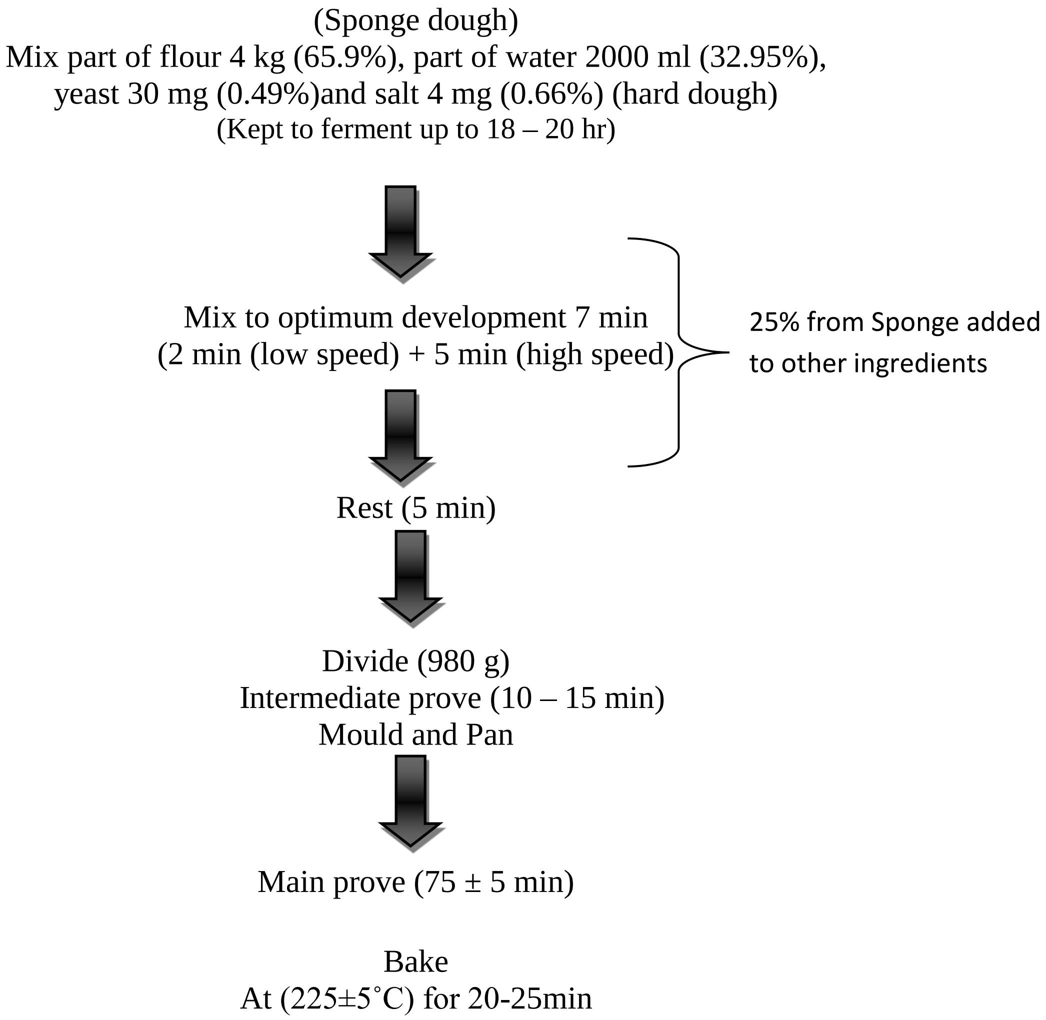

Figure 2.2 Outline diagram of the Sponge method

2.3.1.3 Overnight liquid sponge bread (O.N.L. Sponge)

Figure 2.3 illustrates the process of preparing liquid sponge dough. The process is similar to that for sponge dough but with differences with regards proportions of ingredients particularly the amount of flour against water (2kg: 2000 ml water) while with sponge dough it was (4 kg: 2000 ml water). As a result of this, the form of liquid sponge was as a thick liquid whereas in the case of sponge dough it was solid. Liquid sponge is also kept for to up to 18-20 hours to ferment before being added to the rest of the ingredients and mixed into developed dough, then combined with the rest of the ingredients at rate of 25% of flour weight. Hoseney (1998) reported that Sponge and liquid sponge (pre-ferment dough) when properly used and precisely understood can improve bread quality.

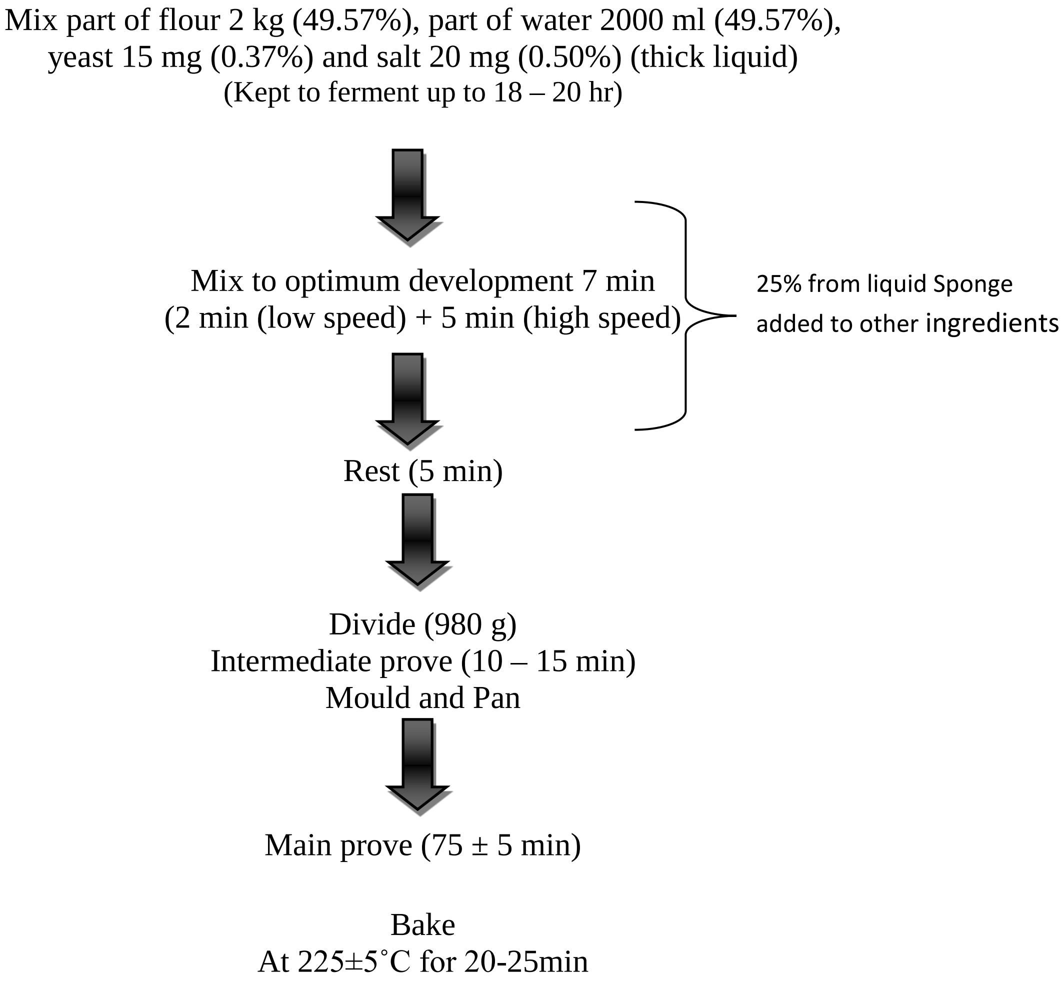

Figure 2.3 Outline diagram of the Liquid Sponge method

2.3.1.4 Panarome bread

Panarome is a concentrated liquid that adds a sponge flavour to white pan bread without requiring pre-fermentation. It is made from water, flour and yeast. These ingredients are mixed together, and then put inside a special container up to 24 hours to ferment, eventually this fermented liquid is pasteurised. The purpose of using Panarome is to improve flavour and other attributes such as crumb softness and crust crispness. Panarome liquid at a rate of 1.78% to the flour weight was mixed with the remaining ingredients in the mixing step. The rest of the procedure was as for the straight dough method.

2.3.1.5 Pre-ferment liquid bread

Pre-ferment liquid was developed by Greggs plc; it consists of a combination of wheat flour, yeast extracts, malt, sucrose, water and yeast. Dry ingredients approx. 35%, Water 55% and Yeast 10% are fermented at 40˚C for 3 hours then chilled. Pre-ferment liquid at a rate of 5% (of flour weight) was added to the flour, and then mixed with the rest of ingredients in the mixing step. The rest of the procedure is as the previous recipes.

2.3.2 Preparation of different bread recipes

Five different bread recipes were prepared using a 40kg mixing bowl. The water temperature was 22°C±2 and the starting temperature of the mixing bowl and flour was 22.5°C and 23°C, respectively. The dough was mixed using a Kemper ST 15 mixer at two different speeds, the mixture was then subjected to a mixing and kneading process for 7 minutes (2 minutes low speed + 5 minutes high speed) until the dough temperature reached 24-26°C. After mixing, the dough was allowed for fermentation for 10 -15 minutes under ambient conditions (RH 38 – 48%, ambient air temperature 20 ± 2˚C). After completion of the bulk fermentation process the dough was divided into equal portions of approximately 980g; and placed in baking trays for further fermentation for 70 -90 min at 30- 35 °C and 90% RH using a PPC1T Kings lynn oven-prover.
Thereafter, the bread samples were baked in an electric oven (a Mono DX Oven FG 145-104T1), maintained at 225 °C for 25 ± 5 minutes (Zobel and Kulp 1996). Because the oven did not contain a steam system, 200 ml of water was sprayed inside the oven after 20 minutes of baking.

2.3.3 Experiment procedure

The baked bread obtained from the previous steps was subjected to determination of physical (mechanical and acoustic) and sensory parameters at two different time points 4 & 24 hours after baking (Figure 2.4).

1. 18 loaves (980g per loaf) for each single type of crusty white bread with a crisp crust were obtained from each batch in the same day according to their recipe and placed in ambient conditions.
2. 10 of 16 loaves were randomly chosen to conduct mechanical and acoustic analysis (hardness and crispness). 6 loaves (3 each day) were sent to the Greggs GTC chemistry lab to test crust moisture content at 4 and 24 hours.
3. For Instrumental analysis, the 10 loaves were equally divided among two days. Five loaves were tested at 4 hours and others were stored in ambient conditions at temperature (20±2°C) and humidity (37 – 41%) to test at 24 hours.
4. Day 1 at 4 hours: the crust of the five loaves was penetrating 3 times in different places (*n*=15) by wedge probe (30˚) to measure crust crispness.
5. The five loaves that had previously been used to determine physical parameters as whole bread were also used to determine crumb hardness after being sliced into 5 slices; thickness of each approximately 25 – 30 mm with both bread ends being excluded (discarded). Total slices obtained were 25.
6. 3 from those 5 slices previously mentioned from each loaf were used for crumb firmness test (*n*=15), 10 slices were left 25-15=10.
7. An addition loaf was sliced into 5 slices and another 10 slices (step No 6) were combined together, then split into two similar halves and provided to organoleptic panellists, resulting in 30 halves, with each panellist being provided with 3 halves, average of three was recorded (*n* = 24).
8. The same procedure was followed at 24, 48 and 72 hours (steps 4 to 7).

Five different bread formulae were evaluated, each at a separate time as the five different recipes had been prepared separately for technical reasons.

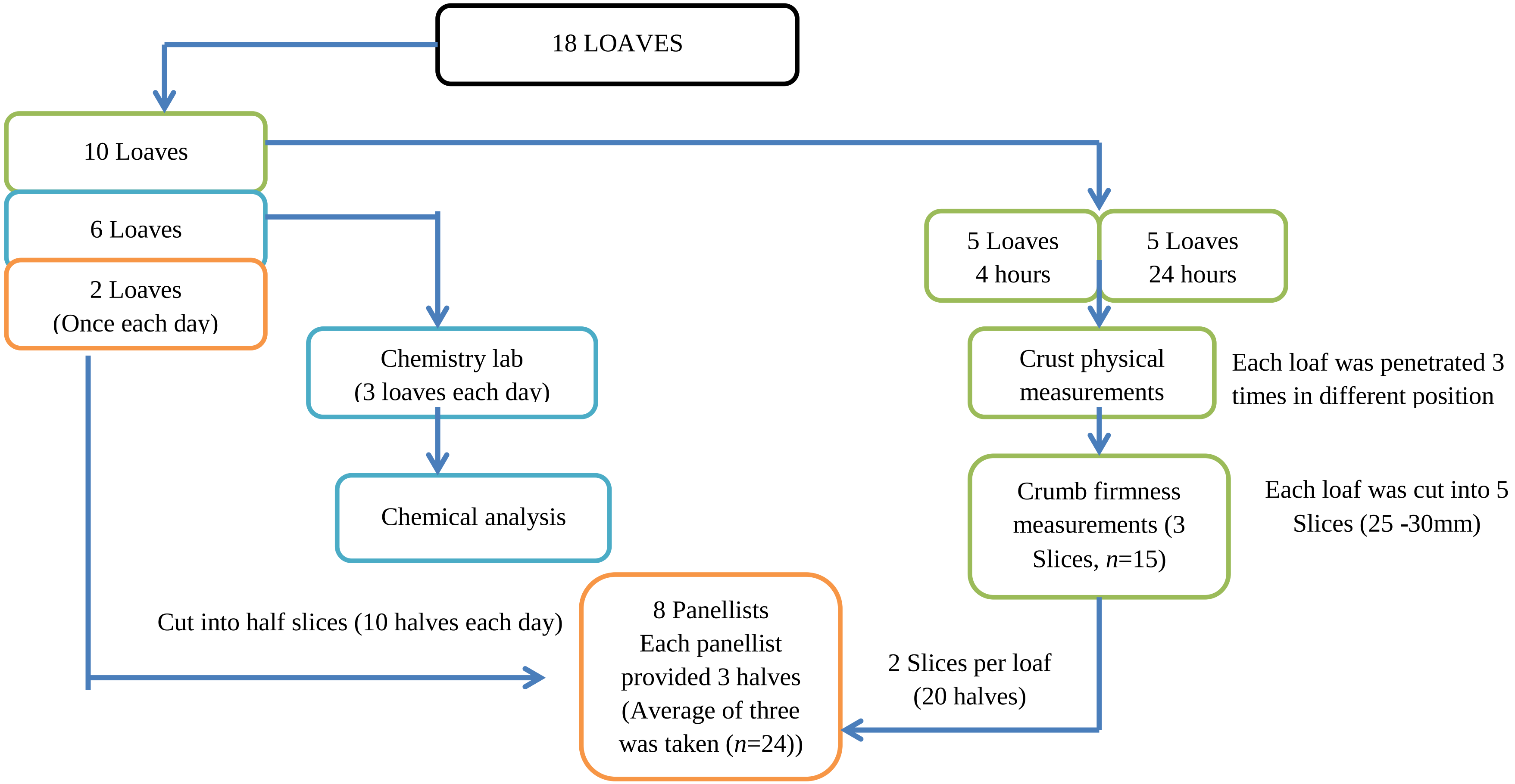

Figure 2.4 distributions of baked bread samples and subjected analysis

2.3.4 Sensory tests

Sensory evaluation is considered the gold standard against which the results of instrumental determinations are compared (Bourne 2002, Carolyn F 2009).

The objective of the sensory evaluation was to detect, identify, and evaluate characteristics of different bread formulae predominantly in terms of their crispness and then to compare the results with the results obtained from the instrumental method (mechanical and acoustic parameters) in an attempt to enhance and update a method to evaluate bread crust crispness.

Sensory tests were made on slices that previously had been tested for their crust crispness and crumb firmness, as well as slices from additional loaves where no instrumental tests had been carried out (Figure 2.4).

The crumb softness, crust crispness, crust hardness of five different bread formulations were evaluated using generic descriptive analysis for two days in line with the instrumental measurements (Harker, Maindonald et al. 2002). The Greggs plc sensory testing laboratory fulfilled the general requirements of ISO standard (8589:1988) for sensory analysis. The expert panels were recruited from the staff of Greggs Plc and Puratos companies. The panellists were selected on the basis of the ability of the individuals to discriminate taste and texture attributes of bread, and had more than ten years' experience of testing bakery products. Previous studies have been shown that the reliability of the methods depends more on experience and training rather than the number of the assessors (Kuti, Hegyi et al. 2004). Harker *et al*. (2002) defined crispness as "the sound intensity during the first bite with the front teeth," crumb softness as "feeling perceived by both touching the bread crumb by finger and mouth", crumb hardness as "force necessary to completely compress the slice on a flat surface with one finger or by lower teeth, crust hardness as "hardness is related to the force needed to break the crust. The texture of bread is very important to the total experience of bread whether it is soft, chewy, moist, dry, dense or airy. Interestingly, consumer's experience of the crust and the crumb has a strong influence on their judgment of whether they like the bread or not. For instance, if they perceive the bread as dry, they will immediately discard the bread no matter the aroma and taste of the bread (Robert 1992, Gambaro, Varela et al. 2002).

An unstructured line scale was used to score bread samples characteristics anchored from low (L) to high (H). The advantage of using free scale line technique, is that it is more likely that it gives a wide size estimation which helps data manipulation, and produce data which are close to the normal distribution (Kuti, Hegyi et al. 2004, Stone and Sidel 2004). The form of sensory evaluation used in this experiment is attached in appendix 1 (7.1 and 7.2).

The following definitions and procedure were used by the panellists in the current study:
Crumb hardness: Force required pressing a sample with one figure and the teeth
L= very hard crumb, to H = very soft crumb.
Crust crispness: the sound intensity during the first bite with the front teeth.
L = no sound, to H = very noisy.
Crust hardness: Hardness is related to the force needed to break the crust both by teeth and hand.
L= sold and thin crust (easy to fracture). H= very hard crust.
The sensory tests were carried out for a quantitative assessment of the parameters previously mentioned. Sensory evaluation was carried out for two consecutive days (4, 24 hours), panellists being asked to grade the samples by rating on an unstructured scale from “highly” (H) to “least” (L) based on the perception from the whole oral, visual and manual process (Thybo, Bechmann et al. 2005). For crispness evaluation, the panellists were allowed to make only one single bite using their front teeth and then grade the sample from L (for least crispy) to H (for highly crispy). Each type of bread was tested eight times each day by eight different panellists (Chen, Karlsson et al. 2005).

2.3.5 Mechanical measurements

A TA-XT.plus Texture Analyser (Stable Micro Systems, Surrey, U.K.) was used for force/displacement measurement with a 5-kg load cell. The crust of the bread was penetrated in three different points, at middle area and at 2 cm distance on both sides using a wedge-shaped aluminium probe (Figure 2.5 A) using 30º cutting angle, 15 mm wide (Vincent, Jeronimidis et al. 1991, Primo-Martín, Beukelaer et al. 2008, Altamirano-Fortoul and Rosell 2011). A sample was placed on the test bed of the texture analyser. Measurements were made at a compression speed of 1 mm/s. This speed was compatible with the TA-XT plus data acquisition rate to capture the maximum number of acoustic peaks within 500Hz. The threshold of 3 N was used for the quantification of the force peaks in order to obtain information about both small and large size events (Castro-Prada, Luyten et al. 2006, Castro-Prada, Luyten et al. 2007). Several parameters relating to the mechanical properties were determined such as; failure force, maximum force, number of force peaks and area.

For bread crumb firmness a 36mm diameter aluminium cylinder probe was used according to the AACC method (74-09). A single slice of 25-30 mm in thickness was compressed at 40% compression (10 mm depth), and the force reading at 25% compression was used as an indication of freshness (Abu-Shakra 1984, Baker A. E. and Walker C. E. 1988) (Figure 2.5 B).

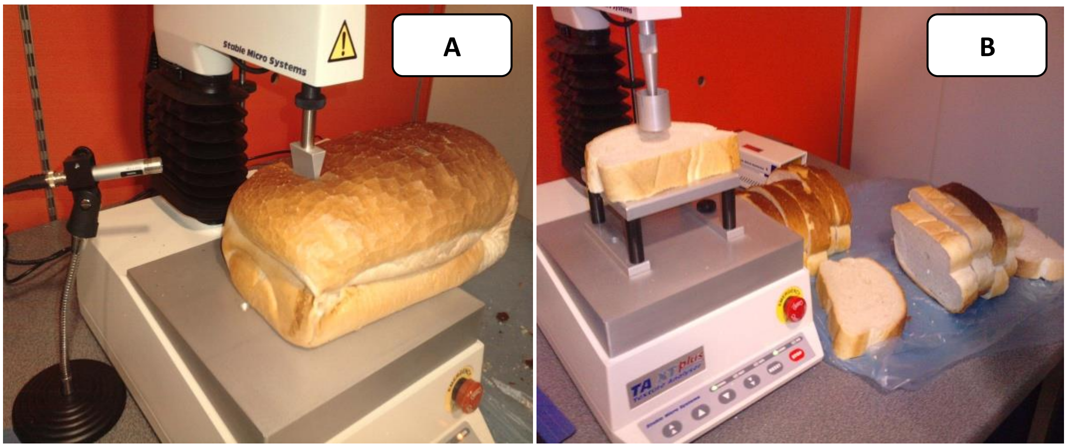

Figure 2.5 determinations of physical parameters (A) using A TA-XT.plus and crumb firmness (B).

2.3.6 Acoustic measurements

A reference Acoustic Envelope Detector (AED) (Figure 2.6), along with texture analysis TA-XT plus and its software package (Texture Exponent 32), supplied by Stable Micro Systems were used to determine the number of sound peaks (AUX) and maximum sound pressure level (SPL). These parameters were determined using special macro designed for crispy products. The macro which was kindly provided separately by Stable Micro Systems allows counting both the number of force and sound peaks and other selected parameters and then display them directly on the results sheet. The gain of the AED was set at 1(Chen, Karlsson et al. 2005). The background noise was screened out by the filter function of the device, removing any mechanical noise and acoustic noise below 1 kHz. A fixed distance of 5-7 cm and 0º angle from the model crust to the microphone was used for sound recording (Castro-Prada, Luyten et al. 2007). The data acquisition rate was set at 500 points per second for both force and acoustic signals. The threshold was set on 60dB to avoid noise produced from engine. All tests were performed in a laboratory with no special soundproof facilities and in the open air with a relative humidity of around 37 + 7 %. The room temperature was 20 ± 2˚C. (Chen, Karlsson et al. 2005, Primo-Martín, Beukelaer et al. 2008).

Figure 2.6 Acoustic envelope detector used to determine the sound emission

The mechanical and acoustic parameters of the crust were calculated by punching the sample at three different points of bread surface: in the middle of the crust area and at 2 cm distance on both sides. The average value was determined for each bread variety (Altamirano-Fortoul and Rosell 2011).

2.4 Statistical Analysis

The Texture Exponent 32 Software associated with the Texture analyser was used to provide the values for mechanical and acoustic parameters.

Statistical analysis: Quantitative data from physical analysis were compared using both analysis of variance (one way ANOVA) using the General Linear Model (GLM) of Minitab 16 to assess significant differences between samples and coefficients of variation (CV%) to determine the reproducibility of the method

The means of each mechanical and acoustic parameter for different types of bread were compared by using the Tukey's HSD test (Honestly Significant Difference). Standard errors were also calculated by using Sigma plot 11.0 to show the variation within and between different samples. For bread sensory analysis GLM (two-way ANOVA) of Minitab 16 was used to compare the differences between recipes and time and the interaction between them. For each parameter data were considered significantly different if $P<0.05$.

2.5: Results

It is known that large factories are completely different from small bakeries in terms of shelf life duration of bread. In small bakeries, the consumer can buy and consume the bread at its best characteristics, but in the case of large factories, which the current study tackled, the bread would be available to consumers after 18-24 hours after baking.

Although the current study has studied bread crust crispness and crumb firmness at 4, 24, 48 and 72 hours after baking to determine which parameters which parameters could reflect the changes occurred during the tested periods, however more attention was paid for data obtained at 4 and 24 hours for the reasons illustrated above.

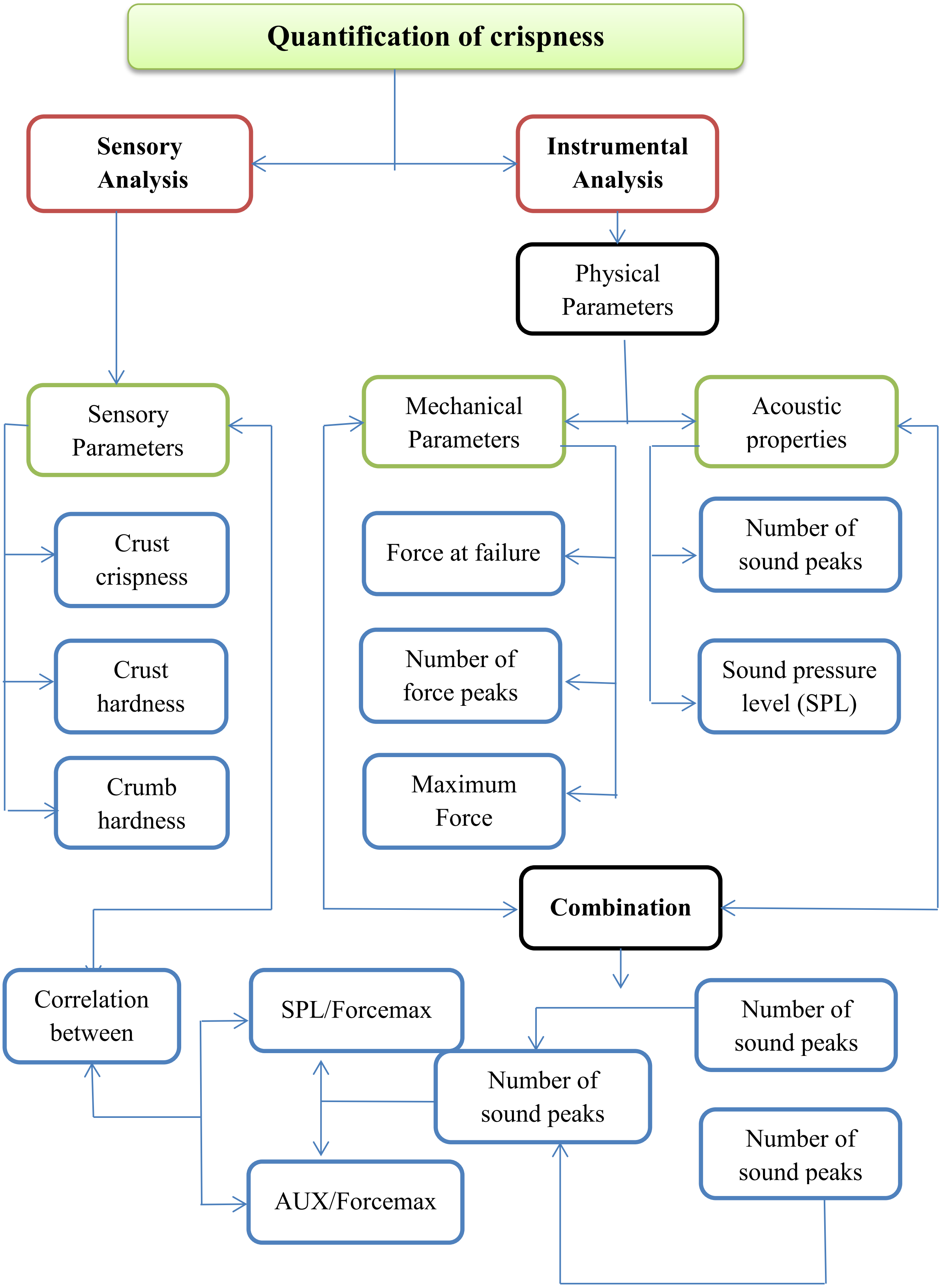

Figure 2.7 Outline of general procedure to evaluation bread crust crispness

2.5.1 Sensory measurements

The mean scores for sensory parameters obtained from eight panellists' (8*3, n = 24) evaluations at 4, 24, 48 and 72 hours are summarised in Table 2.2. The data showed normal distribution, that allowed the use of two way ANOVA for assessment (Kuti, Hegyi et al. 2004).

Two-way ANOVA regarding bread crust crispness showed that the main effect of recipes was highly significant at 4, 24 and 48 hours after baking as shown in Table 2.2 (A, B) and Figure 2.9 (A). The results indicate that the sensory crust crispness of tested bread ranged between 6.1 – 13.2, 3.8 – 13.1, 3.1 – 3.8 and 1.1 – 1.4 at 4, 24, 48 and 72 hours post baking respectively. Two-way ANOVA showed that the difference between Pre-ferment and Panarome bread was not significant. However, they showed highly significant differences in crust crispness from other bread recipes both at 4 and 24 hours. 48 hours after baking only white bloomer bread showed a significant difference in sensory crust crispness from other bread recipes; however at 72 hours post baking no significant differences was detected between bread recipes as shown in Table 2.2 (A, B). O.N.L. Sponge, O.N. Sponge and White bloomer were shown to be less preferable by panellists both at 4, 24 and 48 hours after baking. The main effect of panel was not significant at 4, 24, 48 and 72 hours post baking, however the interaction between panel and recipes was significant at 4 and 24 hours post baking as shown in Table 2.2 (A).

The main effect of time was significant P= 0.018, while the interaction between time and panel was not significant P= 865. The averages calculated for CVs values for the property of sensory crust crispness at 4 different times post baking ranged between 18.5% - 27.2% as shown in Table 2.2 (A and B).

The results regarding sensory bread crumb firmness presented in Table 2.2 (A, B) and Figure 2.8 (A) showed that the main effect of recipes was highly significant at tested time points 4, 24, 48 and 72 hours after baking. The lowest crumb firmness score was for Pre-ferment bread at 4, 24, 48 and 72 hours post baking followed by Panarome bread. Pre-ferment bread showed significant difference with O.N.L.Sponge bread, O.N. Sponge and White bloomer bread, however, did not show a significant difference with Panarome bread at 4 and 24 hours after baking. White bloomer bread at 48 hours post baking showed to be significantly firmer than other bread recipes, however at 72 hours post baking no significant difference between different recipes was detected as shown in Table 2.2 (B). The main effect of panel was significant at both tested time 4 and 24 hours after baking (*F* (7, 80) = 3.56, *P* = 0.002), (*F* (7, 80) = 2.25, *P* = 0.038) respectively, while the main effect of panel at 48 and 72 hours post baking was not significant as shown in Table 2.2 (B). The interaction between recipe and panel also was highly significant at 4 and 24 hours after baking (*F* (28, 80) = 14.64, *P* = <0.001), (*F* (28, 80) = 2.31, *P* = 0.002) respectively, however at 48 and 72 hours post baking the interaction was not significant. The main effect of time was highly significant *P*< 0.001, while the interaction between panel and time was not significant *P*= 0.898. The coefficients of variation (CV) values of sensory crumb firmness at 4 and 24 hours post baking ranged from 19.9% to 36.7% and from 12.8 to 50.1, respectively. However, the range of CV% at 48 and 72 hours showed highly decrease as shown in Table 2.2 (B).

Results of two-way ANOVA relating to sensory bread crust hardness presented in Table 2.2 (A, B) and Figure 2.8 (C) showed that the main effect of recipes was highly significant at 4, 24 and 72 hours after baking, while at 48 hours post baking the main effect of recipe was not significant. Pre-ferment and Panarome bread had easier crust fracture behaviour in comparison to other bread formulae, whilst White bloomer and Sponge bread showed a hard crust. The main effect of panel at 4 time points was not significant. The interaction between panel and recipes at tested time was also not significant except at 48 hours post baking *P* = 0.013 as shown in Table 2.2 (A, B). The main effect of time was highly significant *P* < 0.001, while the interaction between time and panel was not significant *P*= 959. The CV values were 28.5% and 27.0% at 4 and 24 hours post baking. These values decreased at 48 and 72 hours after baking to reach 10.0% and 3.0% as presented in Table 2.2 (B).

Table 2.2 (A) Mean values and the main effect and interaction of the sensory parameters extracted from sensory evaluation for five different bread recipes at 4 and 24 hours after baking.

		Time (4 hours)		Main effect		Interaction	Time (24 hours)		Main effect		Interaction
Recipe	Parameter	4.00	CV%	Recipe	Panel	Recipe*Panel	24.00	CV%	Recipe	Panel	Recipe*Panel
Liquid Sponge	S.Cb.F	3.5	36.7	<0.001	0.002	<0.001	8.6	15.3	<0.001	0.038	0.002
Sponge		4.5	19.9				7.0	25.2			
Panarome		2.2	42.0				3.2	50.1			
Pre-ferment		1.5	22.6				1.9	28.3			
White bloomer		6.4	26.0				11.5	12.8			
Mean All		11.5	29.4				8.6	26.3			
Liquid Sponge	S.Ct.C	7.3	28.0	<0.001	0.194	0.025	6.3	32.6	<0.001	0.450	0.035
Sponge		6.1	24.8				6.9	31.6			
Panarome		12.4	9.9				11.6	12.4			
Pre-ferment		13.2	11.6				13.1	9.5			
White bloomer		8.6	18.5				3.8	27.6			
Mean All		9.5	18.5				8.3	22.8			
Liquid Sponge	S.Ct.H	4.7	27.1	<0.001	0.684	0.214	7.0	18.3	<0.001	0.467	0.300
Sponge		5.6	23.9				4.9	28.7			
Panarome		3.2	26.9				2.6	41.3			
Pre-ferment		2.7	28.1				2.6	26.3			
White bloomer		2.9	36.5				6.9	20.3			
Mean All		3.8	28.5				4.8	27.0			

Averages of 24 replications (8*3) panellists at two time points (4 and 24 hours). CV, Correlation of vibration .

Table 2.2 (B) Mean values and the main effect and interaction of the sensory parameters extracted from sensory evaluation for five different bread recipes at 48 and 72 hours after baking.

		Time (hours)		Main effect		Interaction	Time (hours)		Main effect		Interaction
Recipe	Parameter	48.00	CV%	Recipe	panel	Recipe*panel	72.00	CV%	Recipe	panel	Recipe*panel
Liquid Sponge	S.Cb.F	12.4	9.9	<0.001	0.072	0.071	14.8	2.3	0.012	0.153	0.672
Sponge		12.5	8.3				14.5	2.3			
Panarome		12.2	10.2				14.5	2.3			
Pre-ferment		12.0	7.4				14.4	3.7			
White bloomer		14.4	3.9				14.7	2.7			
Mean All		12.7	3.9				14.6	2.7			
Liquid Sponge	S.Ct.C	3.1	21.6	0.006	0.999	0.289	1.2	26.6	0.156	0.672	0.975
Sponge		3.3	22.0				1.3	38.2			
Panarome		3.2	26.1				1.2	21.0			
Pre-ferment		3.8	17.0				1.4	29.9			
White bloomer		3.2	19.5				1.1	20.3			
Mean All		3.3	21.2				1.3	27.2			
Liquid Sponge	S.Ct.H	11.8	9.6	0.396	0.466	0.013	14.9	1.5	0.013	0.649	0.929
Sponge		11.6	13.6				14.8	2.7			
Panarome		11.6	6.8				14.5	3.4			
Pre-ferment		11.2	11.9				14.5	4.3			
White bloomer		11.7	8.1				14.6	3.2			
Mean All		11.6	10.0				14.7	3.0			

Averages of 24 replications (8*3) panellists at two time points (4 and 24 hours). CV, coefficient of variation

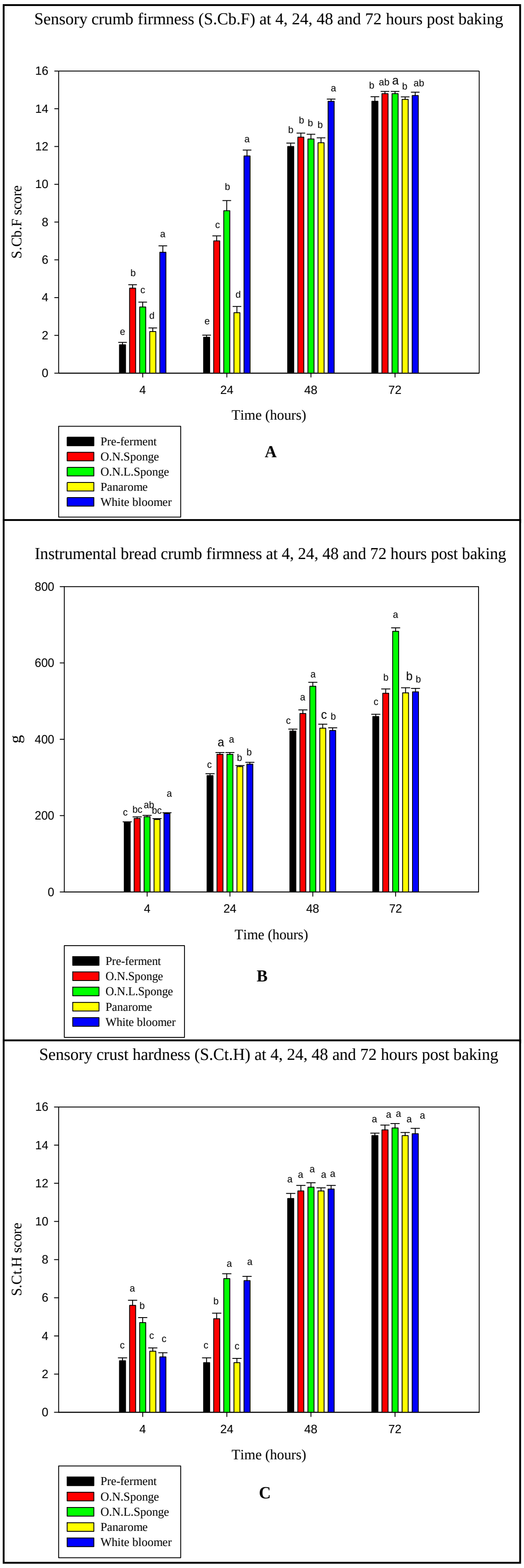

Figure 2.8 mechanical and sensory of bread crumb firmness and sensory crust hardness: (A) sensory crumb firmness, (B) instrumental crumb firmness (C) sensory crust hardness of five different bread recipes

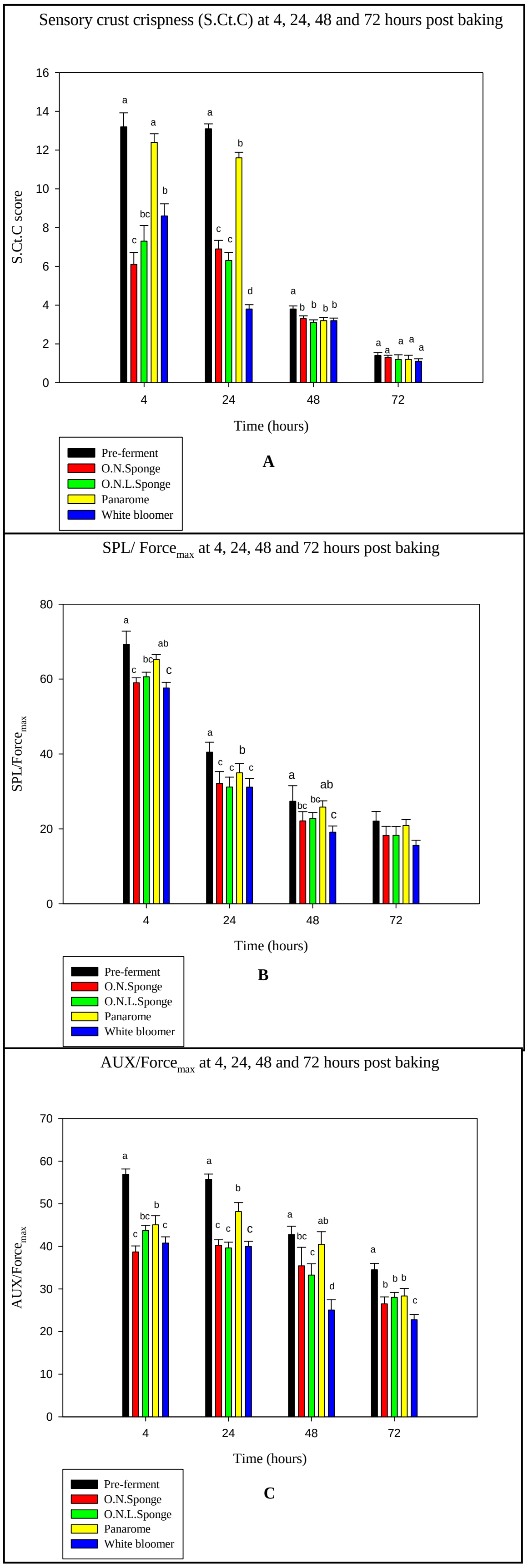

Figure 2.9 instrumental and sensory crust crispness: (A) sensory crust crispness, (B and C) instrumental experimental parameters adopted to evaluate crust crispness instrumentally

2.5.2 Mechanical and acoustic measurements

Table 2.3 (A, B) present's means for the mechanical, acoustic parameters obtained at 4, 24, 48 and 72 hours after baking. The number of sound peaks (AUX) reflects the number of sound peaks resulting from the pressure of the wedge probe on the surface of bread during the process of penetration. This sound is considered to be one of the most important parameters in terms of reflecting bread crispness (Hirte, Hamer et al. 2010). The bar charts of five different bread formulations Figure (2.10 A) shows the number of sound peaks at four different time points 4, 24, 48 and 72 hours after baking. The coefficients of variation for this parameter ranged from 3.59% to 16.31% at 4, 24, 48 and 72 hours post baking as presented in Table 2.3 (A and B). The values of sound peaks detected up to 24 hours after baking were within the range of (50.1 – 117.1) while the range within 48 and 72 hours was (104.7- 130.7) as shown in Table 2.3 (A, B). Pre-ferment followed by O.N.L. Sponge being significantly higher in comparison with other bread formulae at 4 hours, and at 24 hours Pre-ferment bread showed a significant difference with other bread formulae with the exception of Panarome bread. The main trend of sound peaks indicated considerable increase with time post baking for all bread recipes. White bloomer showed to be significantly lower AUX than other recipes at 4, 24, 48 and 72 hours post baking.

The area under the curve (the work required to compress the samples) at 4 hours ranged between 17.1 – 26.6 kg.mm, however, these values dramatically increased with time to ranging from 56.0 – 100 kg.mm as shown in Table 2.3 (A, B) and Figure 2.10 (B). This reflects the change of the mechanical nature of bread crust and crumb, from thin, brittle crust and soft crumb to thick, hard crust and firm crumb (Chen, Varela et al. 2006). Pre-ferment bread showed the lowest compression value both at 4, 24, 48 and 72 hours after baking. The number of total force peaks, which is an index of the jaggedness of the force/displacement curve, showed dramatic increases within 72 hours after baking as shown in Table 2.3 (A, B) and Figure 2.10 (C). This increase in force peaks was accompanied with an increase in the number of sound peaks, therefore, confirming the fact that sound events are mainly produced from force peaks (Dogan and Kokini 2007). Both total numbers of sound and force peaks showed an increase as the force failure increased. The latter reflects two things which are diametrically opposed to each other, the rigidity and the crispness of the texture (Vincent 1998). The maximum of the SPL was significantly lower for the white bloomer bread than the other bread recipes. However, pre-ferment bread had the highest value of sound pressure at 4, 24, 48 and 72 hours post baking as shown in Table 2.3 (A, B).

Table 2.3 (A) Mean values of the instrumental parameters extracted from the force/distance curve for five different bread formulae at 4 and 24 hours post baking

		Acoustic parameters				Mechanical parameters									
Treatments	Time (hr)	AUX	C.V%	SPL (dB)	C.V%	Area (Kg.mm)	C.V%	F.Peaks	C.V%	Force $_{Max}$ (kg)	C.V%	F. Failure kg	C.V%	Firmness (g)	C.V%
O.N.L.Sponge	4	55.3	12.99	76.5	5.24	23.3	15.13	7.9	29.57	1.27	6.41	1.081	2.47	197	7.12
O.N.Sponge		50.5	16.25	76.6	2.94	25.6	22.33	6.4	34.84	1.31	7.86	1.06	2.42	192	8.32
Panarome		52.5	13.17	76.4	3.02	22.6	20.01	8.3	22.15	1.18	7.47	1.083	1.76	190	4.49
Pre-ferment		62.1	6.25	75.5	3.59	17.1	22.63	9.1	14.26	1.09	3.74	1.089	3.54	181	5.12
White bloomer		50.1	16.27	70.4	6.5	26.5	15.97	6.7	31.4	1.23	8.46	1.076	2.58	205	3.84
Mean All		54.08	12.98	75.08	4.25	23.02	19.21	7.68	26.444	1.216	6.78	1.0778	2.55	193	5.78
Significance		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001		0.001		< 0.001	
O.N.L.Sponge	24	102.1	16.31	79.9	2.83	51.6	9.74	10.8	12.22	2.58	8.92	2.102	1.06	373	8.68
O.N.Sponge		99.1	6.71	79.2	2.93	44.5	9.11	10.3	9.36	2.48	8.16	2.101	0.46	361	4.96
Panarome		111.3	7.67	80.5	3.15	45.2	9.35	11.1	8.69	2.31	7.05	2.0119	1.27	328	3.27
Pre-ferment		117.1	8.46	84.9	2.31	44.4	10.16	11.3	9.82	2.1	3.1	2.117	0.49	305	6.28
White bloomer		101.9	5.76	79.5	1.97	51.1	9.7	9.7	5.05	2.57	9.14	2.091	1.28	335	5.6
Mean All		106.3	8.98	80.8	2.63	47.36	9.61	10.64	9.02	2.408	7.27	2.08458	0.91	340.4	5.76
Significance		< 0.001		< 0.001		< 0.001		< 0.001		< 0.001		0.002		< 0.001	

Averages of fifteen replications at two time points (4 and 24 hours). CV, coefficient of variation.

Table 2.3 (B) Mean values of the instrumental parameters extracted from the force/distance curve for five different bread formulae at 48 and 72 hours post baking.

		Acoustic parameters				Mechanical parameters									
Treatments	Time (hr)	AUX	C.V%	SPL (dB)	C.V%	Area (Kg.mm)	C.V%	F.Peaks	C.V%	Force $_{Max}$ (kg)	C.V%	F. Failure kg	C.V%	Firmness (g)	C.V%
O.N.L.Sponge	48	119.4	5.92	81.7	2.33	65.1	8.23	14.3	14.86	3.6	6.18	3.114	0.71	539	7.60
O.N.Sponge		130.6	8.10	82.0	1.50	65.6	12.52	13.7	20.86	3.8	12.01	3.113	0.31	468	7.76
Panarome		126.6	9.49	81.1	2.73	56.1	23.38	12.1	19.93	3.3	18.76	3.131	0.86	429	9.41
Pre-ferment		129.3	3.59	83.15	2.14	56.0	13.80	13.2	18.6	3.1	15.5	3.129	0.33	422	4.70
White bloomer		104.7	5.86	79.9	1.74	78.1	7.47	12.7	27.29	4.2	11.2	3.104	0.86	423	6.40
Mean All		122.12	6.59	81.57	2.09	64.18	13.08	13.2	20.31	3.6	12.73	3.118	0.614	456.2	7.17
Significance		< 0.001		< 0.001		< 0.001		0.201		< 0.001		0.002		< 0.001	
O.N.L.Sponge	72	124.7	11.8	82.7	2.43	82.4	14.79	14.1	24.64	4.53	14.76	4.126	0.54	683	5.09
O.N.Sponge		118.1	10.05	83.0	2.49	80.1	24.57	14.7	14.95	4.65	21.25	4.125	0.23	520	8.31
Panarome		111.3	8.75	82.6	2.76	65.0	31.28	13.5	15.26	4.16	25.75	4.143	0.65	521	10.03
Pre-ferment		131.4	4.27	85.15	1.69	67.6	17.61	14.3	10.08	3.89	13.96	4.142	0.25	456	5.00
White bloomer		119.3	7.19	79.3	2.86	100.0	11.22	14.3	20.98	5.29	9.08	4.116	0.65	524	6.62
Mean All		120.96	8.41	81.57	2.45	79.02	19.89	14.18	17.182	4.50	16.96	4.130	0.464	540.7	7.01
Significance		< 0.001		< 0.001		< 0.001		0.814		< 0.001		0.001		< 0.001	

Averages of fifteen replications at two time points (48 and 72 hours). CV, coefficient of variation.

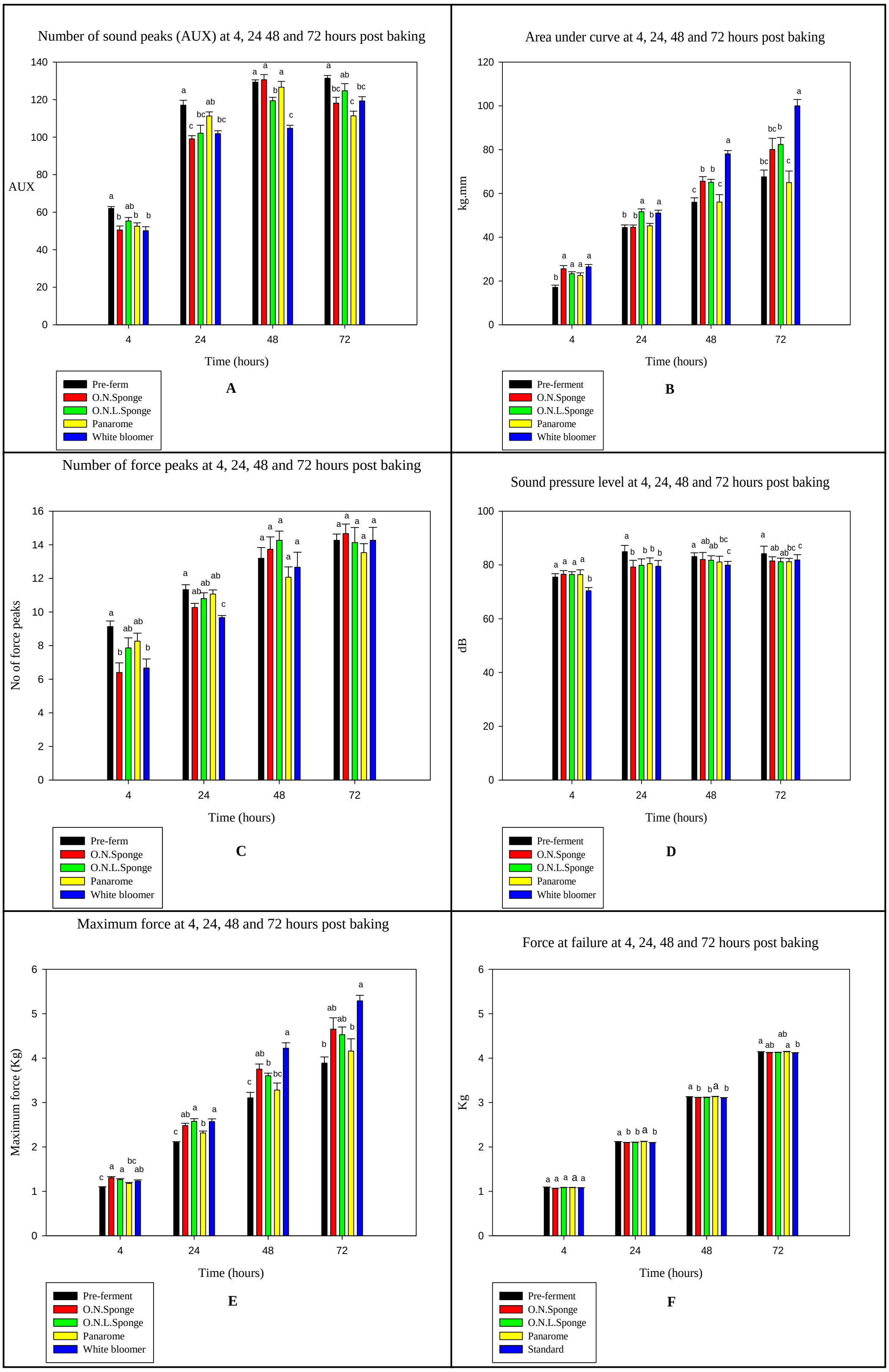

Figure 2.10 mechanical and acoustic parameters: (A) number of sound peaks, (B) area under curve, (C) number of force peaks, (D) sound pressure level, (E) maximum force, (F) force at failure of five different bread recipes at 4 and 24 hours after balking

Average of fifteen replications, identical letters indicating that there is no significant difference at ($P < 0.05$) within each time point

The maximum force applied on bread texture in order to penetrate bread crust for a 15mm distance by wedge probe (Primo Martin, Beukelaer et al. 2008) showed an increase for all bread types within 72 hours post baking. This increase reflects the change occurred to the crust from a dry crispy texture to elastic resistance texture. Force at failure was comparable between samples, thus, no significant difference was detected at 4 hours, however; at 24, 48 and 72 hours after baking Pre-ferment and Panarome bread showed significant difference with other bread formulae as shown in Table 2.3 (A, B).

Instrumental bread crumb firmness results showed a dramatic increase between 4 and 72 hours after baking. Figure 2.8 (B) shows that the firmness of the bread crumb was increased as the age of bread increased. White bloomer and O.N.L Sponge showed the highest values of bread crumb firmness compared with other bread formulae both at 4, 24, 48 and 72 hours after baking. There has been consensus between sensory and instrumental crumb firmness measurements, where both analyses showed that preferment bread was showed to be softer crumb followed by Panarome bread both at 4, 24, 48 and 72 hours post baking as shown in Figure 2.8 (A and B).

2.5.2.1 The Correlation between Mechanical and Acoustic parameters

The correlations (R^2) between Mechanical and Acoustic parameters are illustrated in Table 2.4**.** The results showed that the force at failure was positively correlated both with the number of sound and force peaks (AUX) at 4, 24, 48 and 72 hours after baking , however, these correlations were stronger and significant at 24 hours as shown in Table 2.4. For maximum sound pressure (SPL) the results showed that the correlation with force peaks, sound peaks and force at failure was stronger at 24 hours than 4, 48 and 72 hours post baking.
Interestingly, the maximum force parameter showed negative correlation with the number of sound peaks, the number of force peaks, the sound pressure level and the force at failure particularly at 4, 24, 48 hours, while showed positive correlation only with area under curve at 4, 24, 48 and 72 hours post baking. In addition, correlations between theses parameters which represent the physical parameters (mechanical and acoustic) and sensory evaluations would be made to assess which parameter best characterise of bread crust crispness at 4, 24, 48 and 72 hours post baking.

Table 2.4 Correlations (R^2) between mechanical and acoustic parameters

Parameter	*Time (H)*	*AUX*	*P*	*SPL*	*P*	*F. peaks*	*P*	*Area*	*P*	*F.max*	*P*
SPL	4	0.311	0.611								
F. peaks		0.875	0.052	0.370	0.540						
Area		-0.959	0.010	-0.383	0.525	-0.936	0.019				
F.max		-0.760	0.136	0.057	0.927	-0.848	0.070	0.854	0.066		
F.Fauilar		0.705	0.184	-0.224	0.717	0.805	0.101	-0.688	0.199	-0.840	0.075
SPL	24	0.894	0.041								
F. peaks		0.787	0.114	0.702	0.183						
Area		-0.508	0.382	-0.461	0.434	-0.497	0.395				
F.max		-0.934	0.020	-0.901	0.037	-0.761	0.135	0.757	0.139		
F.Fauilar		0.884	0.047	0.705	0.184	0.911	0.031	-0.711	0.179	-0.892	0.042
SPL	48	0.813	0.094								
F. peaks		0.156	0.802	0.443	0.455						
Area		-0.848	0.069	-0.721	0.169	0.111	0.859				
F.max		-0.784	0.117	-0.766	0.131	0.074	0.905	0.982	0.003		
F.Fauilar		0.713	0.177	0.596	0.288	-0.366	0.545	-0.954	0.012	-0.954	0.012
SPL	72	0.771	0.127								
F. peaks		0.441	0.157	0.234	0.705						
Area		-0.021	0.974	-0.290	0.636	0.449	0.448				
F.max		-0.293	0.633	-0.481	0.412	0.352	0.562	0.960	0.009		
F.Fauilar		0.096	0.878	0.372	0.538	-0.466	0.429	-0.993	0.001	-0.978	0.004

2.5.*3 Evaluation of experimental crispness parameters*

Until now no standard method has been published that can reliably measure and quantify crispness in bread with a dry outer crust layer and a softer moist core. The availability of such an objective technique that can be correlated well with sensory crispness will be beneficial to the food baking industry to produce products with desirable attributes. In response to the need to develop an instrumental determination of bread texture and especially bread crust crispness, with a strong correlation to sensory evaluation, the current study attempted to integrate mechanical and acoustic parameters to create a new parameter with a high correlation with sensory crispness.

This development was dependant on the simple definition of crispness “firm and brittle, snaps easily, emitting a typical sound upon deformation” (Szczesniak 1998, Saklar, Ungan et al. 1999, Roudaut, Dacremont et al. 2002). Several parameters related to the mechanical and acoustic were studied:

- Sound pressure level (dB) which is the highest sound recorded during the fracture of the sample at a certain threshold.
- Maximum force applied on the sample to generate sound (kg).
- Number of force and sound peaks which reflects the total number of sound and force peaks produced during sample penetration by using wedge probe using a certain force (kg).
- Area (kg.mm) reflects the hardness of the sample.
- Force at failure which represents the force value of the first force breakdown at a certain threshold.

It has been reported that number of sound peaks, number of force peaks and sound pressure level are better predictors of crispness for wet and dry crisp products than other parameters (Edmister 1985), but the accurate parameters have yet to be found. The relations between mechanical and acoustic parameters were assessed at 4, 24, 48 and 72 hours to figure out which parameter could reflect the changes occurred on bread at tested period. According to the previous studies, number of sound peaks and either sound pressure level or sound intensity are widely used as better indictors of crispness either for wet or dry products. They demonstrated that as the value of these parameters increased the level of crispness increased.

Also force at failure was used as crispness indicator in determining the crispness of roasted almonds (Chen, Varela et al. 2006). In their study the fore at failure was negatively correlated with crispness while the correlation was positive with bread crust crispness, the reason of this discrepancy might attribute to type of food tested. It has been known that the property of crispness is a sensory sensation which means in order to detect the sensation of crispness the sound propagated during applying certain force using front teeth (bite process) should be reached to ear either by air conducted or bone conducted (Vickers 1976). Therefore it can be concluded that the parameters responsible for crispness sensation are the sound and the force. The former showed excellent correlation of variation (CV%) within 4 times post baking (4.25%, 2.63%, 2.09% and 2.45%) respectively which indicates high repeatability for the evaluation of this parameter, while the latter showed CV% values slightly higher than the former but still in the expectable range as shown in Table 2.3 (A and B) . The correlations between mechanical and acoustic parameters that presented in Table 2.4 showed negative correlation between maximum force applied and both the number of sound peaks (AUX) and maximum sound pressure (SPL) at 4, 24, 48 and 72 hours. As these measurements were conducted simultaneously the integrations between more than one parameter were taken into the consideration particularly those directly related to sensation of crispness.

Table 2.5 Mean values and correlation of variation (CV%) of the SPL/Force$_{max}$ and AUX/Force$_{max}$ for five different bread formulae.

Treatments	Time (hr)	SPL/Force$_{max}$	C.V%	AUX/ Force$_{max}$	C.V%	Time (hr)	SPL/Force$_{max}$	C.V%	AUX/Force$_{max}$	C.V%
O.N.L.Sponge	4	60.6	7.91	43.7	11.18	48	22.8	7.51	33.3	8.61
O.N.Sponge		59.2	8.72	38.7	14.02		22.1	11.04	35.4	17.49
Panarome		65.2	7.82	45.1	18.34		25.8	25.13	40.5	28.16
Pre-ferment		69.2	6.03	56.9	8.58		27.4	15.31	42.7	17.85
White bloomer		57.6	10.2	40.8	13.83		19.1	9.49	25.1	11.14
Mean All		62.3	8.13	45.1	13.19		23.5	13.70	35.4	16.65
Significance		< 0.001		< 0.001			< 0.001		< 0.001	
O.N.L.Sponge	24	31.2	7.38	39.6	13.25	72	18.3	14.71	28.12	16.21
O.N.Sponge		32.2	8.97	40.3	12.12		18.5	20.51	26.5	23.85
Panarome		35.1	8.87	48.2	6.93		20.9	29.13	28.4	24.1
Pre-ferment		40.5	3.33	55.7	8.48		22.1	15.3	34.5	16.83
White bloomer		31.2	8.19	40.0c	11.67		15.6	11.18	22.8	13.51
Mean All		34.3	7.35	44.8	10.49		19.3	18.17	28.1	18.9
Significance		< 0.001		< 0.001			< 0.001		< 0.001	

Averages of fifteen replications of four time points (4, 24, 48 and 72 hours). CV, coefficient of variation.

2.5.3.1 The ratio of maximum sound pressure level (SPL) and maximum force

As mentioned above the potential instrumental parameters that could reflect the crispness instrumentally should combine both the sound and the force. Since the sound is represented by two parameters, the SPL and AUX, their ratio with maximum force was assessed at 4, 24, 48 and 72 hours post baking and the values of both ratios were analysed using one way ANOVA as shown in Table 2.5.

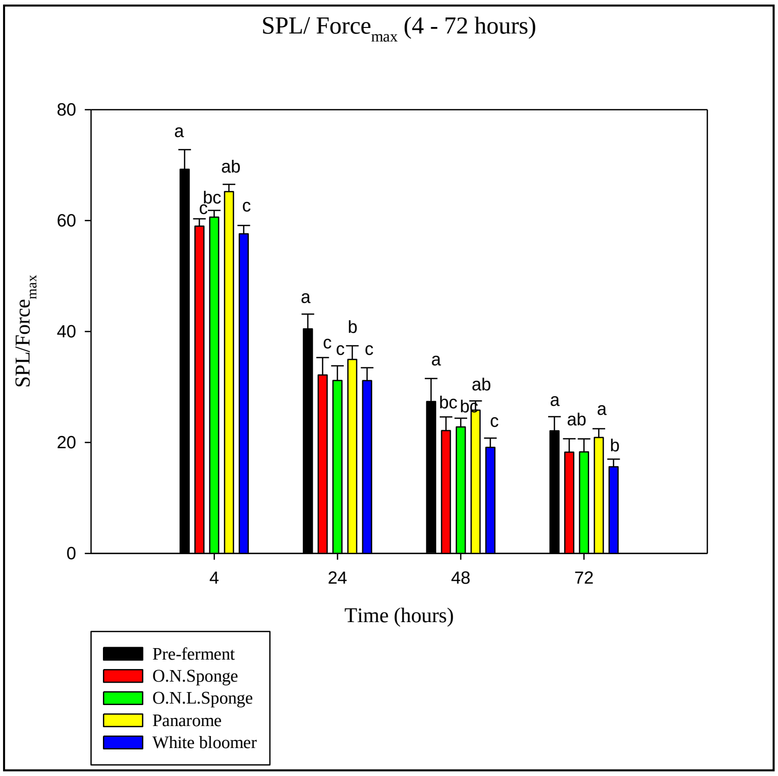

Figure 2.11 SPL/Force$_{max}$ of five different bread recipes at 4, 24, 48 and 72 hours post baking. Average of fifteen replicates, identical letters indicating that there is no significant difference

The ratio between maximum sound pressure level (SPL) and maximum force (Force$_{max}$) applied on bread crust was used to express the bread crust crispness instrumentally. The result pertaining to sound pressure level at 4 hours after baking (Table 2.3 (A)) showed that Pre-ferment bread had value of SPL at 75.5 dB accompanied with the lowest Force$_{max}$ 1.09 kg, therefore the ratio between them SPL/Force$_{max}$ was 69.2 as shown in Table 2.5, reflecting the crispness of bread crust . Panarome bread showed the second best crust crispness value of 65.2, and also showed a statistical difference with Pre-ferment both at 4, 24, 48 and 72 hours after baking. On the other hand, O.N.Sponge and White bloomer bread showed the lowest SPL/Force$_{max}$ values; despite showing comparable SPL values with Pre-ferment bread. This decline in SPL/Force$_{max}$ value contributed to the amount of force applied on the crust to produce maximum peak intensity of SPL. Figure 2.11 shows that the general pattern of bread crust crispness was roughly similar at different time points. Pre-ferment bread was significantly different with other bread formulae except Panarome bread at 4, 24, 48 and 72 hours after baking. In comparison with sensory crust crispness as illustrated in Figure 2.8 (A and B) `it can be clearly seen that SPL/Force$_{max}$ was in line with the results obtained from sensory evaluation at 4 and 24 hours post baking, where both measurements showed that pre-ferment was the most crispness among other bread recipes followed by Panarome bread, also showed that white bloomer was the lowest crust crispness at 4, 24, 48 and 72 post baking.

2.5.3.2 The ratio of number of sound peaks (AUX) and maximum force

A previous study claimed that the number of sound peaks was the acoustic parameter that best discriminated between the samples (Varela, Salvador et al. 2008). The ratio of the number of sound peaks (AUX) and Force$_{max}$ (AUX/Force$_{max}$) has also been used to express bread crust crispness in the current study along with the ratio of SPL/Force$_{max}$. It is evident from the results presented in Table 2.5 that Pre-ferment bread showed the highest value of AUX/Force$_{max}$ followed by Panarome bread at 4, 24, 48 and 72 hours post baking (Figure 2.12).

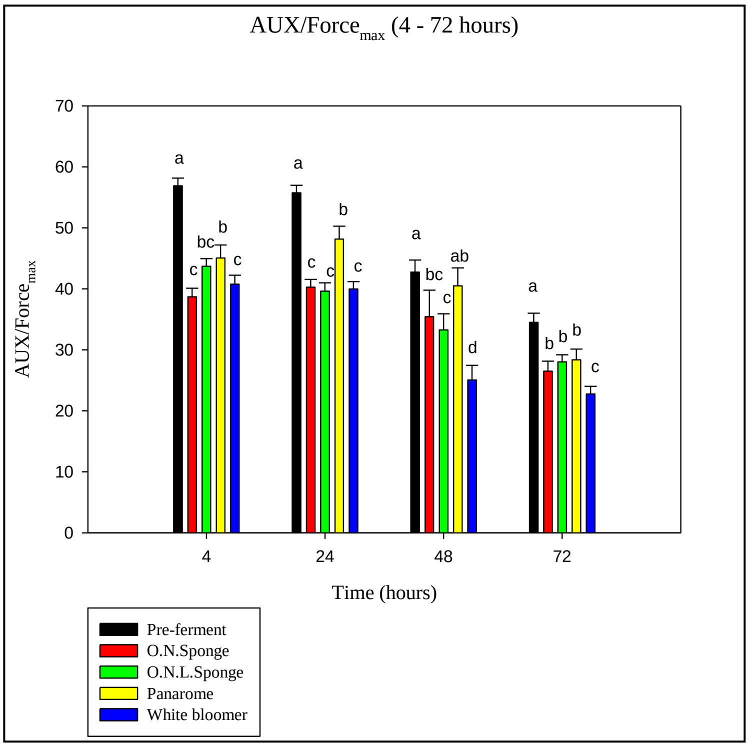

Figure 2.12 AUX/Force$_{max}$ of five different type of bread at 4, 24, 48 and 72 hours post baking. Average of fifteen replicates, identical letters indicating that there is no significant difference at $P \leq 0.05$

This result was in line with both results obtained from SPL/Force$_{max}$ and from the results obtained from sensory analysis (Figure 2.9 B and C), where the analysis of variance showed that Pre-ferment bread was significantly different with all bread formulae at 4 and 24 hours after baking.

2.5.4 The correlations between physical and sensory parameters

To observe possible correlations between the sensory and physical (mechanical and acoustic) parameters, Pearson matrices with Bonferroni adjusted probabilities were constructed at 4 and 24 hours and are presented in Table 2.6 and 2.7.

As can be seen in Table 2.6, sensory crumb firmness showed tendency toward a negative correlation with number of sound peaks R^2 = -0.78, -0.84, -0.91 and 0.022 at 4, 24, 48 and 72 hours post baking respectively, and also had a high positive correlation with Force Maxima (Force$_{max)}$ R^2 = 0.68, 0.92, 0.91 and 0.70 at 4, 24, 48 and 72 hours post baking respectively. There was no correlation between sensory crust crispness and number of sound peaks P = 0.29. Sensory crispness however had high and significant negative correlation with Force$_{max}$ R^2 = - 0.95, P = 0.012 and – 0.94, P = 0.017 at 4 and 24 hours post baking respectively, but at 48 and 72 hours post baking the correlation was not significant. In addition, non-significant correlations were observed between sensory crust crispness and number of force peaks at tested times. A strong but non-significant negative correlation was also detected between sensory crust hardness and Force$_{max}$ R^2 = 0.85, 0.91, 0.61 and 0.41 at 4, 24, 48 and 72 hours post baking respectively.

Since the main purpose of the current study was to find possible correlations between sensory and physical parameters at 4 different time points after baking, therefore, more attention was paid on these parameters showing higher correlation within tested times. Correlations between sensory and physical parameters at 24 hours after baking showed the same pattern as at 4 hours; furthermore, they showed higher correlation at 24 hours after baking than either 48 or 72 hours post baking. For instance, the correlation between sensory crumb firmness and both number of sound peaks and Force$_{max}$ became stronger R^2 = - 0.84, - 0.92. Additionally, sensory crust crispness showed high and significant correlation with number of sound peaks R^2 = 0.91, P = 0.034 and a significant negative correlation with Force$_{max}$ R^2 = -0.94, P = 0.017.

Table 2.6 Correlations between sensory and instrumental parameters. Means at 4, hours post baking

Parameter	*Time (H)*	*S.Cb.F*	*P*	*S.Ct.C*	*P*	*S.Ct.H*	*P*	*AUX*	*P*	*SPL*	*P*	*Count Peaks+*	*P*
S.Ct.C	4	-0.697	0.191										
S.Ct.H		0.234	0.702	-0.835	0.079								
AUX		-0.775	0.123	0.598	0.287	-0.392	0.513						
SPL		-0.707	0.181	0.032	0.958	0.503	0.388	0.311	0.609				
F. peaks		-0.893	0.043	0.824	0.134	-0.562	0.423	0.875	0.010	0.370	0.523		
Area		0.890	0.041	-0.763	0.086	0.471	0.324	-0.959	0.051	-0.383	0.538	-0.936	0.019
F.max		0.664	0.211	-0.951	0.012	0.850	0.071	-0.760	0.135	0.057	0.948	-0.848	0.063
F.Fauilar		-0.453	0.280	0.755	0.119	-0.846	0.139	0.705	0.175	-0.224	0.998	0.805	0.161
I.Cb.F		0.922	0.026	-0.625	0.260	0.150	0.810	-0.749	0.145	-0.657	0.228	-0.739	0.057
SPL/Force$_{max}$		-0.934	0.020	0.876	0.052	-0.530	0.358	0.839	0.076	0.419	0.482	0.937	0.010
AUX/Force$_{max}$		-0.784	0.116	0.801	0.104	-0.615	0.269	0.953	0.012	0.179	0.772	0.914	0.004

Parameter	*Time (H)*	*Area*	*P*	*F.max*	*P*	*F.Fauilar*	*P*	*Firmness*	*P*	*SPL/Force$_{max}$*	*P*
F.max	4	0.854	0.064								
F.Fauilar		-0.688	0.043	-0.840	0.093						
I.Cb.F		0.868	0.153	0.635	0.242	-0.266	0.548				
SPL/Force$_{max}$		-0.958	0.018	-0.882	0.004	0.645	0.169	-0.897	0.039		
AUX/Force$_{max}$		-0.977	0.029	-0.919	0.027	0.790	0.117	-0.768	0.129	0.922	0.026

For mechanical and acoustic parameters, n = 15; for sensory parameters, n = 24. P = < 0.05

Table 2.7 the correlations between sensory and instrumental parameters. Means at 24 hours post baking

Parameter	*Time (H)*	*S.Cb.F*	*P*	*S.Ct.C*	*P*	*S.Ct.H*	*P*	*AUX*	*P*	*SPL*	*P*	*F. peaks*	*P*
S.Ct.C		-0.990	0.001										
S.Ct.H		0.948	0.014	-0.939	0.018								
AUX		-0.843	0.073	0.907	0.034	-0.815	0.093						
SPL		-0.735	0.158	0.784	0.117	-0.650	0.236	0.894	0.041				
F. peaks		-0.893	0.094	0.904	0.147	-0.718	0.045	0.787	0.381	0.702	0.436		
Area	24	0.813	0.041	-0.746	0.036	0.887	0.174	-0.508	0.114	-0.461	0.185	-0.497	0.395
F.max		0.921	0.027	-0.942	0.017	0.914	0.032	-0.934	0.020	-0.901	0.035	-0.761	0.202
F.Fauilar		-0.978	0.007	0.990	0.004	-0.930	0.177	0.884	0.064	0.705	0.228	0.911	0.409
I.C.F		0.594	0.029	-0.665	0.220	0.712	0.077	-0.857	0.064	-0.781	0.119	-0.370	0.409
SPL/Force$_{max}$		-0.871	0.054	0.903	0.036	-0.837	0.059	0.938	0.018	0.959	0.010	0.751	0.218
AUX/Force$_{max}$		-0.884	0.047	0.926	0.024	-0.864	0.059	0.977	0.004	0.933	0.021	0.770	0.243

Parameter	*Time (H)*	*Area*	*P*	*F.max*	*P*	*F.Fauilar*	*P*	*I.C.F*	*P*	*SPL/Force$_{max}$*	*P*
F.max		0.757	0.133								
F.Fauilar		-0.711	0.027	-0.892	0.067						
I.C.F	24	0.484	0.539	0.833	0.082	-0.616	0.324				
SPL/Force$_{max}$		-0.668	0.142	-0.987	0.002	0.839	0.107	-0.833	0.079		
AUX/Force$_{max}$		-0.641	0.127	-0.986	0.002	0.881	0.073	-0.865	0.058	0.988	0.002

For mechanical and acoustic parameters, $n = 15$; for sensory parameters, $n = 24$. $P = <0.05$

2.5.5 The correlations between experimental parameters and sensory crust crispness

The correlations pertaining to the new experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ were investigated on the basis of average values, and the results presented relating to 4 and 24 hours are presented in Table 2.6 and 2.7, while the results relating to 48 and 72 hours post baking are presented in Appendix 2 Table 7.4 (D). High but non-significant correlations were found between sensory crust crispness and both experimental parameters at 4 hours after baking. Results showed that SPL/Force$_{max}$ had high correlation with crust sensory crispness R^2 = 0.88, P = 0.052 at 24 hours post baking, and also showed negative significant correlation with sensory crumb firmness R^2 = - 0.94, P = 0.016. On the other hand, AUX/Force$_{max}$ showed strong non-significant correlation with sensory crust crispness R^2 = 0.80, P = 0.104, and a negative non-significant correlation with sensory crumb firmness R^2 = - 0.80, P = 0.101. Correlations between sensory crust crispness and experimental instrumental parameters at 48 and 72 hours post baking were lower than those at 4 and 24 hours as shown in Figure 2.13 and 2.14.

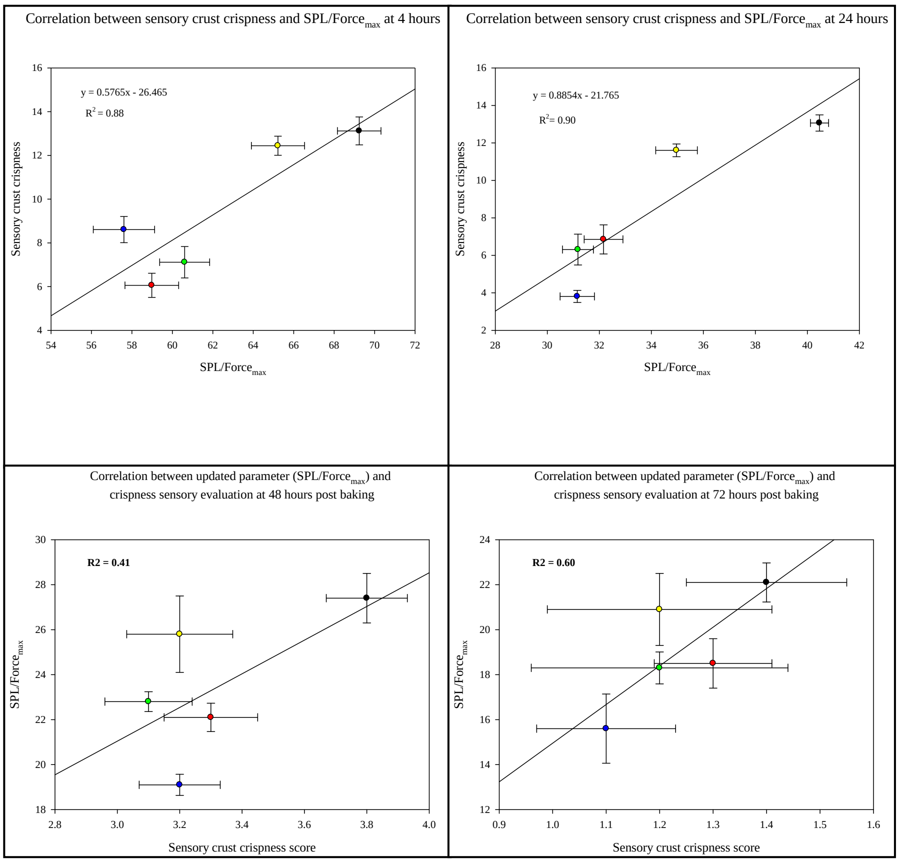

Figure 2.13 Correlation between sensory crispness and SPL/Force$_{max}$ at 4, 24, 48 and 72 hours after baking.

Interestingly, higher and significant correlations between sensory and experimental crispness parameters were observed at 24 hours than 4, 48 and 72 hours after baking. Where the correlation between SPL/Force$_{max}$ and sensory crispness showed significant correlation $R^2 = 0.90$, $P = 0.036$ and also had a significant correlation with sensory firmness $R^2 = 0.87$, $P = 0.054$, while, AUX/Force$_{max}$ showed a significant correlation with sensory crispness $R^2 = 0.93$, $P = 0.036$ and non-significant correlation with sensory crumb firmness $R^2 = 0.89$, $P = 0.05$.

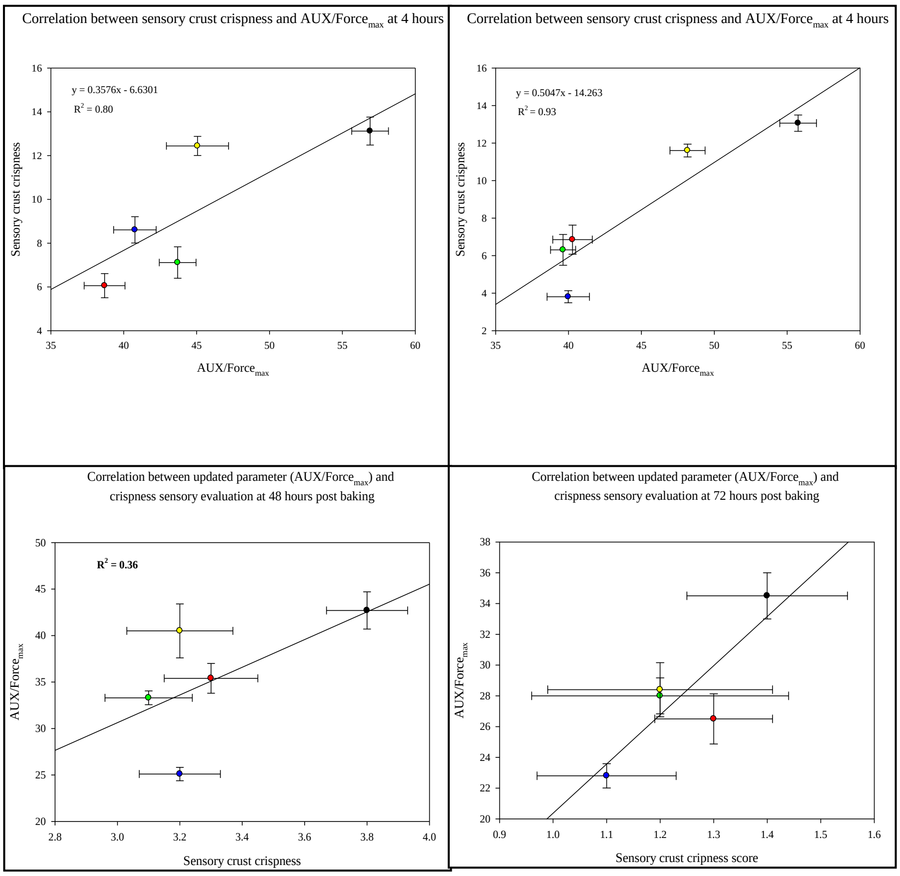

Figure 2.14 Correlation between sensory crispness and AUX/Force$_{max}$ at 4, 24, 48 and 72 hours after baking

● Pre- ferment, ● White bloomer, ● O.N.Sponge, ● O.N.L.Sponge, ● Panarome

Figures 2.12 and 2.13 revealed that the correspondence between experimental parameters and sensory analysis was high at 4 and 24, 48 and 72 hours after baking. It appears that sensory attributes can be well predicted by using the newly developed parameters at this stage of the current research.

Accordingly, the relationship between sensory crispness and experimental parameters can be described by equations 1- 4:

Sensory crust crispness (4 h) = 0.576($SPL/Force_{max}$) + 26.465 ($R^2 = 0.88$) (1)

Sensory crust crispness (24 h) = 0.9203($SPL/Force_{max}$) + 21.765 ($R^2 = 0.90$) (2)

Sensory crust crispness (4 h) = 1.7922($AUX/Force_{max}$) + 6.63 (R2 = 0.80) (3)

Sensory crust crispness (24 h) = 1.7006($AUX/Force_{max}$) + 14.263 ($R^2 = 0.93$) (4)

The positive slope implies that sensory crust crispness increases as the ratio of sound pressure level and number of sound peaks with maximum force increased.

Additionally, several trials were separately conducted (data not shown) to support current finding with regards the reliability and validity of using calculated parameters to estimate bread crust crispness. The results obtained from these trials were highly encouraging as demonstrated by high correlation obtained which ranged between (R^2= 0.75 – 0.95) indicating that the selected parameters are likely to be the keys in determining bread crust crispness.

2.5.6 Effect of bread crust water content on physical and sensory parameters

Bread crust water content increases as bread ages, owing to water sorption from the atmosphere and by mass transport from neighbouring components of the crumb (Altamirano-Fortoul and Rosell 2011). The overall result showed an increase of crumb hardness with lapse of time and moreover, the crust initially dry and crispy became soft and rubbery (Katz and Labuza 1981). Water distribution between crust and crumb also contributes largely to the organoleptic perception of freshness (Table 2.9) (Maga 1975).

Table 2.8 Bread crust moisture content (g/100g) at 4 and 24 hours after baking

	Time after baking (hours)	
Bread recipe	4	24
Overnight Liquid Sponge	24.18±0.031a	24.48±0.302a
Overnight Sponge	24.64±0.254a	24.89±0.184b
Panarome	23.05±0.081b	23.36±0.037b
Pre-ferment	22.93±0.233b	23.47±0.029b
White bloomer	24.94±0.213a	25.11±0.111a
Mean all	23.950	24.26

The analysis of the breads during storage revealed that moisture content of the crust increased in all types of bread (Table 2.8). 4 hours after baking samples had an average moisture content of 22.9 to 24.9 g/100 g and after 24 hours of baking their moisture content ranged from 23.36 to 25.1 g/100 g. Considering that all breads were stored under the same conditions, and thus they will have similar water sorption from the atmosphere, divergence was observed in the amount of crust water content which might be due to variation in the moisture between crust and crumb.

It has been reported that both water content and water activity play an important role in crispness retention, where water activity determine the direction of water migration while water content determine the level of crispness (Roudaut, Dacremont et al. 1998, Van Nieuwenhuijzen, Primo-Martin et al. 2008), ingredients and the porosity are significantly affected the migration of water from crumb to crust. However the contribution of each factor still unclear (Luyten, Plijter et al. 2004).

Table 2.9 Correlations between bread crust water content and physical and sensory parameters at 4 and 24 hours after baking

		Time post baking (hours)			
		4		24	
Parameters		Water content	*P*	Water content	*P*
S.Cb.F	Sensory analysis	0.95	0.01	0.92	0.03
S.Ct.C		-0.87	0.05	-0.95	0.01
S.Ct.H		0.49	0.40	0.86	0.06
AUX	Physical analysis	-0.71	0.18	-0.91	0.03
SPL		-0.50	0.39	-0.69	0.20
Area		0.87	0.05	0.56	0.33
F. Peaks		-0.93	0.02	-0.91	0.03
Forcemax		0.82	0.09	0.84	0.08
F. Failure		-0.73	0.16	-0.98	0.00
I.Cb.F		0.84	0.07	0.62	0.26
SPL / Force_{max}	Experimental parameters	-0.97	0.01	-0.80	0.10
AUX/Force_{max}		-0.81	0.10	-0.86	0.06

Previous studies indicated that water content determines product crispness level (van Nieuwenhuijzen, Tromp et al. 2010). Table 2.9 shows the correlations between bread crust water content with physical and sensory parameters. Water content showed a significant negative correlation with all crispness indicators such as sound peaks, force peaks and force at failure. On the other hand it showed a positive correlation with force maximum.

2.6 Discussion

The first aim of this stage of this study was to determine which, if any, mechanical and acoustic parameters best characterize bread crust crispness. Crust crispiness of five different bread formulae was determined by measuring its fracture behaviour and the accompanying sound emission at 4, 24, 48 and 72 hours post baking.

Structurally, crispy crust of bread has a tendency to be cellular. When a force is applied to such a cellular product, each cell ruptures, creating a sound and the overall rupture pattern produces an irregular frequency and amplitude signature (Duizer 2004).

It is generally agreed that crispness perceived and determined by both the fracture behaviour of the product and the accompanied sound emission (Fineberg, Gross et al. 1991, Luyten, Plijter et al. 2004), therefore several parameters were extracted from the force/displacement and sound pressure level (SPL) curves. These parameters included (1) Number of sound peaks, which was the number of peaks of the sound plot; (2) Max sound pressure level; (3) Area of force curve; (4) Number of force peaks (5) Maximum force as index of the hardness; and (6) the force at failure.

2.6.1 Number of sound peaks

The number of sound peaks obtained from bread crust represents the sound emitted by total force drop. Pre-ferment bread showed significantly higher number of sound peaks than other bread recipes, while White bloomer showed a significantly lower force peaks at 4, 24, 48 and 72 hours post baking. The possible explanation for a variation in sound peaks is likely due to the inclusion of preferment liquid in the recipe and/or the lower crust water content comparing with other recipes (Table 2.3 (A, B), Figure 2.10(A)). The small differences within the same formula are presumably due to the heterogeneity of the crust, the presence of air pocket and crust water content (Fu, Tong et al. 2003).

The findings here confirmed that the number of sound peaks was the acoustic parameter that best discriminated between the samples, but taking into account the value of maximum force applied. This finding was in line with Luyten et al., (2004); Mohamed et al., (1982); Vickers, (1987), who reported that high SPL and a large number of acoustic events suggest a very crisp product, this crispness ranking highly corresponded with the ranking obtained from sensory evaluations.

The positive relationship between ratings of sensory crispness and number of sound peaks was consistent with the work of Attenburrow et al. (1989), who demonstrated the advantages of using the total sound peaks in correlation with the sensory perception of crispness. Despite the larger number of sound peaks suggesting “crispness”, however; they probably also indicate “hardness” (Vincent 1998, Primo-Martín, Beukelaer et al. 2008), where the number of sound peaks are dramatically increased at 72 hours compared with 4 hours after baking.

2.*6.2 Maximum sound pressure level (SPL)*

In the current study, maximum sound pressure (SPL) was between 70.4 - 76.6, 79.2 – 84.9, 79.9 – 83.2 and 79.3 – 85.2 dB at 4, 24, 48 and 72 hours after baking respectively as shown in Fig 2.10(D). Pre-ferment recipe was found to have the highest SPL, while White bloomer recipe (standard) showed the lowest SPL; moreover this bread type also showed high values of the maximum force. Previous studies suggest that the higher the SPL and the large the number of sound peaks, the crisper the product will be (Vickers 1987, Luyten, Plijter et al. 2004). This finding in the current study was in agreement with Chen (2005) who also found that high SPL suggested a very crisp biscuit.

2.6.3 Force at failure and maximum force

Force at failure is completely different from maximum force. Force at failure was defined as the value of the force at the first crack, while the maximum force is the highest force detected during the penetration of the sample by the probe for a certain distance. Although, the values of force at failure were comparable between different bread formulae and no significant differences were detected at 4 hours, however significant different between bread recipes was detected at 24, 48 and 72 hours post baking. The highest values of force at failure were observed for Pre-ferment and Panarome bread compared with other bread formulae at four different time points. The former and latter breads were assigned as more crisp during the sensory analysis (Table 2.2 (A, B). Presumably, the presence of preferment and Panarome liquid in the recipe of Pre-ferment and Panarome bread could be responsible for strengthening the cell wall of the crust. Also they showed higher number of sound and force peaks at 4, 24, 48 and 72 hours post baking (Table 2.3 (A, B)). This finding was in agreement with Rosell, C. (2010) who found that crisper bread showed higher force at failure than less crisp bread.

The crust failure force after 72 hours was shown to be higher than at 4, 24, 48 and 72 hours after baking due to moisture redistribution (water migration from crumb to crust) that leads to a tough crust (He and Hoseney 1990). This finding was in agreement with Primo-Martin et al (2008), who reported that the crispy roll bread tends to appear more hard than non-crispy which is reflected in increasing initial force needed to penetrate the crust. On the other hand, it was in disagreement with Vincent (1998) and Chen (2005), the reason is probably because of the type of food tested, in their case the sample was potato crisp and biscuits which consist of one layer and the fracture will happen in a short time but the cracks will continue for a while until the sample is completely breakdown, however this may not be the case for many soft food. In our case the sample (bread) consist of two layers, the first is the crust which represents the dry part of the sample while the second layer is the crumb which represents the soft part, therefore the final drop will take longer than the samples consist of one layer. It can be seen from Figure 2.10 (E) that the higher the maximum force detected the harder the products were. The maximum force for Pre-ferment bread was shown to be significantly lower than other bread formulae accompanied with lower crust water content and lower crust thickness compared with other bread formulae. The hardness of the bread crust in this measurements is mainly reflecting the fracture behaviour being shown by both crispy and less crispy crust (Van Nieuwenhuijzen, Meinders et al. 2008). This result was in agreement with Luyten et al (2004) who found that dry foods are considered crispy when only a low level of force is necessary for the entire fracture process. This study also revealed that the crust which required higher maximum force was always associated with higher crust water content (Table 2.9) and higher crust thickness.

2.6.4 Number of force peaks

A higher number of total force peaks is generally associated with a higher number of total sound peaks (Salvador, Varela et al. 2009). Chen et al. (2005) reported that a high number of force and sound peaks are associated to a high sensory crispness.

Dogan and Kokini (2007) showed a relation between crispness and the number of force peaks formed during fracture. The results presented in this chapter are in agreement with these results, where the number of force peaks was related with the number of sound peaks $R^2 = 0.88$ both at 4 and 24 hours after baking.

It can be clearly observed that the number of force peaks was highly related to the higher force failure and lower maximum force as shown in Figure 2.10 (C). Pre-ferment followed by Panarome bread showed a higher number of force peaks at 4, 24, 48 and 72 hours post baking. Each peak theoretically represents one cell being broken (Cheng, S. et al. 2007), and reflects the crispy behaviour of both bread formulations. In addition, it can be clearly observed that the number of force peaks were often less than the number of acoustic peaks, which was also reported by Chen et al. (2005) and Piazza et al. (2007). Castro-Prada et al. (2007) reported that when the number of force peaks is less than the number of acoustic events (sound peaks) this could be because of a low data acquisition rate, which is recommended to be between 50 – 60 kHz when the speed of the test is more than 0.1mm/sec. The speed of 1 mm/s was chosen in the current study along with an acquisition rate of 500 points per second based on previous studies to reach a compromise of having reproducible results, and where the sound peaks could be distinguished (Chen, Karlsson et al. 2005). Chen et al. (2006) who studied the crispness of roasted almond found that for each major force drop a group of acoustic events occurred and many sound events did not appear to be directly related to drops in force. This was not as a one-to-one ratio, as the sound emission was the result of a sudden release of energy, while the force curve is a reflection of the energy applied to, or released from the sample.

2.6.5 Area under curve

There was a positive but not significant relationship between the area under the curve and to the total force applied $R^2 = 0.75- 0.86$ at 4 and 24 hours, however at 48 and 72 hours post baking the correlatio was significant . Therefore, the more force applied, the more hard and the less crisp the crust was. The work required to compress the samples (area under the curve) increased as the bread age increased. This reflects the changes of the mechanical nature of the bread crust from brittle to tough and the partially retrogradation of starch existing in bread crust (Fu, Tong et al. 2003).

2.6.6 Correlations between parameters

Correlation coefficients relating the physical, texture and sound emission properties are listed in Table 2.6 and 2.7. Positive and negative correlations between the following parameters were found: Number of sound peak (AUX), maximum sound pressure (SPL), and area under curve, number of force peaks, maximum force and force at failure. Also their relations with different sensory parameters were also included in these tables. Interestingly, most of tested parameters showed negative correlations with maximum force at 4, 24, 48 and 72 hours post baking. The increase of crust moisture content of all bread formulae led to increase in maximum of force and decrease the number of sound and force peaks and therefore to decrease in sensory crust crispness. This finding was in line with Primo- Martian et al. (2008), who worked on crispy rolls and found a negative correlation between crust water content and both force at failure and number force peaks $R^2 = -0.56$, and -0.59 respectively.

The number of sound peaks recorded during the penetration of the crust in the current study exhibited very good correlation with the number of force peaks (Table 2.6 and 2.7). These results are in agreement with the finding reported by both Saeleaw, (2010) regarding cassava crackers and Van Nieuwenhuijizen (2008) regarding rusk roll bread. This indicates that the number of sound peaks is one of the variables that can be considered as a good parameter for objectively determining crispiness. The maximum value of sound pressure increased with the increase in both the number of sound and force peaks. This finding is in agreement with Duizer et al. (1998) who reported that crispy products have more peaks as well as peaks with higher amplitude than less crispy products. On the other hand, the observation was not in line with Saeleaw and Schleining, (2010). The possible explanation for this disagreement is that the sound pressure level and its correlations depend on many factors such as the type and the structure of the material, its mechanical behaviour and composition (Saeleaw and Schleining 2011).

2.6.7 Developed experimental crispness parameters

The mechanical profile of bread crust has a jagged shape as a result of multiple fracture effects. Each fracture event is characterized by a relatively slow increase in force, followed by a sudden drop. The rising parts of the curve are a function of the rigidity of the bread crust. The jagged pattern (force peaks) reflects the crispy behaviour of bread crust (Cheng, Alavi et al. 2007).

The mechanical curve starts with a silent period during the rising time of the force followed by sudden drop; this sudden drop is known as force at failure. In the case of bread crust in this study the values for force failure were comparable (Table 2.3 (A and B)). However force at failure showed highly positive correlations with both force and sound peaks. The highest peak of the force curve is a reflection of the maximum force applied on bread crust which therefore reflects the rigidity of the bread crust. Results presents in Table 2.4 regarding maximum force showed that the number of sound peaks, force peaks and maximum sound pressure decreased as the maximum force increased.

There has been consensus between researchers that the number of sound peaks, force peaks, sound pressure level, force at failure and maximum force are the most important parameters and most frequently used to express products crispness (Chen, Karlsson et al. 2005, Castro-Prada, Luyten et al. 2007). They demonstrated that, as these mentioned parameters increased the crispness of the product increased with the exception of force maximum.

The current study was in line with their finding particularly when the product is fresh. In this study, it was found that as the bread became stale, the values of the number of sound peaks, number of force peaks, sound pressure level, force at failure and maximum force increased, while crispness and total acceptability decreased.

From a scientific point of view, bread crust loses its crispness with lapse of time; therefore the main target of the current study was to identify which parameters can respond to the alteration occurred on bread crust crispness with different time points. Depending on the preliminary results obtained from five different bread formulae, it has been found that there is no single parameter can reliably reflect bread crust crispness at four different time points (4, 24, 48 and 72 hours), thus combining two or more parameters was the alternative approach. the increases in the values in mentioned parameters are attributed to the rigidity of both bread crumb and crust, therefore the increase in sound propagated and the number of both sound and force peaks reflect the hardness of the crust rather than the crispness which was clear force applied to produce the sound and both sound and force peaks.

Since the mechanical and acoustic technique was applied simultaneously in this study, hence, the ratio between them was expected to reveal further information. To perceive the sensation of the crispness two criteria should be met. There must be sufficient force to be applied to break to break the bonds that connect between the ingredients which form the structure of the bread crust and there must be sufficient energy to be released in form of sound (Vincent 1998). Accordingly, maximum force was the first criteria and both sound pressure level and number of sound peaks were the second criteria. Furthermore, the correlations made between mechanical and acoustic parameters which presented in Table 2.4, 2.6 and 2.7 supported these criteria. Although several attempts at this particular approach were made, however; the most interesting finding was achieved by using the ratio between Maximum sound pressure levels (SPL)/Maximum force ($Force_{max}$), also the ratio between the number of sound peaks (AUX) and $Force_{max.}$ The results obtained by using both parameters showed very interesting correlations with sensory analysis as shown in Table 2.6 and 2.7. Both ratios of SPL/$Force_{max}$ and the number of sound peaks/Force$_{max}$ have not previously been mentioned in the literature, as far as we are aware. To validate their reliability of determining the property of crispness, both experimental parameters will be used as indicators of crispness in next chapter to study the effect of selected additives on bread crust crispness at two different time points 4 and 24 hours after baking.

2.6.8 Bread crumb firmness

The mean bread crumb firmness values of different bread formulations were illustrated in Table 2.3 (A, B). For bread formulations, as the bread had become stale, the crumb firmness values increased as expected. The firmness value of White bloomer bread was significantly higher than other bread formulae at 4, 24, 48 and 72 hours post baking. The trend of the increase in firmness for bread formula is likely to be linear or a quadratic effect due to the extent of rapid changes between 4 and 72 hours after baking. It is clear from Figure 2.8 (B) that as the degree of compression increased, the amount of force required increased, regardless of the type of formula. Since the bread formulae in the current study had been prepared from the same ingredients and exposed to the same conditions, the possible reason of the variation in bread crumb firmness must be attributed to the recipe. Therefore, two possible explanations should put into consideration. Firstly, preferment and Panarome liquid had a significant positive effect in retarding crumb firmness, secondly, Overnight and liquid sponge had accelerated crumb firmness. The effect of Pre-ferment and Panarome liquid in bread making have not been studied before as far as we are aware, further work should be done to identify the role of these two ingredients on bread crump firmness. Despite the fact that water content plays an important role in crumb firming, other factors also cause crumb firming without a change in moisture. Research studies have indicated that bread firmness is influenced by a variety of factors, including formulations (Gray 2003). There has been an agreement between researchers that firmness was a major sign that can be used to monitor bread staling; however, they differ on the source of this firmness. Some of them suggested that starch retrogradation is a major factor in bread firmness since the starch is a major portion of bread flour, and therefore followed amylopectin recrystallisation in aged bread. Others have found that bread firming is not related with amylopectin recrystallisation in bread and proposed different mechanisms for bread firming showing the role of other starch components. Water migration and redistribution were also had a role in accelerating bread crumb firmness (Knightly 1977, Hug-Iten, Escher et al. 2003, J. A. Gray and J. N. Bemiller 2003).

2.6.9 Repeatability of the study

The reproducibility of data derived from both experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ was determined by evaluating the 20 loaves at four different time points 4, 24, 48 and 72 hours post baking as presented in Table 2.5. Fifteen replication at each time point were evaluated, 3 replications from each loaf. SPL/Force$_{max}$ produced results with similar reproducibility at 4 tested times where CVs averaged 8.13%, 7.35%, 13.7% and 18.7% at 4, 24, 48 and 72 hours post baking respectively. The reproducibility at 24 hours showed better CV% than other tested times. For AUX/Forcemax the CVs were averaged 13.19%, 10.49%, 16.65% and 18.9% at 4, 24, 48 and 72 hours post baking respectively. Both of experimental parameters showed the lowest value of CV at 24 hours post baking. In general, coefficients of variation should be below 5%, and should rarely exceed 10%, (Joglekar and May, 1987). Usually, the higher the value of CV, the lower is the reliability of experiment. Here, a lower value of CV for both experimental parameters indicated a greater reliability and excellent repeatability. The current study showed that the correlation of variation obtained from sensory evaluation was higher than those obtained from physical measurements. These high values are to be expected and mentioned in several researches which attributed to panellists and their opinions in determining the samples.

2.7 Conclusion

The current study suggests that the conduction of the acoustical and mechanical measurements simultaneously was more efficient to recognize which parameters better reflecting the property of crispness of bread crust. The relationship between sensory crust crispness and instrumental parameters suggests that both SPL/Force$_{max}$ and AUX/Force$_{max}$ parameters can be used to measure and explain sensory crispness in bread crust. The former and latter had higher correlation with sensory crispness at 4 and 24 than 48 and 72 hours after baking R^2 = 0.88, R^2= 0.90, R^2= 0.76, R^2= 0.62 and R^2 = 0.80, R2= 0.93, R^2= 0.86, R2= 0.58 respectively. The current study showed that more efficient in determining the property of crust crispness at period of 24 hours post baking, therefore both experimental parameters were suggested to be used as crust crispness indicator in following chapters to validate their validity and reliability in determining the crispness at 4 and 24 hours post baking of bread treated with different additives at different amounts, as well as determining the proper use of both experimental parameters.

Chapter 3: Effect of selected additives on bread crust crispness and crumb softness

3.1 Abstract

The influence of the selected additives on the crispness of bread crust and crumb firmness are presented in this Chapter. Polydextrose, sodium alginate, and enzymes dough conditioner (EDC), citrus fiber and mono & di-glyceride in three different ratios were used to modify the bread formulation. These additives resulted in a modification of both bread crust crispness and crumb softness. Two experimental parameters, SPL/Force$_{max}$ and AUX/Force$_{max}$ were adopted to instrumentally evaluate bread crust crispness. Experimental crust crispness parameters were evaluated by simultaneous analysis of the fracture behaviour and sound emission while breaking the crust. Addition of 1% polydextrose, (0.25%, 0.50% and 0.75%) sodium alginate and 1% EDC increased the number of force peaks, the number of sound peaks and sound pressure level. On the other hand these additives resulted in significant decrease in maximum force, indicative of higher crust crispness. The number of fracture and sound peaks correlated negatively with the crust moisture content. This property is affected by the use of polydextrose, sodium alginate and EDC additives.

The addition of mono and di-glycerides (M&D-G) to the dough formulation did not show an effect on bread crust crispness. Neither did the addition of citrus fibre. The effect of the former and later on bread crumb softness was opposed to each other, where crumb softness increased as the ratio of M&D-G in the bread increased and decreased as the ratio of citrus fibre increased. Both experimental parameters showed high correlation with sensory analysis.

Whether the observed positive effect of the additives on crust crispness and crumb firmness is due to a direct effect on the flour components properties or interactions or to an indirect effect via structure-water migration properties is still open to discussion.

3.2 Introduction

Cereal products such as bread are considered to be the most common food in the world wide. The processes of making bread are the same since decades. However these processes have been continuously enhanced over the years, and many technologies and additives were established to produce bread with better quality (Selomulyo, Vania Octaviani et al. 2007). Several ingredients contribute in bread making; however the main ingredients for bread making are flour, water, salt and yeast. The improvers such as emulsifiers, stabilizers and added enzymes such as alpha-amylase and proteases are considered as main ingredients in some countries, but as supplementary ingredients in other countries (Gujral and Singh 1999).

Bakery products have a relatively short shelf-life in view of the fact that during their storage, several physical and chemical changes occur. These alterations have been defined as staling of bread. The latter is divided into two types, staling of the crumb and staling of the crust. Bread staling comprises an increase in crumb hardness and a decrease in crust crispness (leathery crust) as well as a decrease in flavour and aroma, which lead to loss of consumer acceptance. To decrease the rate of staling, and therefore to extend the period of storage, several ingredients have been used such as additives, hydrocolloids surfactants, and enzymes in the bread recipes (Rosell CM. 2008).

The use of additives has become a common procedure in bread making (Kohajdová Z 2009). In this work, the significance of polydextrose, sodium alginate, and EDC, citrus fibre and M&D-G on bread crust crispness and crumb firmness are described.

M&D-G are commonly added to the bakery products as antistaling agents or crumb softeners and also to improve bread quality and dough handling characteristics (Farvili, Walker et al. 1995).

Polydextrose is an indigestible synthetic compound; it is synthesized during multi condensation of glucose in the presence of sorbitol, and citric acid (Craig, Holden et al. 1999). Polydextrose has been widely used due to its versatility as a bulking agent and texture improver. Many types of baked products such as bread, cake and other pastries are highly susceptible to staling (Knightly 1977); as a result they lose their desirable texture and flavour and other features associated with freshness. In food manufacture, polydextrose is widely used as a humectant due to its ability to prevent or delay the rate that wet products lose their moisture or absorb water from surrounding air (Craig 1998).

The role of polydextrose in adjusting water absorption and moisture loss depends on several factors such as recipe, storage conditions and packing (Esteller, Amaral et al. 2004).

Alginates are widely used as additives in the food industry, because they are useful for modifying the rheology and texture of aqueous suspensions. Since alginate are form of hydrocolloids, its high water retention capacity property was utilized in the food industry in some products like custard creams and restructured food (Kohajdová and Karovičová 2009). It has been reported that an improvement in wheat dough stability during proofing can be obtained by the addition of sodium alginate (Guarda, Rosell et al. 2004). Bekaert, (1996) reported that the use of sodium alginate for improving the fresh bread quality resulted softening of the final product due to its high water retention capacity or hindering of the gluten–starch interactions. Another study showed that adding sodium alginate in a range of between (0.1% - 0.5%) resulted an increase in water content in the final product which indicated the usefulness of using sodium alginate (Selomulyo and Zhou 2007).

Dough conditioners are substances that contain functional ingredients used to improve both processing and product quality in several industries such as breadmaking. There are several types of dough conditioner ingredients used in countless combinations, but they are grouped according to their composition and functional ingredient into several categories such as, vital wheat gluten, yeast nutrients, pH regulators, oxidizing agents and enzymes (Lallemand 1996). Enzymes are natural compounds which works as catalysts to accelerate a certain reactions in dough or provide intermediate compounds that make reactions take place that otherwise would not. They exist in several forms such as concentrated microbial enzymes in liquid, powder, or tablet, and enzymes are naturally presented in wheat flour or malt syrup form. Each enzyme is responsible for specific reaction, but the amount of enzymes used in dough conditioners offers several functions (Barrett, Cardello et al. 2002). They have been used for decades for bread making. Because of the developments in the field of baking industry and the need for more different and natural products, enzymes have obtained more significance in bread preparations. Enzymes have been used for dough conditioning in order to extending shelf life and increasing crumb softness and improving dough elasticity, and also for dough strengthening. Alpha-amylases, which hydrolyse alpha 1, 4-glycosidic bonds of amylose and amylopectin molecules from starch is considered as the most commercial amylase used in baking industry.

Addition of amylase leads to increase the amount of fermentable sugars in dough and therefore, increases the volume of the loaf. Furthermore, they facilitate the reaction of Millard between reducing sugars and amino acids to produce the flavour and crust colour (Si 1997, Hoseney 1998).

Citrus fibre is produced from citrus pulp that surrounds the fruits such as orange. Citrus fibre provides several positive properties when added to bakery products. For example, it controls moisture migration, increases dietary fibre, reduces harmful fats, reduces calories, extends shelf life and most importantly, does not interact with taste of the product (Nassar 2008). Citrus fibre had water holding capacity of 11:1 (11g water/1 g) sold, and a fat absorption capacity of 3 to 4 times its weight. Organoleptic characteristics of the citrus fibre did not adversely affect food properties (McKee and Latner 2000). It has been shown that citrus peel fibre has a large effect on bread weight due its role in increasing water absorption. On the other hand, bread containing citrus peel fibre decreased loaf volume but crumb firmness was similar to control loaves (Miller 2011). Citrus fibre can be obtained from different sources such as sour orange, satsuma, lemon and sweet orange as raw material for industrial processes (Cauvain SP 2001).

“Emulsifiers are fatty substances possessing both lipophilic and hydrophilic properties. The surface tension between two normally immiscible phases is reduced with emulsifiers; therefore the two liquids are able to form an emulsion” (Stampfli and Nersten 1995). Mono- and diglycerides of fatty acids are anionic oil-in-water emulsifiers that are used as dough straighteners. They are usually used in ratios between 0.3 to 0.7% of flour weight in a variety of bread and fermented products (Cauvain SP 2001). Mono and diglycerides are added to dough to increase mixing tolerance, gas retention capability and increase loaf volume (Selomulyo and Zhou 2007). It has been reported that mono and diglycerides of fatty acids have an important role in producing a strong protein network, which in turn will produce bread with a better texture and increased volume. Mono and di-glycerides are the major emulsifiers used in food products (Liu, Lee et al. 1993). The positive effect of mono and di-glycerides is reflected on improving dough properties and bread quality. Thus mono and di-glycerides will remain important additives in breadmaking, despite increases of other additives such as enzymes.

Emulsifiers and enzymes are acting synergistically, however each of them cannot replace the other, because they function in different ways and each ingredient has other functions to achieve (Stampfli and Nersten 1995).

The hypothesis for this stage is that the including of selected additive in different ratios would enhance both crust crispness and crumb firmness of tested bread and relative attributes.

The aims of this stage of this work were to:

Investigation of the usefulness of using the experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$, through evaluation of the effect of five different ingredients predominately on bread crust crispness.

To examine the effect of several addition ingredients, in different amounts on bread crust predominately on its crispness and other relative quality attributes such as: bread crumb softness, crust water content, bread weight, crust thickness and finally on attributes. To relates the effects of ingredients on crust crispness to their effects on other properties such as water content.

3.3 Effect of selected additives content on bread crust crispness and crumb firmness

3.3.1 Material and methods

The pre-ferment bread recipe was chosen to be the control recipe in the rest of this research due to its highest crispness and greats crumb freshness compared to other breads as described in chapter 2. Therefore, selected additives such as polydextrose, sodium alginate, and enzymes dough conditioner (EDC), citrus fibre and emulsifier were added into the Pre-ferment recipe. The ingredients and preparation of Pre-ferment bread was as described in Chapter 2. All experiments and evaluations were carried out at Greggs plc research facility, Newcastle upon Tyne, UK as described in Figure 3.2.

The type of dough conditioner used in this study was grouped under enzymes dough conditioner (EDC) due to its composition and function. The composition of enzyme dough conditioner is described in Appendix3 Table 7.5.

Fluid shortening is the commercial name of the emulsifier used in this study, while the legal name according to the Food Labelling Regs. (1996) is blend of emulsifier (Mono & Di-Glycerides of Fatty Acids (E471) and vegetable oils (palm and rapeseed). The product was supplied by Cereform limited. Nutritional information and chemical composition are presented in Appendix3 Table 7.6. The term M&D-G is used in the entire study rather than either the commercial or legal name mentioned above.

Citri-Fi is the commercial product name of citrus fibre used in this study while the legal name is citrus fibre (dried orange pulp**)** extracted from orange pulp. Citrus fibre was supplied by Ideal Food Ingredients (FIBERSTAR INC). Nutritional information and chemical composition are presented in Appendix3 Table 7.7.

3.3.1.1 Preparation of bread dough

The composition of the dough containing no additive (control) and those containing different amounts of additives are presented in Table 3.1.

Four bread formulae were prepared by using the straight dough method and all the ingredients were mixed together in a single batch. After mixing, there was an intermediate fermentation step (5-15min).

The fermented dough was then divided into pieces and shaped; each piece weighed 980±3g. After this step, proofing took place (70-85 min), which is defined as the last fermentation period where the loaf reaches its desired volume. Then, the samples were baked in the oven for 25 min at 225+ 5˚C.

Table 3.1 Composition of bread recipes for Control bread and with different amount of selected additives

	Dough ingredients g per 100g of flour weight			
Ingredients	Different recipes %			
	Control	Recipe 2	Recipe 3	Recipe 4
Bread Flour	100	100	100	100
Salt	1.4	1.4	1.4	1.4
Delta	0.98	0.98	0.98	0.98
Extra fresh	0.98	0.98	0.98	0.98
Gluten	1.53	1.53	1.53	1.53
Crumb soft	0.46	0.46	0.46	0.46
M&D-G	0.46	0.46	0.46	0.46
Polydextrose	0	1	2	3
Sodium alginates	0	0.25	0.5	0.75
EDC	0	1	2	3
Citrus fibre	0	1	2	3
M&D-G	0	1	2	3
Pre-ferment	5	5	5	5
Water	57.78	57.78	57.78	57.78
Yeast	2.29	2.29	2.29	2.29

3.3.1.2 Mechanical and acoustic measurements

The settings of the experiments regarding the mechanical and acoustic and sensory analyses were as explained in detail in chapter 2. As regards to the determination of bread crust crispness, the experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ along with sensory analysis were used to assess bread crust crispness. For determining bread crumb firmness AACC method (74-09) was used as described in chapter 2.

3.3.1.3 Relative humidity and water content

The room humidity was monitored using a Thermo-hydrometer. It measured room temperature from -10 - 60°C with Accuracy of ± 1°C, and the humidity of the room from 20 to 95% RH with accuracy of ± 5% RH. It was calibrated to UKAS standards once a year.

Crust water content was measured by using. This device is depending on Infrared (NIR) technology instrument Food scan (Foss Ltd). Representative samples were homogenized by grinding according to AOAC Official Method 983.18. Approximately 180 g of ground sample was placed in a 140 mm round sample dish, and the dish was placed in the FoodScan. Results were displayed as percent water content (g/100 g). Three duplicates of samples were measured at each time points (4 and 24 hours). The Infrared (NIR) technology was adopted as trusted method to determine water content for different types of food as demonstrated in previous work of Büning-Pfaue, Hans (2003) and Alava et al. (2000) and has been validated in another publications as cited by (Miralbés 2004).

3.3.1.4 Bread weight

The weight of five loaves in each trial was measured at 4 and 24 hours after baking. The loaves were measured by using a digital balance (0.01 g accuracy) (Super - 6 Scales 1g - 15kg from Country Scales Ltd) (Shittu, Dixon et al. 2008).

3.3.1.5 Bread crust thickness

Bread crust thickness was measured according to Mohd Jusoh, Chin et al (2007) who defined bread crust thickness as the distance between the outer crust and the point of the inner crust where its colour changes such that the crust and crumb can easily be removed from the crust. The crust thickness was measured by using a Sealey S0707 - Digital Electronic Vernier Calliper 0-150mm/0-6" This method was developed Papadakis (2004), Collar et al. (2005) and has been validated as crust thickness approach against image method by Yusof. Y. and Rahman. R (Jusoh, Chin et al. 2007).

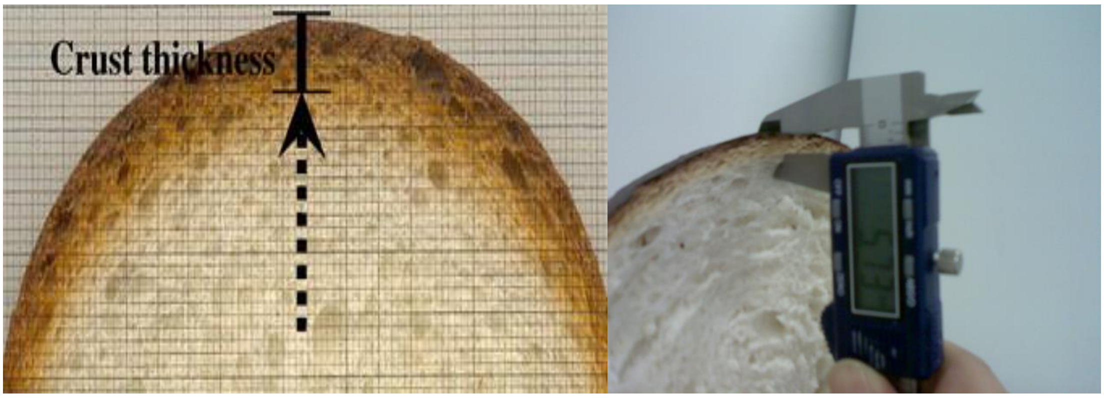

Figure 3.1 Measurement of crust thickness of bread using slice digital electronic vernier

3.3.1.6 Sensory analysis

Evaluation of the loaves was carried out over a period of two days (4 and 24 hours after baking) in four sessions of 10 minutes at each session. During each session, three slices of each type of bread was presented to 10 panellists (*n* = 30).

Each sample was presented as a half slice on a plate, identified with a random three digit code in order to blind panellist to the different samples. Panellists assessed the samples seated in individual sensory booths under white light. Each panellist was also provided with a glass of water to cleanse the palate before and between tasting of samples. Additionally, each panellist received a written methodology of assessment and the list of descriptors with definitions. The sensory evaluation laboratory was maintained at a temperature of 20˚C±2 (Szczesniak 1998). Samples were rated for crust crispness and crumb firmness on unstructured 15-cm line scales (L-H) where L refers to the lowest value and H to the highest value (Thybo, Bechmann et al. 2005). Responses were analysed by three-way analysis of variance (ANOVA) and compared by using the Tukey's HSD test (Honestly Significant Difference) using the Minitab software (Kuti, Hegyi et al. 2004).

3.3.1.7 Replicates (Trials)

The data in this chapter are based on results gathered from two trials. Each trial was carried out separately on a different day, which meant that ambient conditions such as relative humidity might change, whereas the rest of bread processing and evaluation methods were the same in both trials as shown in Table 3.2.

Table 3.2 Temperature and relative humidity during conducting each trial for five different additives at 4 and 24 hours post baking

	Trial 1		Trial 2	
Treatments	C°	RH%	C°	RH%
Polydextrose	20±2	41-45	20±2	37-41
S. alginate	20±2	39-41	20±2	33-36
EDC	20±2	39-42	20±2	41-45
M&D-G	20±2	39-43	20±2	34-41
Citrus fibre	20±2	43-46	20±2	44-47

3.3.2 Statistical Analysis

The current experiment was conducted twice (2 Trials), each trial was separately conducted; each trial included four independent batches, each batch included a different ratio of selected ingredient. The data generated from both trials were subjected for data analysis to evaluate selected parameters. The distribution of data was normal in the most of cases except the case when data collected at 4 hours was combined with data collected at 24 hours post baking to assess the main effects and interactions between recipes and time, therefore these data were transformed by using Logarithmic transformation (Log10). Analysis of variance for each recipe for physical parameters was conducted using two-way ANOVA, while the data relating to sensory evaluation was conducted using three-way ANOVA to study the interactions between recipes, trials and panel using. Minitab 16, post multiple pairwise comparison test (Tukey), and Sigma plot 11.0 were used (Kuti, Hegyi et al. 2004).

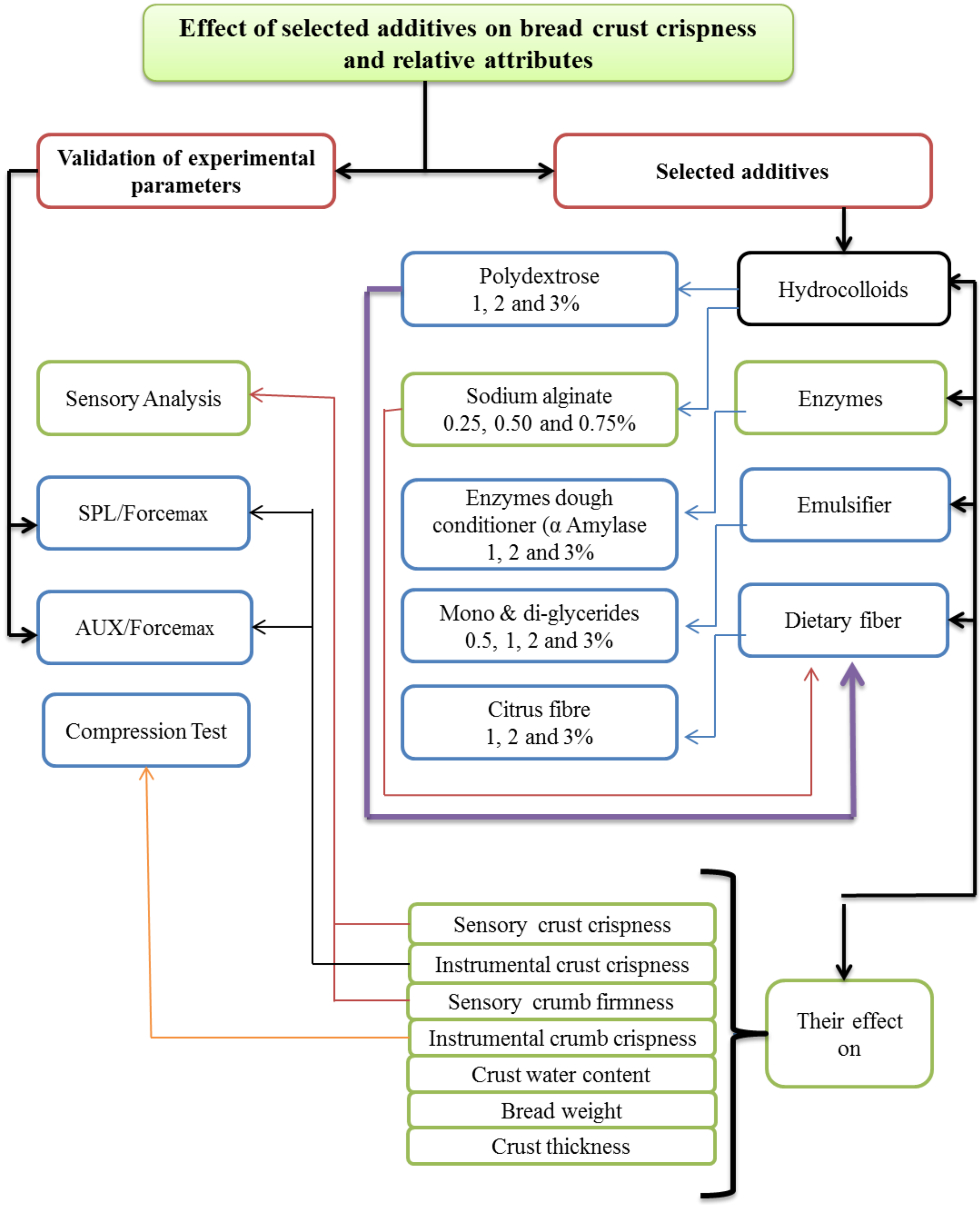

Figure 3.2 outline of general procedure to evaluation the effect of selected additives on bread crust crispness and related attributes

3.3.3 Results

3.3.3.1 Effect of selected additives content on bread crust crispness measured by instrument and represented by SPL/Force$_{max}$ and AUX/Force$_{max}$

According to the positive results and high correlation obtained between experimental crispness parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ and sensory analysis as explained in detail in chapter 2, those parameters were adopted to assess bread crust crispness instrumentally in subsequent experiments. Table 3.3 and 3.4 presents means values of two trials for measurements of bread prepared with different content of additives and analysed using two-way ANOVA at 4 and 24 hours post baking.

3.3.3.1.1 Main effect of selected additives content and trials on experimental crispness parameters and interaction between trials and recipe

For SPL/Force$_{max}$ at 4 hour after baking table 3.3, the main effect of recipes regarding polydextrose, sodium alginate and EDC was highly significant (F (3, 72) = 21.12, P = < 0.001), (F (3, 72) = 6.48, P = < 0.001) and (F (3, 72) = 8.30, P = < 0.001) respectively. For recipe made with polydextrose, bread made by 1% polydextrose showed higher value of SPL/Force$_{max}$ than Control and other formulations included 2% or 3% polydextrose. Bread made with sodium alginate, bread included sodium alginate in ratios 0.50% and 0.70% showed no significant differences with recipe contained 0.25% and Control bread, but the latter showed the highest value of SPL/Force$_{max}$ amongst bread contained sodium alginate as well as showed significant different with Control bread. For recipe made by ECD, bread made with 1% EDC showed significantly higher SPL/Force$_{max}$ than Control and bread included EDC in ratios 2% and 3%. Regarding recipes made with both M&D-G and Citrus fibre, the main effect of recipes was not significant as shown in Table 3.3. Similar effect regarding to the recipes was shown at 24 hours post baking except for bread made with citrus fibre, where the main effect of recipe was highly significant (F (3, 72) = 13.16, P = < 0.001) indicating bread made with 1% citrus fibre showed significant higher value of SPL/Force$_{max}$ than other bread recipes.

Table 3.3 Effect of selected additives content ± SE on bread crust crispness measured by instrument and represented as SPL/Force$_{max}$

SPL/Force$_{max}$	Time (hours)	Main effect		Interaction	Time (hours)	Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	68.5±2.8b	< 0.001	< 0.001	0.067	35.9±2.1b	< 0.001	< 0.001	0.149
Polydextrose 1%	74.0±3.0a				41.3±2.1a			
Polydextrose 2%	62.2±2.4c				31.0±3.4c			
Polydextrose 3%	58.7±2.4c				29.6±1.5c			
Mean All	65.8				34.4			
Control	63.2±2.1b	< 0.001	0.462	0.943	32.2±1.1b	< 0.001	0.11	0.051
S. alginate 0.25%	73.4±3.1a				37.8±1.7a			
S. alginate 0.50%	67.6±1.6ab				37.9±1.9a			
S. alginate 0.75%	69.2±2.2ab				36.6±1.4a			
Mean All	68.4				36.1			
Control	61.7±2.1b	< 0.001	7.30	0.843	38.2±1.2b	< 0.001	< 0.001	< 0.001
EDC 1%	73.0±3.1a				44.5±1.7a			
EDC 2%	66. 9±1.6b				43.1±1.7a			
EDC 3%	66.7±7.1b				41.5±1.5a			
Mean All	67.1				41.8			
Control	69.9±0.9a	0.998	0.384	0.061	40.0±0.4a	0.895	0.042	0.429
M&D-G 1%	69.0±0.7a				40.0±0.7a			
M&D-G 2%	69.1±1.2a				40.4±0.5a			
M&D-G 3%	68.9±0.7a				39.8±0.4a			
Mean All	69.0				40.0			
Control	64.3±0.8a	0.269	0.081	0.26	37.8±0.8b	< 0.001	0.522	0.855
Citrus 1%	65.7±1.0a				41.0±0.6a			
Citrus 2%	66.8±1.0a				37.8±0.4b			
Citrus 3%	65.0±1.1a				36.0±0.4b			
Mean All	65.5				38.1			

Identical letters for each additive indicates that there is no significant difference at (P>0.05). Average 2 trials

Table 3.4 Effect of selected additives content ± SE on bread crust crispness measured by instrument and represented as AUX/Force$_{max}$

AUX/Force$_{max}$	Time (hours)	Main effect		Interaction	Time (hours)	Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	59.0±2.5b	< 0.001	0.008	2.01	42.7±3.7b	< 0.001	< 0.001	0.039
Polydextrose 1%	66.3±3.0a				50.9±2.5a			
Polydextrose 2%	29.4±2.3c				31.7±2.5c			
Polydextrose 3%	22.6±2.1d				24.51.5d			
Mean All	44.3				37.4			
Control	41.5±2.7b	< 0.001	0.365	0.247	40.0±1.7b	0.001	0.123	0.605
S. alginate 0.25%	69.4±4.8a				48.5±1.8a			
S. alginate 0.50%	51.1±3.6b				44.9±2.0ab			
S. alginate 0.75%	46.7±2.7b				40.8±3.1b			
Mean All	52.2				43.5			
Control	39.9±2.2c	< 0.001	0.32	0.151	39.0±2.0c	< 0.001	< 0.001	0.001
EDC 1%	63.1±3.8a				50.7±2.2a			
EDC 2%	48.9±2.4b				47.8±2.1ab			
EDC 3%	44.4±3.1bc				43.9±1.8b			
Mean All	49.1				45.4			
Control	54.3±1.3a	0.073	< 0.001	0.461	44.0±0.9a	0.296	0.021	0.57
M&D-G 1%	50.5±1.1a				46.2±1.2a			
M&D-G 2%	51.3±1.0a				46.4±1.1a			
M&D-G 3%	53.4±1.1a				47.0±1.5a			
Mean All	52.4				45.9			
Control	47.8±1.4a	0.758	0.494	0.999	39.2±1.6a	0.105	0.908	0.747
Citrus 1%	48.6±1.3a				42.6±1.3a			
Citrus 2%	50.1±1.9a				39.7±0.8a			
Citrus 3%	49.5±1.7a				39.0±0.6a			
Mean All	49.0				40.2			

Identical letters for each additive indicates that there is no significant difference at (P>0.05). Average 2 trials

The main effect of trials was not significant in the most of cases, the only case that the main effect of trials was highly significant was the case of trials made with polydextrose, where trial 2 showed a higher average than trial 1 (F (1, 72) = 45.03, P = < 0.001). The main effect of trials at 24 hours post baking, in addition to trials of recipe made with polydextrose, bread made with EDC showed significant different between trials (F (1,72) = 40.37, P = < 0.001). Two-way ANOVA regarding SPL/Force$_{max}$ at 4 and 24 hours after baking showed that there was no significant interaction between trials and recipes, except in the case of bread made with EDC at 24 hours post baking (F (3, 72) = 6.46, P = < 0.001) as shown in Figure 3.3.

For the second instrumental parameter adopted to reflect the attribute of crust crispness AUX/Force$_{max,}$ analysis of variance showed that the main effect of recipes on the value of AUX/Force$_{max}$ was similar to the effect on SPL/Force$_{max}$ at 4 hours post baking. Regarding the types of additive had significant effect on the values of AUX/Force$_{max}$, bread made with polydextrose, sodium alginate and EDC at ratio of 1% showed significant differences with Control and other bread recipes (F (3, 72) = 166.8, P = < 0.001), (F (3, 72) = 20.89, P = < 0.001) and (F (3, 72) = 23.57, P = < 0.001) respectively. Bread made with different ratios of both M&D-G and citrus fibre did show any significant different either between Control bread or between each other. The main effect of recipe after 24 hours post baking was similar as 4 hours after baking as shown in Table 3.4.

The main effect of trials was not significant in the cases of recipe made with sodium alginate, EDC and citrus fibre at 4 hours post baking, however the main effect of trials was highly significant in trials made with polydextrose and M&D-G (F (1, 72) = 7.46, P = 0.008) and (F (1,72) = 8.45, P = < 0.001). The main effect of trials at 24 hours post baking, recipes made with polydextrose, M&D-G and bread made with EDC showed significant different between their trials as shown in Table 3.4.

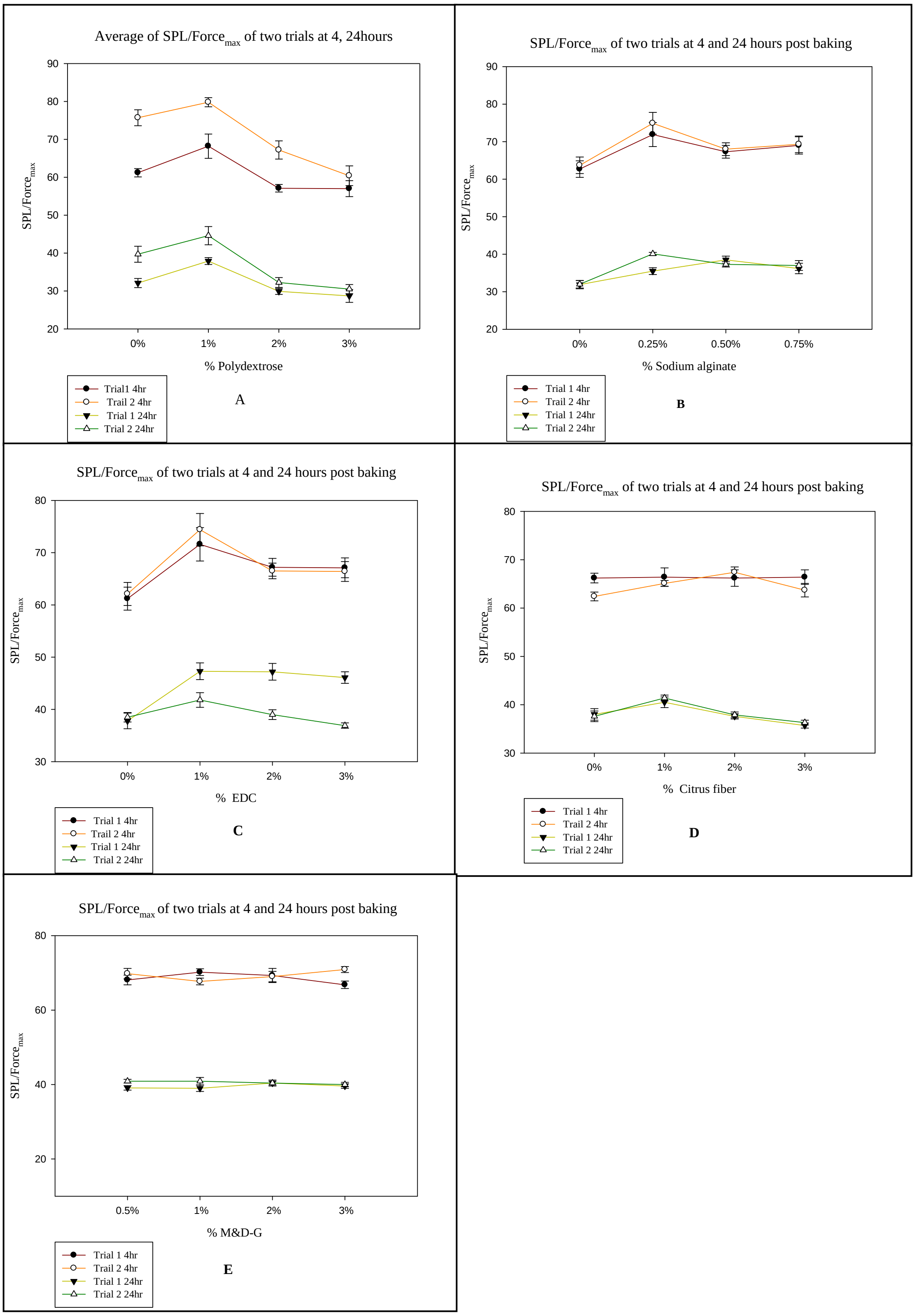

Figure 3.3 Effect of selected additives content on SPL/Force$_{max}$ values of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

The interaction between recipes and trials was not significant as illustrated in Figure 3.4 at 4 post baking, but there was significant interaction between recipe and trials in the case of bread made with EDC at 24 hours after baking (*F* (3, 72) = 6.15, *P* = < 0.001) as shown in Figure 3.4 and Table 3.4.

3.3.3.1.2 Main effects of time on experimental crispness parameters and interaction between time and recipes

The main effect of time regarding SPL/Force$_{max}$ and AUX/Force$_{max}$ was highly significant in the tested recipes treated with different additives, where all bread recipes showed higher values of SPL/Force$_{max}$ and AUX/Force$_{max}$ at 4 hours than 24 hours post baking. This result was expected due to the changes occurred in bread with time, where bread converts from soft crumb and crispy crust into firm crumb and either hard or leathery crust.

The interaction between time and recipes regarding SPL/Force$_{max}$ was not significant, except in the case of bread made with citrus fibre (*F* (3, 232) = 5.94, *P* = 0.001). In contrast to that the interaction between time and recipe regarding AUX/Force$_{max}$ was significant in the most cases, except the case of recipe made with citrus fibre *F* (3, 232) = 0.82, *P* = 0.484) as shown in Figure 3.3 and 3.4. This interaction between values of experimental parameters and time indicating that the value of crust crispness particularly for AUX/Force$_{max}$ at certain content of the additive at 4 hours was equally to the values of AUX/Force$_{max}$ either for Control or other recipe at 24 hours post baking.

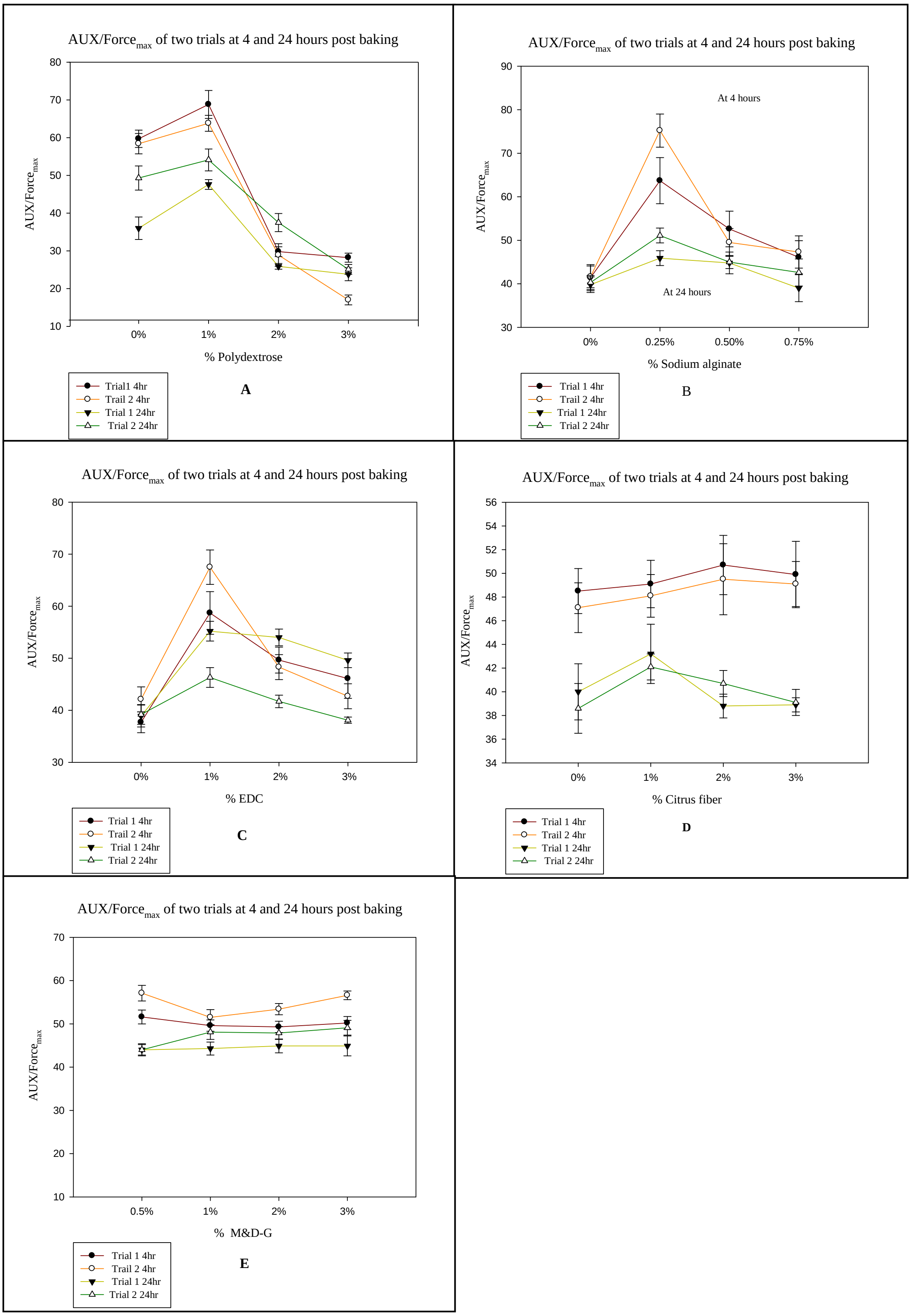

Figure 3.4 Effect of selected additives content on AUX/Force$_{max}$ values of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.2 Effect of selected additives content on bread crust crispness measured by sensory analysis

A three-way ANOVA presented in Table 3.5 and 3.6 showed significant differences between recipes for each additive at 4 and 24 hours post baking.

3.3.3.2.1 Main effects of selected additives content and trials on sensory crust crispness and interaction between trials and recipes

As can be seen from Table 3.5 that the main effect of recipes at 4 hours after baking was significant in the most cases, except the case of bread made with M&D-G and citrus fibre (F (3, 160) = 4.47, P = 0.087), (F (3, 160) = 3.11, P = 0.099) respectively. Bread made with 1% polydextrose, 0.25% sodium alginate, 1% EDC showed the highest values of crust crispness than other formulations at 4 hours post baking as shown in Table 3.5. These results supported the results obtained by using both experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max}$ (Table 3.5 and 3.4) indicating that the experimental parameters are able to detect the differences between different formulations made with different ratios of additives. The main effect of trials was only significant in the recipes made with sodium alginate and EDC. The main effect of recipes at 24 hours after baking was identical with 4 hours post baking. The reasons that can be provided to explain the significant variation between trails might be related ambient condition particularly RH which has highly effect in perceiving the property of crispness either by sensory analysis or instrumental measurements. Although significant differences between trials were detected in some cases, however the consensus regarding recipes had the highest and the lowest values of sensory crust crispness was observed as demonstrated in Figure 3.5 and 3.6. The analysis of variance conducted by using three-way ANOVA indicated that the interaction between recipes and trials was only significant at 4 hours post baking at the case of bread made with sodium alginate at 4 after baking (F (3, 160) = 7.0, P = < 0.001) as shown in Table 3.5 and figure 3.5. The main effect of time was significant at both tails for all bread recipes. As expected bread crust at 4 hours after baking showed higher crispness than at 24 hour.

Table 3.5 Main effect of selected additives content on sensory crust crispness and interactions measured at 4 hours post baking

	S.Ct.C	Main effect			Interactions			
Recipe	4 hours	Recipe	Trials	Panel	Recipe*Trial	Recipe*Panel	Trial*Panel	Recipe*Trial*Panel
Control	11.3±0.21a	< 0.001	0.087	0.357	0.063	0.027	0.733	0.131
Polydextrose 1%	11.4±0.21a							
Polydextrose 2%	5.8±0.18b							
Polydextrose 3%	4.0±0.14c							
Mean All	8.1							
Control	10.3±0.25c	< 0.001	< 0.001	0.773	0.000	0.422	0.930	0.732
S. alginate 0.25%	13.9±0.12a							
S. alginate 0.50%	11.6±0.18b							
S. alginate 0.75%	11.1±0.22b							
Mean All	11.7							
Control	12.3±0.16b	< 0.001	< 0.001	0.388	0.891	0.441	0.952	0.194
EDC 1%	13.3±0.14a							
EDC 2%	12.2±0.17b							
EDC 3%	11.1±0.18c							
Mean All	12.2							
Control	11.8±0.18a	0.087	0.751	0.513	0.959	0.733	0.692	0.923
M&D-G 1%	12.1±0.19a							
M&D-G 2%	12.4±0.18a							
M&D-G 3%	12.5±0.19a							
Mean All	12.2							
Control	12.6±0.17a	0.099	0.552	0.835	0.405	0.976	0.315	0.346
Citrus 1%	12.8±0.16a							
Citrus 2%	12.1±0.16a							
Citrus 3%	12.1±0.15a							
Mean All	12.4							

Identical letters in the same column indicates that there is no significant difference $P > 0.05$. Average 2 trials ± SE. units are scale of 1(low) to 15 (High).

Table 3.6 Main effect of selected additives content on sensory crust crispness and interactions measured at 24 hours post baking

	S.Ct.C	Main effect			Interactions			
Recipe	24 hours	Recipe	Trials	Panel	Recipe*Trial	Recipe*Panel	Trial*Panel	Recipe*Trial*Panel
Control	8.7±0.19b	< 0.001	< 0.001	0.189	0.470	0.982	0.498	0.750
Polydextrose 1%	10.0±0.14a							
Polydextrose 2%	6.3±0.17c							
Polydextrose 3%	4.7±0.15d							
Mean All	7.4							
Control	8.6±0.19d	< 0.001	0.003	0.470	0.007	0.149	0.205	0.725
S. alginate 0.25%	11.2±0.19a							
S. alginate 0.50%	10.4±0.21b							
S. alginate 0.75%	9.6±0.20c							
Mean All	9.9							
Control	10.9±0.18ab	< 0.001	<0.001	0.442	0.993	0.796	0.629	0.989
EDC 1%	11.8±0.19a							
EDC 2%	11.1±0.15ab							
EDC 3%	10.7±0.16b							
Mean All	11.1							
Control	11.0±0.16a	0.214	0.323	0.240	0.461	0.739	0.028	0.445
M&D-G 1%	10.8±0.14a							
M&D-G 2%	11.3±0.13a							
M&D-G 3%	11.4±0.14a							
Mean All	11.1							
Control	11.8±0.17a	0.068	0.053	0.306	0.258	0.064	0.365	0.750
Citrus 1%	11.9±0.19a							
Citrus 2%	11.5±0.23a							
Citrus 3%	11.4±0.35a							
Mean All	11.7							

Identical letters in the same column indicates that there is no significant difference *P*> 0.05. Average 2 trials ± SE. units are scale of 1(low) to 15 (High).

3.3.3.2.2 Main effects and interaction between panellists VS recipes and time

A three-way ANOVA of sensory analysis of bread crust crispness by ten trained panel members and the interaction between panellists and both recipes and time were determined. Results showed that the main effect of recipes was significant indicating that using of different content of additives had significant effects on sensory bread crust crispness, but the main effect of panellists was not significant both at trials and different tested times as shown in Table 3.5 and 3.6 indicating that panellists were able to differentiate between samples made with different ratios of different additives as shown in Figure 3.5. A significant interaction was not observed between the panellists and recipes, except the case of bread made with polydextrose at 4 hours post baking where the interaction between recipe and panel was significant (*F* (27, 160) = 1.68, *P* = 0.027).
A result pertaining to the interaction between panellists and time was not significant at all tested recipes. A significant interaction was not observed among the panellists, time and trials as shown in Table 3.5 and 3.6.

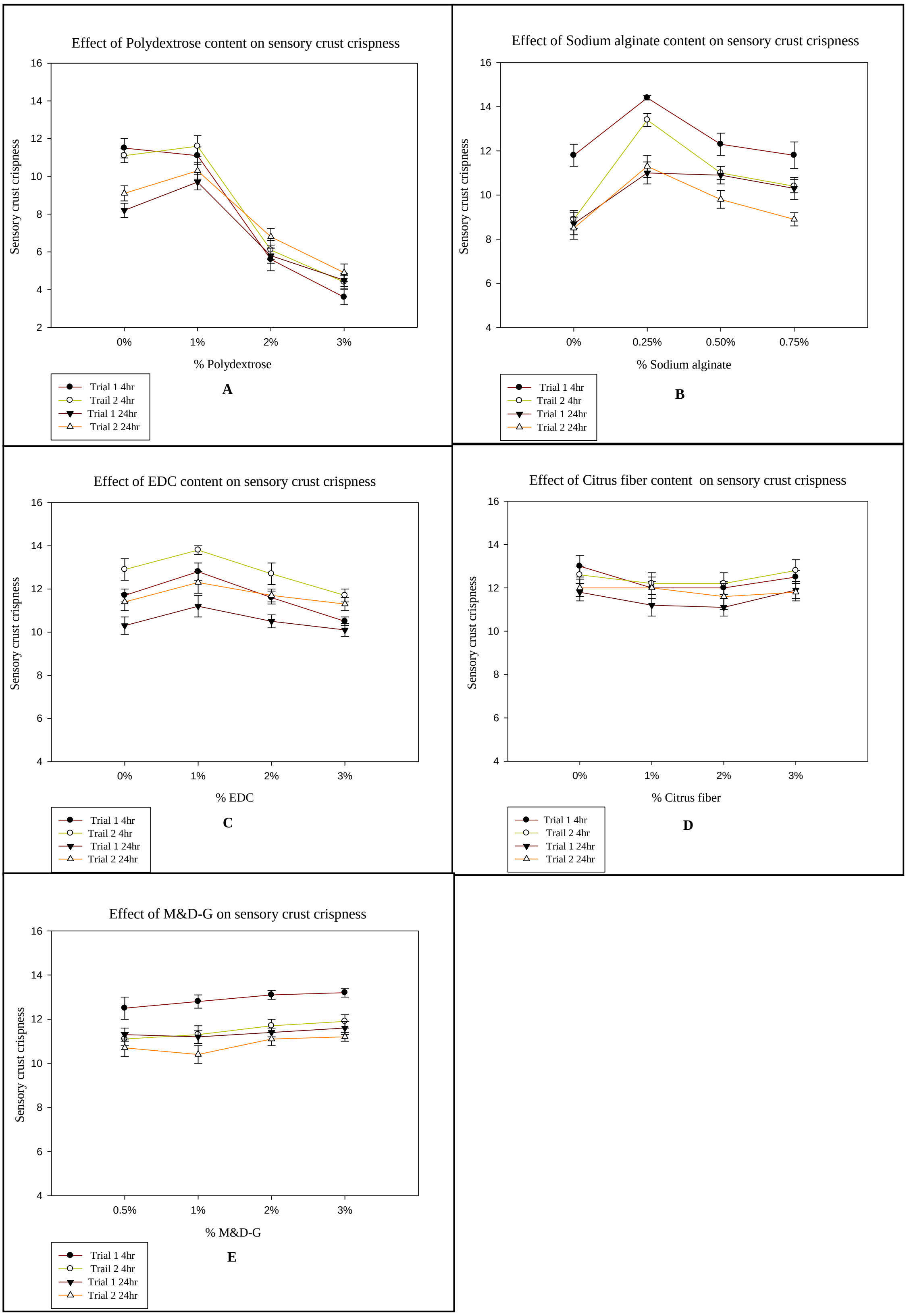

Figure 3.5 Effect of selected additives content on sensory crust crispness of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.3 Effect of selected additives content on bread crumb firmness measured by instrument

It has been demonstrated that the changes occurred on bread crumb after baking which known as staling of bread are considered as one of the most important factors effecting both the quality of product and consumer acceptability (Hug-Iten, Escher et al. 2003). The inclusion of selected additives in different bread dough significantly affected the physical and mechanical properties of crust and crumb as well.

3.3.3.3.1 Main effects of selected additives content and trials on bread crumb firmness measured by instrument and interaction between trials and recipes

For bread crumb firmness at 4 hours after baking, the main effect of recipes was highly significant at the five recipes as shown in Table 3.7. For recipe made with polydextrose, bread included 1% polydextrose, 0.25% sodium alginate, 3% M&D-G showed a lower value of crumb firmness than Control and other formulations. Regarding EDC, bread treated with EDC at different ratios showed lower significant value of bread crumb firmness than control bread, while bread made with 3% citrus fiber showed significant higher crumb firmness than those bread included 1%, 2% EDC and Control bread as illustrated in Table 3.7. The effect of selected additive after 24 hours post baking was similar to 4 after baking which demonstrated in figure 3.6,where at the most cases the additive showed the same pattern at 4 and 24 hours post baking.

The main effect of trials was only significant at two recipes, bread made with polydextrose and bread made with citrus fibre (F (1, 72) = 23.53, P = < 0.001), (F (1, 72) = 26.87, P = < 0.001) respectively. Regarding the main effect of trials at 24 hours after baking, the significant difference between trails only detected in bread made with emulsifier (F (1, 72) = 17.87, P = < 0.001) as shown in Table 3.7.

Table 3.7 Effect of selected additives content ± SE on bread crumb firmness measured by instrument

	I.Ct.F	Main effect		Interaction		Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	181±7c	< 0.001	< 0.001	0.013	304±7c	< 0.001	0.153	< 0.001
Polydextrose 1%	163±6c				272±10d			
Polydextrose 2%	234±10b				362±12b			
Polydextrose 3%	256±8a				429±8a			
Mean All	208.0				342.0			
Control	204±6a	< 0.001	0.674	0.102	304±9a	< 0.001	0.929	0.021
S. alginate 0.25%	150±4c				244±10c			
S. alginate 0.50%	182±6b				275±10b			
S. alginate 0.75%	173±7b				250±8c			
Mean All	177.0				269.0			
Control	175±6a	< 0.001	0.365	0.432	295±9.5a	< 0.001	0.425	0.088
EDC 1%	152±3.6b				273±8.4ab			
EDC 2%	148±4.3b				272±8.1b			
EDC 3%	144±3.7b				248±7.8c			
Mean All	154.0				272.0			
Control	186±3.1a	< 0.001	0.347	0.002	302±4.3a	< 0.001	< 0.001	0.166
M&D-G 1%	173±2.6b				268±5.3b			
M&D-G 2%	159±3.3c				266±5.9bc			
M&D-G 3%	144±2.3d				248±5.7c			
Mean All	165.0				271.0			
Control	169±3.1c	< 0.001	< 0.001	< 0.001	302±5.8c	< 0.001	0.062	0.847
Citrus 1%	176±1.0c				313±2.2bc			
Citrus 2%	187±2.8b				325±2.9b			
Citrus 3%	201±3.8a				342±1.1a			
Mean All	183.0				321.0			

Identical letters for each additive indicates that there is no significant difference at (P>0.05). Average 2 trials

A two-way ANOVA showed that the interaction between trials and recipe was significant at 4 hours post baking in the case of recipe made with polydextrose, M&D-G and citrus fibre (*F* (3, 72) = 3.85, *P* = 0.013), (*F* (3, 72) = 5.13, *P* = 0.002) and (*F* (3, 72) = 7.58, *P* = < 0.001) respectively. However, bread made with M&D-G showed that the interaction between trials and recipe was not significant after 24 hours post baking. These interactions implying that the effect of trial and trial was different on the different time, however, there seems to be no consistent interaction pattern: the curve for the effect of polydextrose, M&D-G and citrus fibre at 4 or 24 hours post baking (Figure 3.6) appears to cross each other in a random way. It was therefore concluded that there was no real interaction.

3.3.3.3.2 Main effects of time on bread crumb firmness measured by instrument and interaction between recipes and time

The main effects of time in terms of bread crumb firmness was highly significant at all recipes where bread crumb at 4 hour after baking showed significantly lower value of crumb firmness than bread crumb at 24 hour after baking. These results was expected because of the changes occurred in the crumb structure. The migration of the water from crumb to the crust and then to the air, retrogradation of starch and cross-link between starch and protein play an important role in increasing bread crumb firmness.

Two-way ANOVA showed that there was no significant interaction between time and recipes in the most cases, except the case of recipes made with sodium alginate (*F* (3, 152) = 3.02, *P* = 0.032) which appeared to be randomly accoutred as illustrated in Figure 3.6 (B).

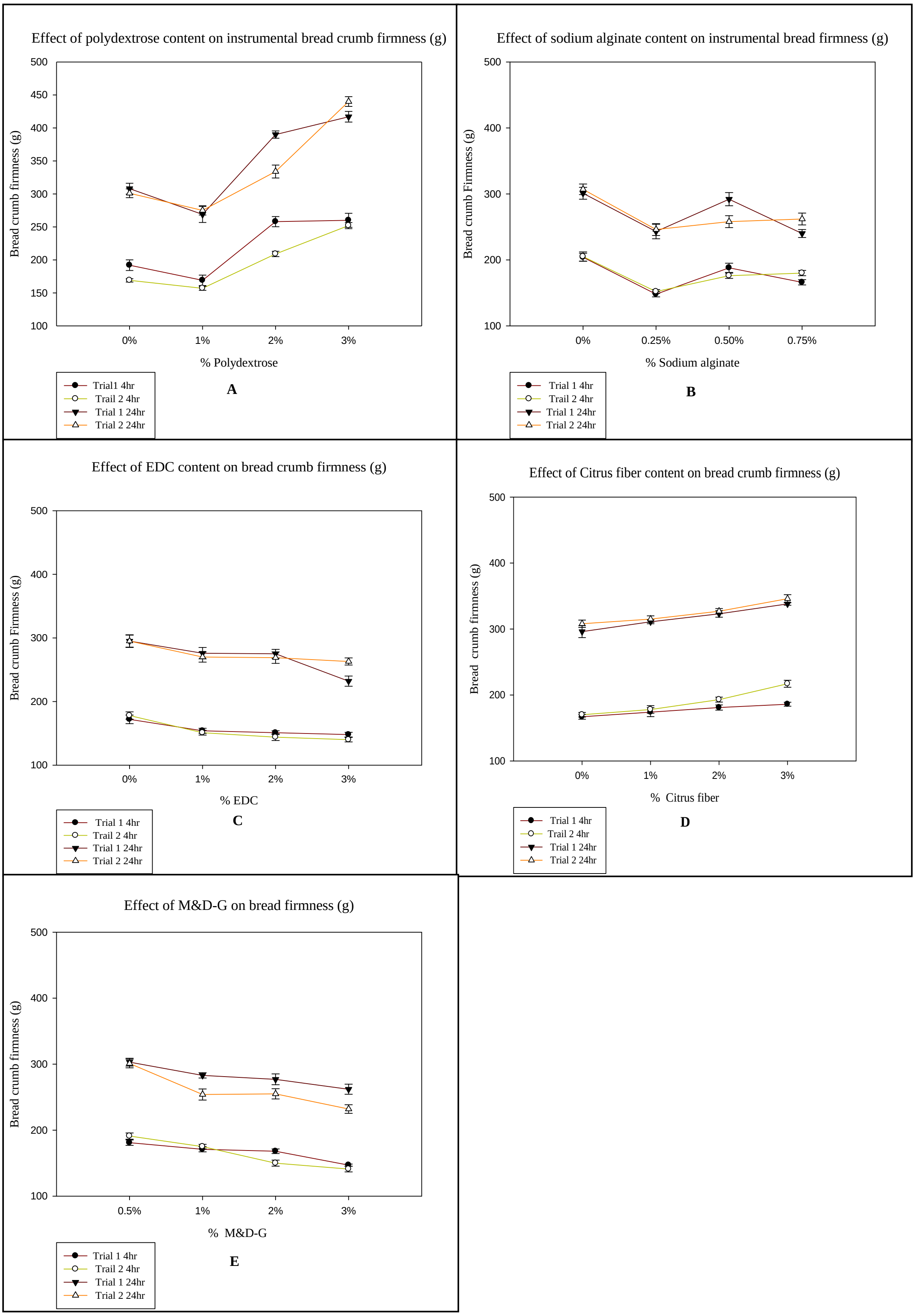

Figure 3.6 Effect of selected additives content on instrumental crumb firmness of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.4 Effect of selected additives content on bread crumb firmness measured by sensory analysis

Bread crumb firmness is one of the most important bread characteristics that directly reflect the freshness of the bread. A three-way ANOVA presented in Table 3.8 and 3.9 showed significant differences between recipes when bread included different ratios of additives.

3.3.3.4.1 Main effects of selected additives content and trials on crumb firmness measured by sensory analysis and interaction between trials and recipes

A three-way ANOVA demonstrated that the main effect of recipes at 4 hours after baking was highly significant, indicating that the treatment of recipes with different ratios of additives had significant effect on bread crumb firmness as shown in Table 3.8.

Bread made with 1% polydextrose, 3% M&D-G, bread made with 2% EDC and 1% sodium alginate showed the lowest values of crumb firmness than other formulations and Control bread. In the case of bread treated with citrus fibre, Control bread showed significant lower crumb firmness value than those treated with different ratios of citrus fibre as illustrated in Table 3.8. The general trend of the effect of selected additives on sensory crumb firmness after 24 hours post baking was similar to the trend at 4 hours after baking, however, a little improve was shown due to the inclusion of some additive in bread recipes. Bread made with 1% polydextrose, 3% M&D-G, bread made with EDC and sodium alginate showed the lowest values of crumb firmness than other formulations and Control bread. The former and later showed significant different than Control bread at three different ratios as shown in Table 3.8. Bread treated with 1% and 2% citrus fibre did not show any significant difference from Control bread, while bread made with 3% citrus fibre showed higher significant crumb firmness than other bread recipes.

Table 3.8 Main effect of selected additives content on sensory crumb firmness and interactions measured at 4 hours post baking

	S.Ct.F	Main effect (*P*)			Interactions (*P*)			
Recipe	4 hours	Recipe	Trials	Panel	Recipe*Trial	Recipe*Panel	Trial*Panel	Recipe*Trial*Panel
Control	5.1±0.12c	<0.001	<0.001	0.388	<0.001	0.291	0.427	0.835
Polydextrose 1%	3.7±0.24d							
Polydextrose 2%	9.1±0.35b							
Polydextrose 3%	11.8±0.39a							
Mean All	7.4							
Control	4.1±0.33a	<0.001	<0.001	0.309	0.555	0.752	0.275	0.682
S. alginate 0.25%	2.3±0.24b							
S. alginate 0.50%	3.9±0.22a							
S. alginate 0.75%	4.1±0.27a							
Mean All	3.6							
Control	5.1±0.21a	<0.001	<0.001	0.093	0.015	0.796	0.792	0.759
EDC 1%	3.8±0.27b							
EDC 2%	3.1±0.24c							
EDC 3%	2.7±0.27b							
Mean All	3.7							
Control	5.0±0.26a	<0.001	0.015	0.457	0.001	0.574	0.108	0.416
M&D-G 1%	3.7±0.21b							
M&D-G 2%	3.7±0.31b							
M&D-G 3%	2.1±0.24c							
Mean All	3.6							
Control	2.1±0.30c	<0.001	<0.001	0.576	0.003	0.166	0.834	0.672
Citrus 1%	4.1±0.22b							
Citrus 2%	4.7±0.25b							
Citrus 3%	5.7±0.18a							
Mean All	4.2							

Identical letters in the same column for each recipe indicates that there is no significant difference ($P>0.05$). Average 2 trials ± SE. units on scale of 1(low) to 15 (High).

Table 3.9 Main effect of selected additives content on sensory crumb firmness and interactions measured at 24 hours post baking

	S.Ct.F	Main effect			Interactions			
Recipe	24.00	Recipe	Trials	Panel	Recipe*Trial	Recipe*Panel	Trial*Panel	Recipe*Trial*Panel
Control	6.1±0.29c							
Polydextrose 1%	5.2±0.25d							
Polydextrose 2%	9.3±0.51b	<0.001	<0.001	0.007	<0.001	0.813	0.623	0.952
Polydextrose 3%	11.2±0.48a							
Mean All	7.9							
Control	5.6±0.34a							
S. alginate 0.25%	3.2±0.31b							
S. alginate 0.50%	4.1±0.28b	<0.001	<0.001	0.259	<0.001	0.717	0.639	0.973
S. alginate 0.75%	4.1±0.29b							
Mean All	4.2							
Control	4.9±0.28a							
EDC 1%	3.9±0.24b							
EDC 2%	3.9±0.22b	<0.001	0.171	0.027	<0.001	0.067	0.832	0.975
EDC 3%	3.3±0.36b							
Mean All	4.0							
Control	6.2±0.35a							
M&D-G 1%	5.6±0.25b	<0.001	<0.001	0.225	0.403	0.495	0.444	0.059
M&D-G 2%	5.6±0.38b							
M&D-G 3%	4.1±0.39c							
Mean All	5.4							
Control	5.7±0.3b							
Citrus 1%	7.0±0.35ab	<0.001	0.974	0.545	0.051	0.377	0.097	0.602
Citrus 2%	6.9±0.34ab							
Citrus 3%	8.1±0.35a							
Mean All	6.9							

Identical letters in the same column for each recipe indicates that there is no significant difference (*P*>0.05). Average 2 trials ± SE. units on scale of 1(low) to 15 (High).

The main effect of trials both at 4 and 24 hours post baking was highly significant at all cases as shown in Table 3.8 and 3.9. the most accepted reason can be provided to explain the significant differences between trail is the sensory evaluation was conducted separately, therefore panellists could not remember what score they gave in previous trial and also due to the absence of reference sample to compare with. As a result of that significant interactions were observed between trials and recipes as shown in Figure 3.7.

3.3.3.4.2 Main effect of time on crumb firmness measured by sensory analysis and interaction between time and recipes

Results showed that the main effect of time was not significant, despite the panel evaluated samples at separate time and without references sample.

For the interactions between recipes and time, a two-way ANOVA revealed that the interaction between time and recipe was only significant in the case of bread treated with sodium alginate (*F* (3, 472) = 3.02, *P* = 0.032) as shown in Figure 3.7.

3.3.3.4.3 Main effects and interaction between panellists VS recipes and time

A two-way ANOVA of sensory bread crumb firmness showed that the main effect of panellists was not significant at all cases, except the case of bread treated with polydextrose at 24 hours post baking (*F* (9, 479) = 0.59, *P* = 0.802) as shown in Table (*F* (9, 120) = 2.65, *P* = 0.007). This indicated that panellists were able to differentiate between samples equally in the most cases. A significant interaction was observed among the panellists and recipes at 4 and 24 hours post baking. Results pertaining to the interaction between panellists and time were not significant at all tested recipes. A three-way ANOVA showed the interaction between recipe, trial and panel was not significant both at 4 and 24 hours post baking as illustrated in Table 3.8 and 3.9.

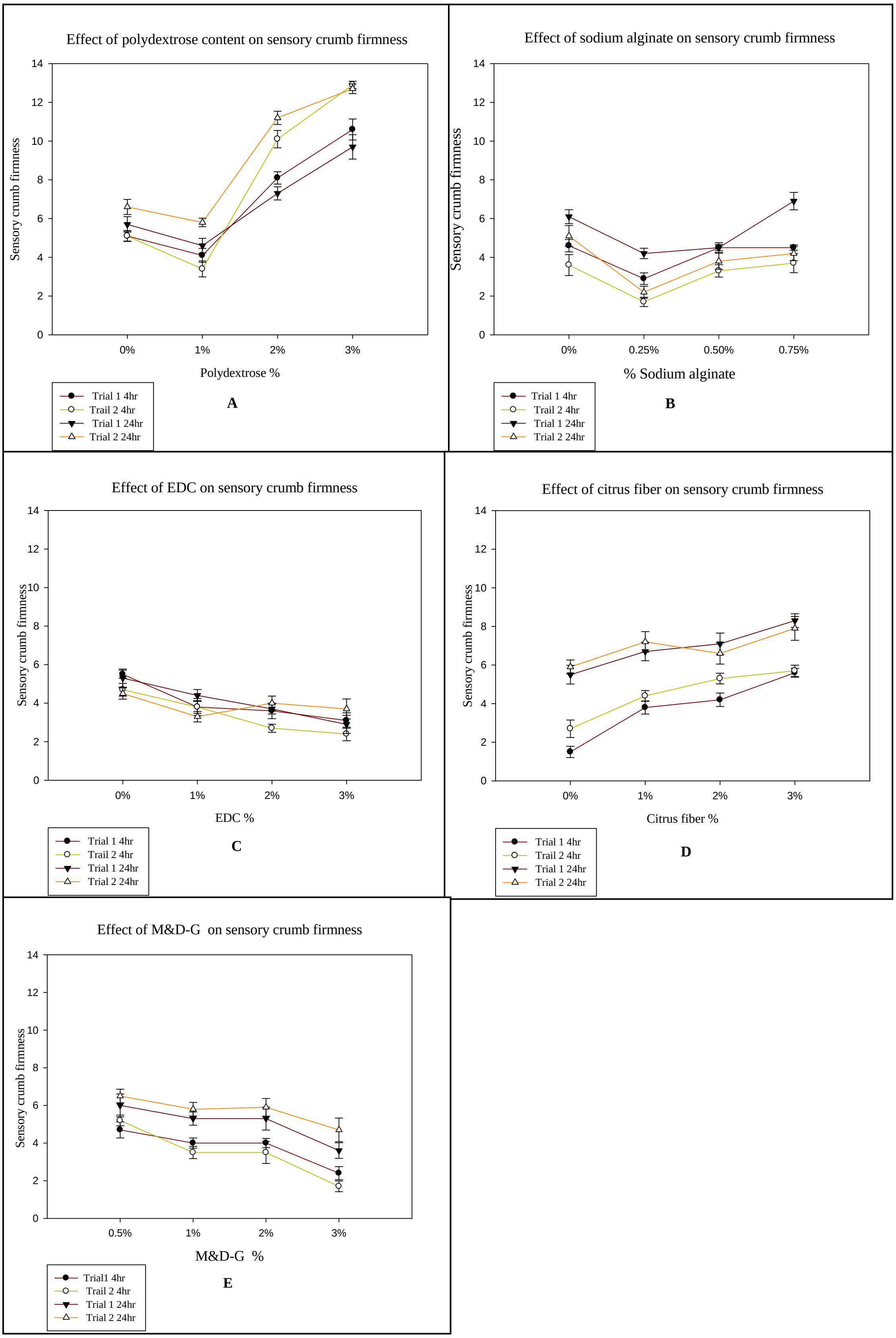

Figure 3.7 Effect of selected additives content on sensory crumb firmness of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.5 The effect of selected additives on bread crust water content

Bread crust loses its crispness when water migrates from wet crumb or ambient air into the crust. This loss in crispness will be reflected as a decrease in number of parameters such as number of sound peaks and force peaks, or increase in other parameters such as area and force (Van Nieuwenhuijzen, Primo-Martin et al. 2008). Water content in bread crust for different bread formulation was determined as described in section 3.3.1.3 and results presented in Table 3.10.

3.3.3.5.1 Main effect of selected additives content and trials on bread crust water content and interaction between trials and recipes

The main effect of recipes at 4 hours post baking was highly significant when bread made with polydextrose and EDC (*F* (3, 16) =109.5, *P* = < 0.001) and (*F* (3, 16) =30.2, *P* = < 0.001) respectively. Bread made with 1% polydextrose and 1% EDC showing lower value of crust water content than the Control and other bread formulations as shown in Table 3.10. At 24 hours post baking bread made with sodium alginate, M&D-G and citrus fibre did not show any significant difference either between three different ratios or with Control bread. The main effect of trials at 4 hours post baking was not significant in the most cases, except the case of bread made with M&D-G (*F* (1, 16) = 33.65, *P* = < 0.001). After 24 hours of baking bread made with polydextrose, sodium alginate and M&D-G showing significant difference between their trials (*F* (1, 16) = 8.55, *P* = 0.001), (*F* (1, 16) = 12.49, *P* = 0.003) and (*F* (1, 16) = 26.58, *P* = < 0.001) respectively. the main effect of recipes at 24 hours after baking, bread included 1% polydextrose showed significantly lower crust water content than those bread included 0, 2% and 3% polydextrose (*F* (3,16) = 56.79, *P* = 0.000), the values of water content of trial 1 was scored significantly higher than trial 2 (*F* (1,16)= 8.55, *P* = 0.044).

Table 3.10 Main effects of selected additives content on bread crust water content (g/100g) and interactions measured at 4 and 24 hours post baking

	C.W.C	Main effect		Interaction	C.W.C	Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	23.8±0.3b	< 0.001	0.347	0.351	24.3±0.2b	< 0.001	0.010	0.044
Polydextrose 1%	22.8±0.2c				23.5±0.3c			
Polydextrose 2%	24.1±0.1b				25.6±0.3a			
Polydextrose 3%	26.9±0.3a				25.7±0.3a			
Mean All	24.9				24.8			
Control	23.8±0.3a	0.082	0.077	0.798	24.6±0.4a	0.001	0.003	0.248
S. alginate 0.25%	23.5±0.4a				23.9±0.3b			
S. alginate 0.50%	23.9±0.6a				24.1±0.3b			
S. alginate 0.75%	24.2±0.4a				24.5±0.2b			
Mean All	23.8				24.2			
Control	24.8±0.3a	< 0.001	0.819	0.017	24.8±0.2a	< 0.001	0.618	0.005
EDC 1%	21.4±0.2c				21.5±0.2c			
EDC 2%	22.6±0.4b				22.7±0.3b			
EDC 3%	22.7±0.3b				22.9±0.3b			
Mean All	22.9				23.0			
Control	24.3±0.20a	0.233	< 0.001	0.514	24.6±0.16a	0.276	< 0.001	0.898
M&D-G 1%	24.4±0.14a				24.9±0.13a			
M&D-G 2%	24.5±0.16a				24.9±0.15a			
M&D-G 3%	24.4±0.11a				24.6±0.17a			
Mean All	24.4				24.7			
Control	22.7±0.20a	0.305	0.493	0.799	23.1±0.16a	0.304	0.841	0.997
Citrus 1%	21.8±0.14a				22.3±0.13a			
Citrus 2%	21.9±0.16a				22.4±0.15a			
Citrus 3%	22.2±0.11a				22.5±0.17a			
Mean All	22.2				24.7			

Identical letters in the same column for each recipe indicates that there is no significant difference (P>0.05). Average 2 trials ± SE.

3.3.3.5.2 Main effects and interaction between recipes and time

A two-way ANOVA showed that the main effect of time was significant at the most cases of recipes treated with different ratios of selected additives, except the case of bread made with EDC (*F* (1, 40) = 0.10, *P* = 0.960). These differences were expected due to either the migration of water from crumb to crust or water being absorbed from surrounding air.

Figure 3.8 shows that the interaction between recipes and time was not significant at the five bread recipes treated with five different additives. For the interaction between recipe and trials as revealed by two-way ANOVA was not significant, except the case of bread made with EDC at both 4 and 24 hours post baking (*F* (3, 16) = 4.61, *P* = 0.0.017) and (*F* (1, 16) = 6.29, *P* = 0.005) respectively as shown in Figure 3.8.

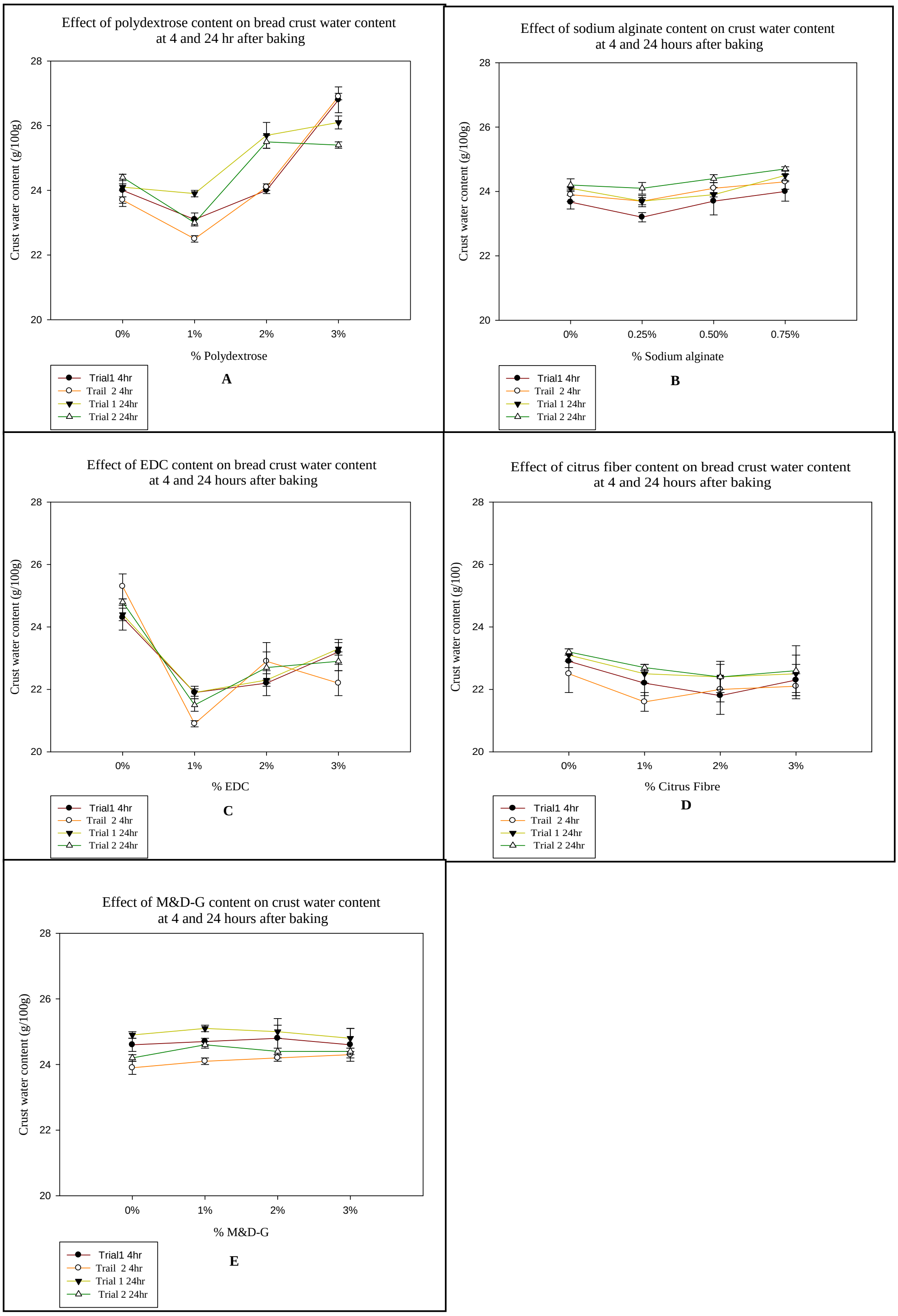

Figure 3.8 Effect of selected additives bread crust water content of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.6 The effect of selected additives content on bread weight

It is clear from the results presented in Table 3.11 that the different ratios of selected additives added to bread dough had a positive effect in retaining water which reflected in bread weight particularly at 24 hours post baking.

3.3.3.6.1 Main effect of selected additives content and trials on bread weight and interaction between trials and recipes

A two-way ANOVA showed that the main effect of recipes was a highly significant at all bread recipes treated with different ratios of selected additives, except the case of bread made with EDC at 4 hours post baking (*F* (3, 32) = 1.97, *P* = 0.138). Bread included 3% polydextrose, 0.50% and 0.75% sodium alginate, 3% M&D-G and 2%, 3% citrus fibre showed the highest value of bread weight than Control and other formulations at their own recipes. Bread made with different ratios of EDC showed non-significant difference in comparison with Control sample as illustrated in Table 3.11. For the main effect of recipes at 24 hours post baking was similar as 4 hours post baking, however bread made with 3% EDC showed significantly higher bread weight value than Control and those bread treated with different ratios of EDC. The effect of trials at 4 hours post baking was significant at bread made polydextrose, sodium alginate, EDC and citrus fibre; however the main effect of trials was not significant in the case of bread made with M&G-D. After 24 hours after baking the main effect of trials showed to be significantly different only at the case of bread treated with polydextrose. These differences between trials can be considered as random error caused during cutting bread dough into pieces equally sized.

Table 3.11 Main effect of selected additives content on bread weight (g) and interactions between recipe and trials at 4 and 24 hours post baking

Bread weight	B.W	Main effect		Interaction		Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	865±3c				806±4d			
Polydextrose 1%	865±3c				820±3c			
Polydextrose 2%	875±4b	< 0.001	0.001	0.092	832±3b	< 0.001	< 0.001	< 0.001
Polydextrose 3%	894±5a				853±7a			
Mean All	875.0				828.0			
Control	862±2.7b				806±3.1c			
S. alginate 0.25%	862 ±1.5b				812 ±1.6b			
S. alginate 0.50%	872 ±3.2a	< 0.001	0.036	0.494	819 ±1.8a	< 0.001	0.106	0.767
S. alginate 0.75%	869 ±3.5ab				822 ±2.0a			
Mean All	866.0				815.0			
Control	868±1.8a				816±1.5b			
EDC 1%	868±1.7a				818±1.2b			
EDC 2%	874±2.5a	0.138	0.027	0.986	819±1.9b	0.001	0.241	0.619
EDC 3%	875±4.6a				825±1.0a			
Mean All	871.0				820.0			
Control	869±1.67b				820±1.65b			
M&D-G 1%	873±1.76b				823±1.16b			
M&D-G 2%	875±2.80ab	0.001	0.306	0.05	830±1.56a	< 0.001	0.568	0.695
M&D-G 3%	882±2.08a				834±1.25a			
Mean All	875.0				827.0			
Control	869±1.7c				819±1.1c			
Citrus 1%	874±1.7b				824±1.3bc			
Citrus 2%	878±1.6ab	< 0.001	< 0.001	0.596	829±2.2b	< 0.001	0.74	0.402
Citrus 3%	881±1.2a				837±1.2a			
Mean All	876.0				827.0			

Identical letters in the same column for each recipe indicates that there is no significant difference (*P*>0.05) Average 2 trials ± SE

Regarding the interaction between recipes and trials, results showed that the interaction was not significant at all the cases of bread treated with different ratios of sleeted additive at 4 hours after baking, however significant interaction between trials and recipe was detected at the recipe of bread treated with polydextrose after 24 hours of baking as shown in Figure 3.9 (*F* (3, 32) = 12.13, *P* = < 0.001). This interaction between trials was occurred in one point when bread treated with 2% polydextrose, they appears to cross each other in a random way. It was therefore concluded that there was no real interaction.

3.3.3.6.2 The main effects and interaction between recipes and time

The main effect of time was highly significant at all tested sample, where bread weight at 24 hours after baking was less than the weight of bread at 4 hours post baking. This results was expected due to the migration of water from the core to the crust and then to surrounding air.

Regarding the interactions between recipes and time, a tow-way ANOVA revealed that there was significant interaction between time and recipes, except the case of bread made with polydextrose (*F* (3, 72) = 3.63, *P* = 0.017)as shown in Figure 3.9.

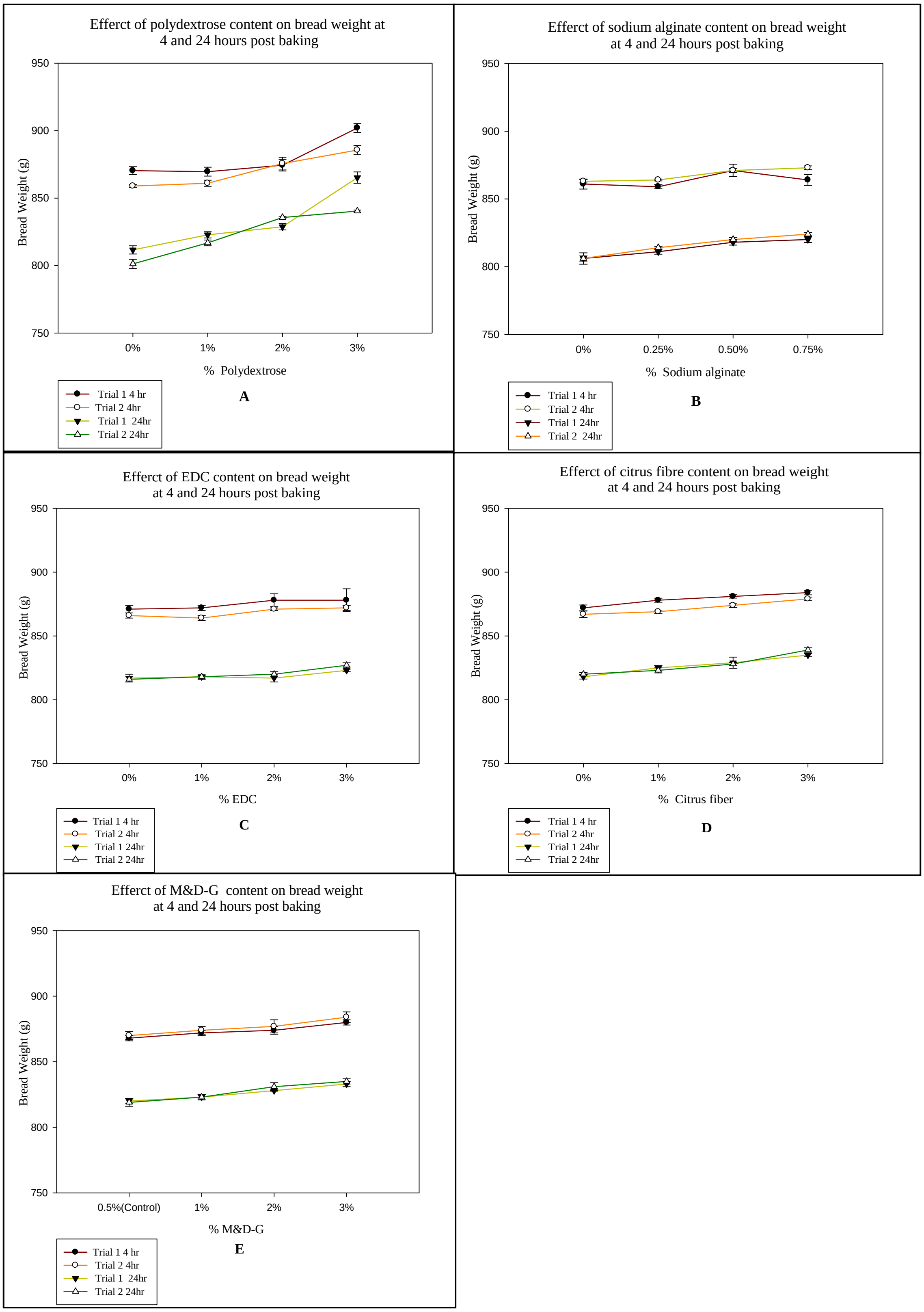

Figure 3.9 Effect of selected additives bread crust water content of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.3.3.7 The effect of selected additives content on bread crust thickness

3.3.3.7.1 Main effect of selected additives content and trials on bread crust thickness and interaction between trials and recipes

A two-way ANOVA showed that the main effect of recipes was significant when bread recipes treated with polydextrose, sodium alginate, EDC and citrus fibre, however bread made with M&D-G showed non-significant differences between either Control or each other (*F* (3, 32) = 1.92, *P* = 0.146) as illustrated in Table 3.12. Bread made with 3% polydextrose and the control samples of sodium alginate, EDC and citrus fiber showing the highest value of crust thickness at 4 hours post baking. Similar effect of recipe was shown at 24 hours after baking; only bread made with M&D-G did not show any significant difference in crust thickness. This means that emulsifier used had no effect on water retention therefore the amount of water migrated through the crust was similar at different samples comparing with the Control. The main effect of trials at 4 hours post baking was highly significant at the cases of bread made with both polydextrose and sodium alginate (*F* (1, 32) = 9.24, *P* = 0.005), (*F* (1, 32) = 46.28, *P* = < 0.001) respectively. After 24 hours of baking, the main effect of trials showed to be highly significant at bread made with polydextrose, EDC and citrus fiber. The reproducibility in the case of bread crust thickness is often problem, because of the heterogeneous nature of the crust (Mallikarjunan 2004).

The interaction between recipe and trials at 4 hours post baking was only significant at the case of bread made with sodium alginate (*F* (3, 32) = 5.45, *P* = 0.004). However bread treated with citrus fibre at 24 hours after baking showed that the interaction between recipe and trials was highly significant (*F* (3, 32) = 21.18, *P* = < 0.001). This contradiction between 4 and 24 hours seems to indicate that the interaction between recipe and trials was randomly occurred as illustrated in Figure 3.10. The main effect of time was highly significant, indicating that the thickness of the crust was highly increased at 24 hours than 4 hours post baking as shown in Figure 3.10 and Table 3.12.

Table 3.12 Main effect of selected additives content on bread crust thickness (mm) and interactions between recipe and trials at 4 and 24 hours post baking

Crust thickness	C.T	Main effect		Interaction		Main effect		Interaction
Recipe	4.00	Recipe	Trials	Recipe*Trials	24.00	Recipe	Trials	Recipe*Trials
Control	4.1±0.048b	0.005	0.005	0.741	8.6±0.23c	< 0.001	0.023	0.365
Polydextrose 1%	4.1±0.045b				7.9±0.20d			
Polydextrose 2%	4.3±0.028b				9.6±0.15b			
Polydextrose 3%	4.3±0.060a				11.1±0.11a			
Mean All	4.2				9.3			
Control	4.9±0.23a	< 0.001	< 0.001	0.004	8.0±0.14a	0.001	0.831	0.831
S. alginate 0.25%	4.2±0.17b				7.0±0.09b			
S. alginate 0.50%	4.2±0.98b				7.4±0.21ab			
S. alginate 0.75%	4.3±0.10b				7.7±0.16a			
Mean All	4.4				7.5			
Control	4.1±0.12a	< 0.001	0.33	0.537	8.5±0.16a	0.001	0.018	0.874
EDC 1%	3.7±0.18c				7.6±0.19b			
EDC 2%	3.9±0.15bc				7.9±0.14b			
EDC 3%	4.1±0.14ab				8.1±0.13ab			
Mean All	3.9				8.1			
Control	4.1±0.12a	0.146	0.928	0.721	8.5±0.14a	0.109	0.377	0.964
M&D-G 1%	4.3±0.11a				8.7±0.11a			
M&D-G 2%	4.2±0.13a				8.8±0.12a			
M&D-G 3%	4.3±0.10a				8.8±0.14a			
Mean All	4.2				8.7			
Control	4.0±0.12b	0.001	0.263	0.833	8.8±0.10b	< 0.001	< 0.001	< 0.001
Citrus 1%	4.2±0.15b				7.8±0.34c			
Citrus 2%	4.2±0.14ab				8.8±0.09ab			
Citrus 3%	4.4±0.13a				8.9±0.12a			
Mean All	4.2				8.4			

Identical letters in the same column for each recipe indicates that there is no significant difference (*P*>0.05) Average 2 trials ± SE

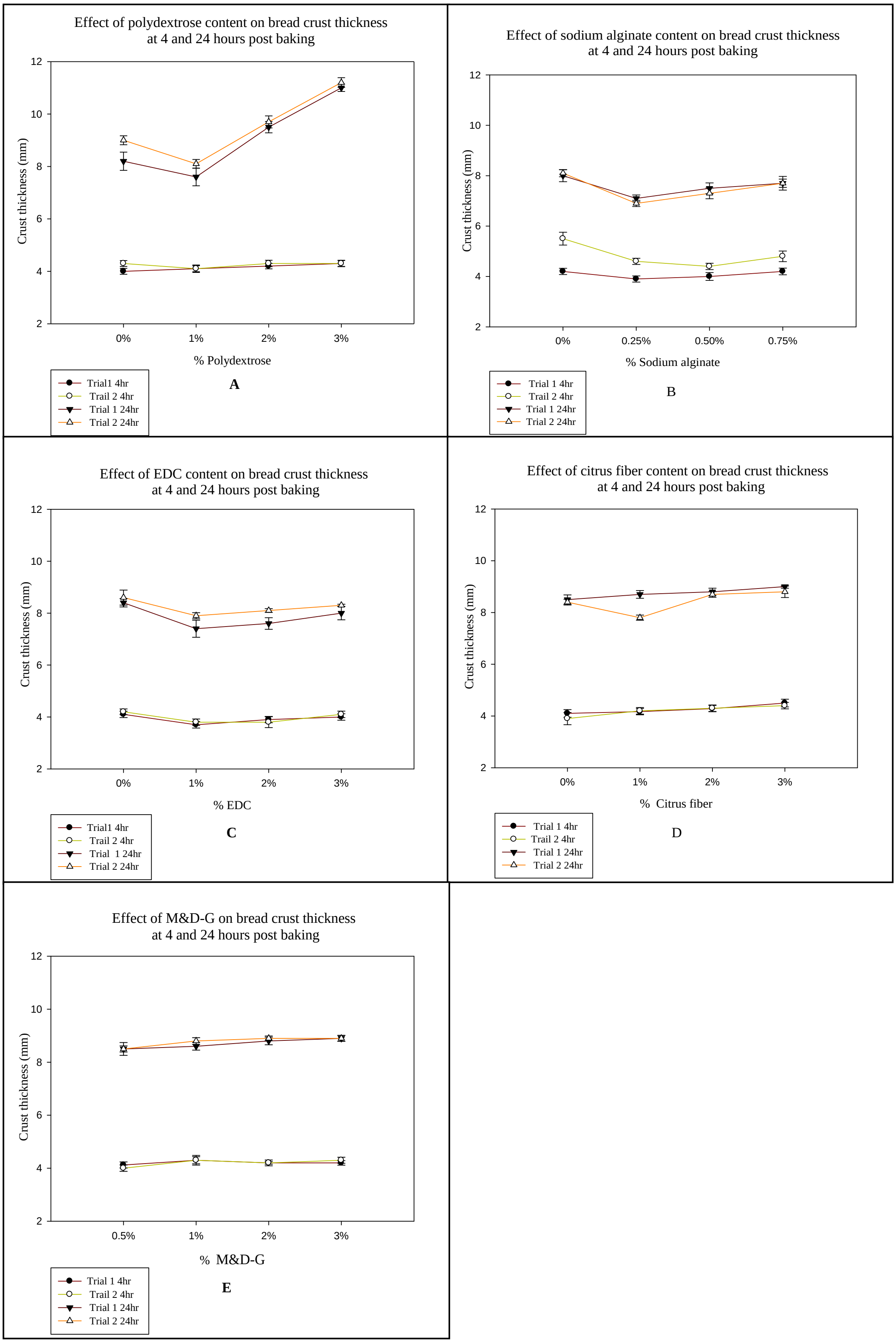

Figure 3.10 Effect of selected additives bread crust thickness of two trials, (A) polydextrose, (B) sodium alginate, (C) EDC, (D) citrus fibre and (E) M&D-G

3.4 Comparison different characteristic across different experiments

In this stage of work, the correlations between selected parameters were investigated. Eight different parameters from each experiment (20*2 trials, n= 40) at two different time points (4 and 24 hours after baking), data from each time point were combined to calculate the correlation coefficients between selected parameters and the results are graphically illustrated.

3.4.1 The correlation between experimental crispness parameters and sensory analysis

Figure 3.11 shows the correlation between bread crust crispness measured using both of the experimental parameters SPL/Force$_{max}$ and AUX/Force$_{max,}$ and the sensory evaluation for two different time points post baking. Both experimental parameters showed significant correlation with sensory analysis at 4 and 24 hours post baking respectively. SPL/Force$_{max}$ showed R^2 = 0.51, *P*< 0.01, R^2 = 0.68, *P*< 0.001, while AUX/Force$_{max}$ showed R^2 = 0.73, *P*< 0.001, R^2 = 0.62, *P*< 0.001 as shown in Table 3.13 and illustrated in Figure 3.11 (A and B). Both experimental parameters were in agreement about which sample was either the most or the lowest crisper.

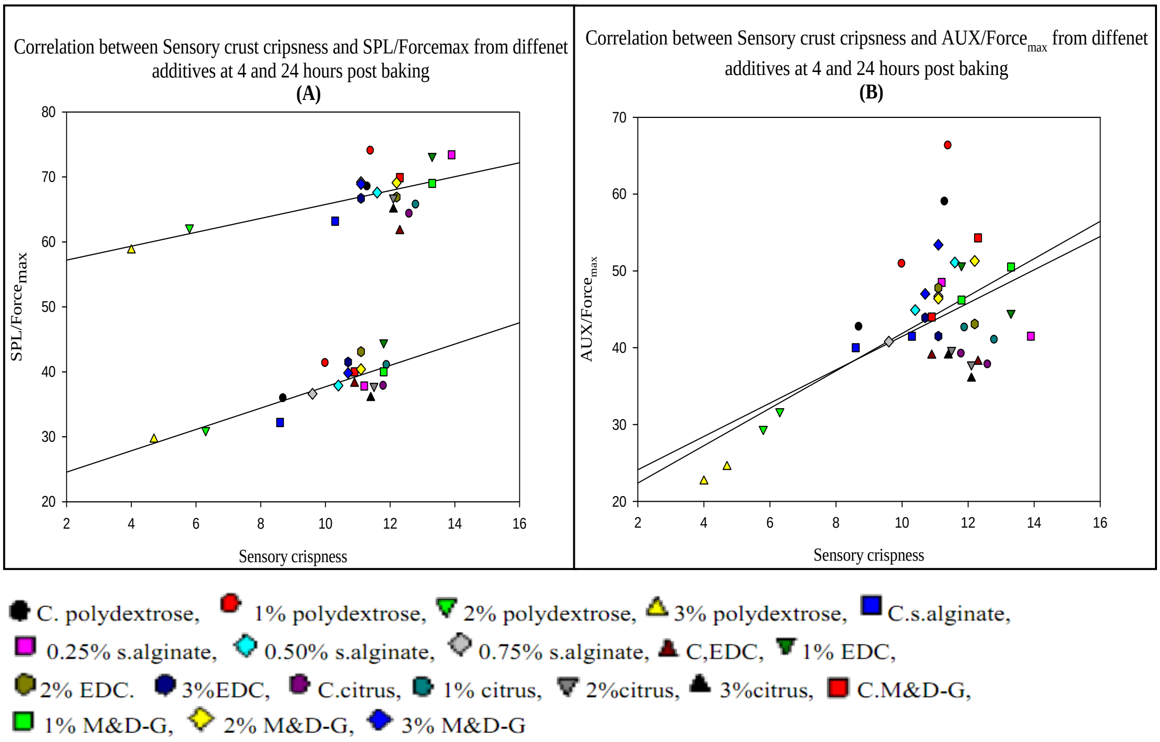

Figure 3.11 Correlation between experimental crispness parameters and sensory analysis

Table 3.13 Correlation coefficients of sensory and physical parameters of two trials for different additives investigated

	Parameter	*Time*	SPL/F_{max}	AUX/F_{max}	*S.Ct.C*	*I.Cb.F*	*S.Cb.F*	*C.W.C*	*B.W*		SPL/F_{max}	AUX/F_{max}	*S.Ct.C*	*I.Cb.F*	*S.Cb.F*	*C.W.C*	*B.W*
Polydextrose	AUX/F_{max}	4 hr	0.66							Sodium alginate	0.90**						
	S.Ct.C		0.71*	0.96***							0.66	0.76*					
	I.Cb.F		-0.88*	-0.90**	-0.93**						-0.94***	-0.82*	-0.75*				
	S.Cb.F		-0.65	-0.97***	-0.94**	0.86**					-0.75*	-0.83*	-0.36	0.65			
	C.W,C		-0.69	-0.79*	-0.82*	0.81*	0.88**				-0.20	-0.49	-0.75*	0.34	0.23		
	B.W		-0.40	-0.86*	-0.82*	0.73	0.88**	0.84*			0.02	-0.17	-0.39	0.17	0.16	0.73*	
	CT		-0.18	-0.72*	-0.71*	0.52	0.74*	0.62	0.72*		-0.26	-0.27	-0.79*	0.42	-0.20	0.50	0.11
	AUX/F_{max}	24 hr	0.96***								0.75*						
	S.Ct.C		0.90**	0.96***							0.76*	0.72*					
	I.Cb.F		-0.80*	-0.93**	-0.97**						-0.60	-0.43	-0.62				
	S.Cb.F		-0.60	-0.65	-0.79*	0.79*					-0.65	-0.93**	-0.44	0.27			
	C.W,C		-0.88*	-0.88**	-0.94**	0.85**	0.72*				-0.79	-0.38	-0.50	-0.15	0.20		
	B.W		-0.47	-0.64	-0.75*	0.84**	0.81*	0.61			0.69	0.14	0.25	-0.54	-0.15	0.59	
	CT		-0.69	-0.80*	-0.92**	0.94**	0.90**	0.84**	0.83*		-0.79*	-0.91**	-0.86**	0.72*	0.75*	0.34	-0.29
EDC	AUX/F_{max}	4 hr	0.96***							Citrus fire	0.68*						
	S.Ct.C		0.44	0.62							-0.32	-0.72*					
	I.Cb.F		-0.58	-0.36	0.17						-0.10	0.35	-0.54				
	S.Cb.F		-0.41	-0.20	0.17	0.92**					0.17	0.52	-0.56	0.80*			
	C.W,C		-0.91**	-0.80*	-0.25	0.76*	0.54				-0.13	-0.34	0.24	-0.36	-0.65		
	B.W		-0.14	-0.32	-0.86**	-0.39	-0.33	-0.05			0.45	0.87**	-0.61	0.44	0.58	-0.15	
	CT		-0.81*	-0.80*	-0.39	0.52	0.32	0.75*	-0.05		0.48	0.79*	-0.74*	0.67	0.82*	-0.39	0.85**

Table 3.13 continued

	AUX/F_{max}	24 hr	0.98***								0.87**						
	S.Ct.C		0.60	-0.21							0.63	0.58					
	I.Cb.F		-0.41	-0.34	0.22						-0.55	-0.33	-0.53				
	S.Cb.F		-0.41	-0.36	-0.12	0.86**					-0.32	-0.13	-0.63	0.89**			
	C.W,C		-0.45	-0.56	-0.43	0.38	0.55				0.02	-0.23	0.39	-0.64	-0.67		
	B.W		-0.20	0.23	-0.06	-0.68	-0.50	-0.21			-0.57	-0.31	-0.60	0.98***	0.89**	-0.66	
	CT		-0.87**	-0.93**	0.02	0.30	0.32	0.75*	0.12		-0.75*	-0.42	-0.67	0.51	0.35	-0.44	0.62
	Parameter	*Time*	*SPL/F_{max}*	*AUX/F_{max}*	*S.Ct.C*	*I.Cb.F*	*S.Cb.F*	*C.W.C*	*B.W*		*SPL/F_{max}*	*AUX/F_{max}*	*S.Ct.C*	*I.Cb.F*	*S.Cb.F*	*C.W.C*	*B.W*
M&D-G	AUX/F_{max}	4 hr	0.49							All Ingredients in one	0.74***						
	S.Ct.C		-0.21	-0.76*							0.51**	0.73***					
	I.Cb.F		-0.03	-0.01	-0.30						-0.67***	-0.67***	-0.79***				
	S.Cb.F		0.01	-0.04	-0.20	0.92**					-0.50**	-0.70***	-0.82***	0.85***			
	C.W,C		-0.10	-0.79*	0.96***	-0.20	-0.12				-0.35*	-0.49**	-0.55***	0.45**	0.49**		
	B.W		0.11	0.21	0.10	-0.93**	-0.96***	-0.02			-0.27	-0.55***	-0.50**	0.35*	0.49**	0.30	
	CT		0.08	-0.37	0.23	-0.56	-0.68	0.32	0.53		-0.11	-0.20	-0.29	0.32*	0.09	0.27	0.08
	AUX/F_{max}	24 hr	0.47								0.86***						
	S.Ct.C		0.76*	-0.26							0.68***	0.62***					
	I.Cb.F		-0.13	-0.91**	-0.02						-0.63***	-0.79***	-0.63***				
	S.Cb.F		0.33	-0.12	-0.67	0.51					-0.57***	-0.66***	-0.59***	0.82***			
	C.W,C		-0.63	-0.47	0.40	0.27	-0.32				-0.53***	-0.41**	-0.63***	0.25	0.32*		
	B.W		0.05	0.59	0.49	-0.83	-0.74*	-0.10			-0.22	-0.45**	-0.32*	0.55***	0.60***	0.20	
	CT		0.33	0.72*	0.18	-0.90**	-0.62	-0.13	0.91**		-0.50**	-0.68***	-0.58***	0.76***	0.79***	0.46	0.74**

*P<0.05, **P<0.01, ***P<0.001.

SPL/F_{max} = Sound pressure level/Force maximum ($SPL/Force_{max}$), *AUX/F_{max}* = Number of sound peaks/ Force maximum ($AUX/Force_{max}$), *S.Ct.C* = Sensory crust crispness, *I.Cb.F* = Instrumental crumb firmness *S.Cb.F* = Sensory crumb firmness (g), CWC= Crust water content (g/100g), BW= Bread weight (g), CT= Crust thickness (mm)

It seems that both experimental parameter can be used as crispness predictor, however SPL/Force$_{max}$ showed higher capability to differentiate between samples as shown in Figure 3.13. SPL/Force$_{max}$ and AUX/Force$_{max}$ had the ability to work with different formulae; this observation was obvious by following the points on trade line which represents the value of crust crispness from different formulae both at 4 and 24 hours after baking which are shown by different coloured shapes in the above Figures 3.13.

3.4.2 The correlation between experimental crispness parameters and crust water content

Several previous studies have investigated the effect of crust water content either migrated from the wet crumb or condensed from surrounding air. The results from these studies strongly indicated that the crispness decreased as the amount of water content of the crust increased. In the current work the crust water content of different types of bread made with different additives were plotted against experimental parameters (instrumental crispness) and the results are presented in Figure 3.12 (A and B).

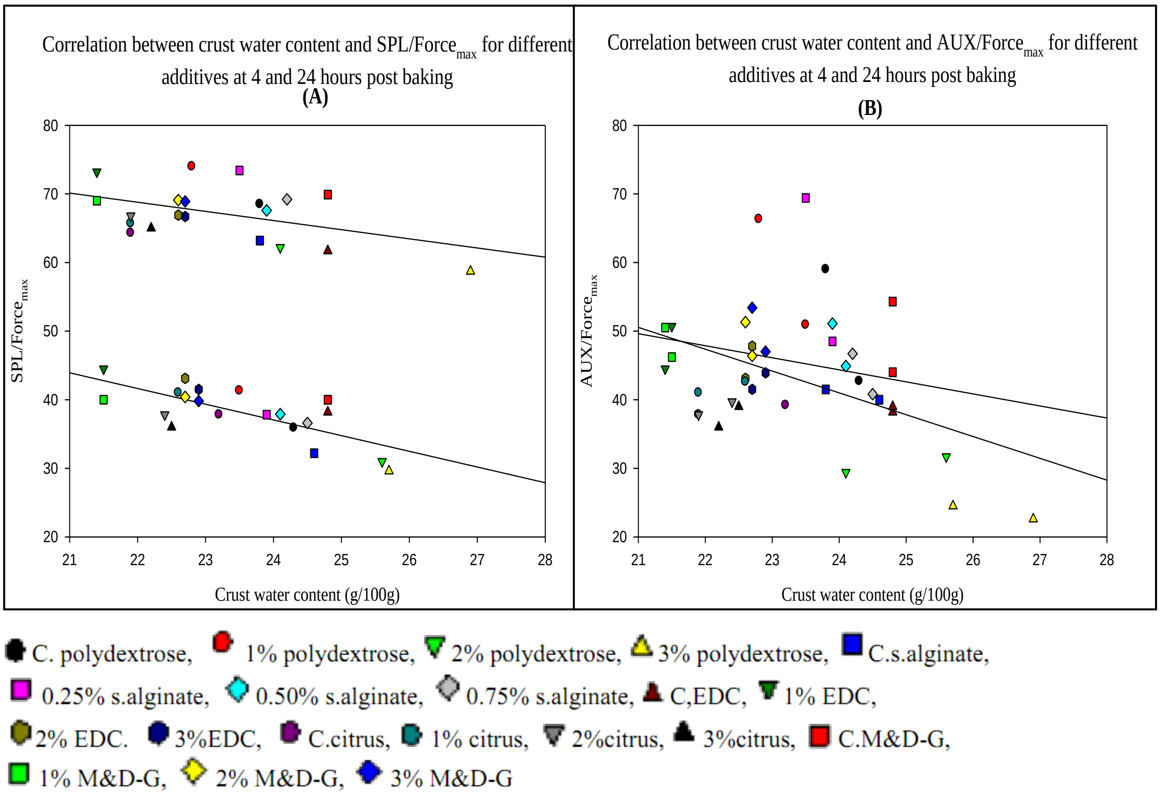

Figure 3.12 Correlation between experimental crispness parameters and crust water content
E= EDC, p= polydextrose and M= M&D-G, CS.

The values of both experimental parameters were affected by crust water content. Both experimental parameters showed significant negative correlations with crust water content, however SPL/Force$_{max}$ showed a higher negative correlation with crust water content at 24 hours after baking than AUX/Force$_{max}$ $R^2 = -0.53$, $P<0.001$ (Table 3.13). Bread made with 2% and 3% polydextrose showed the highest values of crust water content, hence they showed the lowest instrumental crust crispness. To investigate this finding, the correlation between sensory crust crispness and crust water content was made and the result showed highly significant negative correlation both at 4 and 24 hours after baking $R^2 = 0.55$, 0.63, $P< 0.001$, respectively (Figure 3.12).

3.4.3 The correlation between sensory and instrumental crumb firmness

The determination of crumb firmness instrumentally was made according to the AACC method (74-09). Since the reliability of this method has been approved by researchers, a high correlation with sensory analysis was expected.

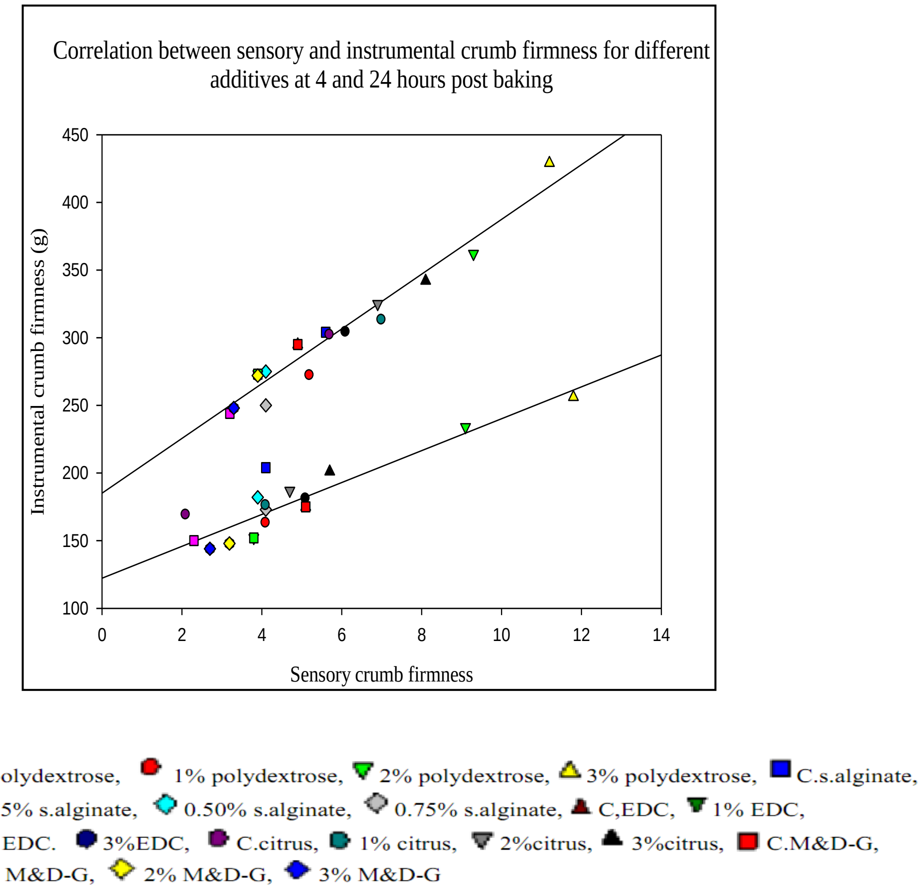

Figure 3.13 Correlation between sensory and instrumental crumb firmness

The results showed that the correlation between instrumental and sensory crumb firmness was highly significant at both time points $R^2 = 0.85, 0.82$, $P<0.001$.

Instrumental and sensory crumb firmness showed significant negative correlation with crust crispness both by instrumental evaluations and sensory evaluations (Table 3.13). Bread crumb of bread made with 3% polydextrose showed to be more firm than the other additives (Figure 3.13), and less crust crispness as previously shown in Figure 3.11. The data were divided into separate lines rather than showing one linear correlation. The reason of that is probably attributed to the procedures adopted during the evaluation, where the samples were evaluated separately and thus the panellists found a difficulty in remembering what score they gave last time. Therefore further work in this particular area should be carried out to investigate the effect of using this procedure on the results obtained from this study.

3.4.4 The correlations between crust thickness and both instrumental crumb firmness and sensory crust crispness

The crust of the bread forms at the early stages during the baking of the bread, and it works as barrier to prevent water migration from the crumb to the surrounding air. As the bread become stale the thickness of the crust increased. Therefore the thickness of the crust was related to less freshness. In other words, fresh breads are characterised by a thinner crust thickness.

The results presented in Figure 3.14 (B) showed highly positive correlation between the thickness of the crust and the firmness of the crumb at 24 hours after baking $R^2 = 0.76$, $P<0.001$.

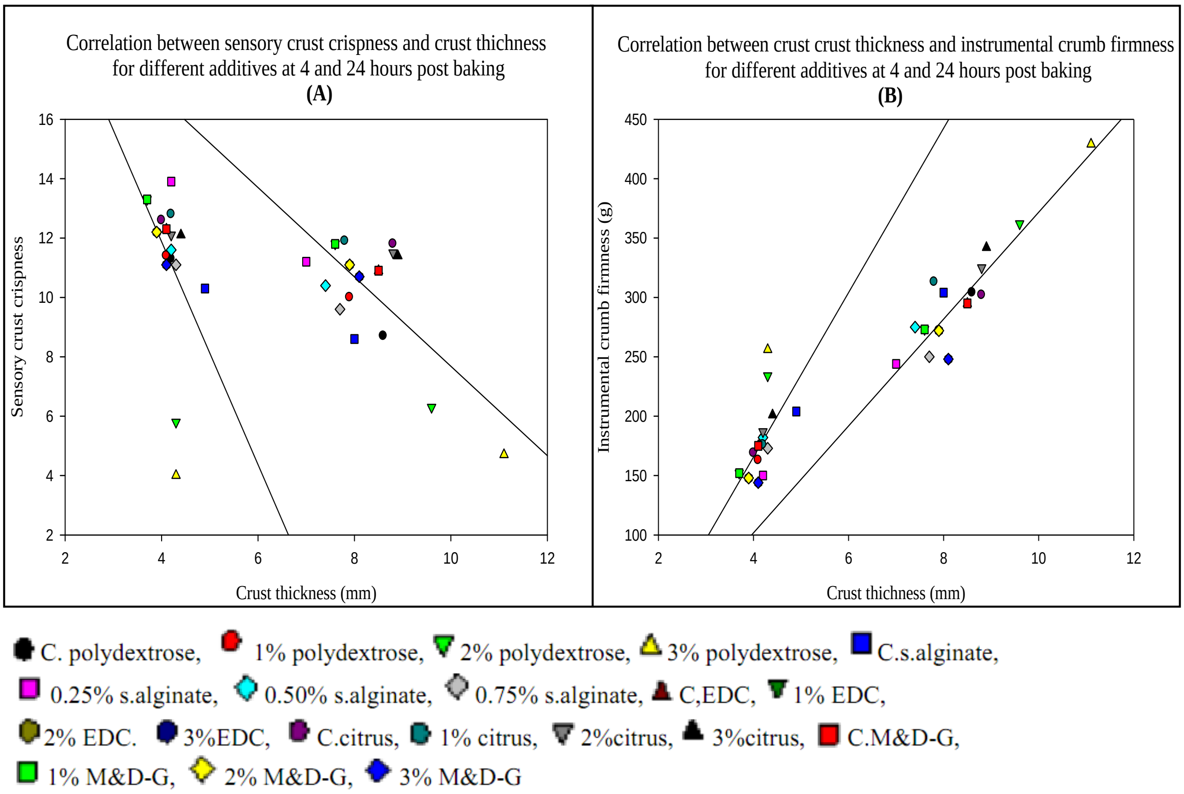

Figure 3.14 Correlation between crust thickness and both sensory crust crispness and crumb firmness. M= M&D_G, P= polydextrose, E= EDC, and C.S= Control of sodium alginate

Sensory crust crispness was also affected by the thickness of the crust (Figure 3.14, A). However bread that showed a more crispy crust was characterised by a thinner crust thickness. Breads made with 2% and 3% polydextrose which showed the highest values of crust thickness had the lowest value of crust crispness using both instrumental and sensory analysis.

The current study showed that the correlation between sensory crust crispness and crust thickness (Table 3.13) was highly negative correlated at 24 hours after baking $R^2 = - 0.58$, $P<0.001$.

3.5 Discussion

This chapter aimed to study the effect of five different selected additives (polydextrose, sodium alginate, enzymes dough conditioner, citrus fibre and mono and di-glycerides on both bread crust crispness measured by sensory analysis and by instrumental analysis. In addition, the study aimed to investigate the effect of selected ingredients on related properties such as crumb softness, crust water content, crust thickness and on bread weight, and the relations between selected ingredients.

The selection of the additives was based on previously positive reported effects shown on bread quality parameters such as bread volume, morphology of the bread and crumb softness (Primo Martin, Beukelaer et al. 2008).

From the literature, it is known that alpha amylase additive modifies the structure of the bread crumb and retards crumb staling (Primo-Martín, Beukelaer et al. 2008). Sodium alginate and polydextrose were chosen due to their high water holding capacity, thus they might prevent or delay the migration of water from the crumb to the outer crust of the bread (Craig, Holden et al. 1999, Brownlee, Seal et al. 2009). The effect of above mentioned ingredients on the crispness of bread have not been discussed in the literature before as far as we are aware, except for some types of enzymes and hydrocolloids (Guarda, Rosell et al. 2004, Primo Martin, Beukelaer et al. 2008). Therefore, we were answer about whether these ingredients to also modify the crispness of the bread crust.

As mentioned in earlier chapters of this research that the evaluation of bread was made in two different time points (4 and 24 hours) after baking, however more attention will be paid on the changes that occurred after 24 hours after baking, since this is expected to be the usual time of consumption of this type of bread manufactured by the Greggs bakery.

3.5.1 Effect of polydextrose

As expected, differences relating to bread crust crispness were found among samples. Bread included 1% polydextrose showed significantly higher crust crispness than all other bread formulation made with polydextrose. This finding was demonstrated both using modified instrumental method and sensory analysis (Table 3.3, 3.4, 3.5 and 3.6). What is surprising is that bread included 2% and 3% polydextrose showed significantly lower crust crispness than the Control bread.

This is an important distinction that has not been recognized in previous research, however no definitive explanation for this observation can be provided yet, due to the lack of information in the literature and the lack of methodology to further quantify the morphology of bread crust. The most important reason of choosing polydextrose was its highly attraction to the water and therefore will play an important role in preventing water from migration to outer layer, it seems that polydextrose played similar role on the crust which caused increase water content which in turn decreased the level of crispness in bread treated with polydextrose in ratios more than 1%. The only support information found regarding the effect of polydextrose addition on food crispness was reported by Sibel Roller (1996) who reported that the addition of polydextrose to shortcruts pastry increased the crispness. However the level of polydextrose addition was not reported in mentioned study. It is interesting to note that bread included 1% polydextrose also showed significantly lower instrumental and sensory crumb firmness than other bread formulae followed by Control bread at 4 and 24 hours after baking (Figure 3.6 A and 3.7 A). It has been reported that the rate of crumb staling can be retarded by adding polydextrose to the dough as an ingredient. One of the limitation of this study that rate of staling did not determined by using DSC (Differential scanning calorimetry) along with compression test (Texture analyser). This due to both Greggs plc and the University did not have this device. The other beneficial effect of adding polydextrose can be clearly reflected in enhancing handling properties and might also contribute in increasing bread volume. (Kilibwa and Niantic 2004) .

In the current work, polydextrose was added in ratio from 1% to 3% which was within preferable amounts as demonstrated by Killwa and Niantic (2004) who reported that for bread, polydextrose is preferably added in amount of between 1 - 5% by flour weight for firmness reduction. This finding also was supported by Esteller, Amaral et al. (2004), however this is disagreement with the mentioned studies regarding the most effective ratio, where they reported that polydextrose in amounts between 2-3% was preferred. Another agreement between the current study and the mentioned studies is that adding too much polydextrose results in sticky dough which cannot be processed efficiency (Esteller, Amaral et al. 2004). Overall, there is agreement consensus between the current and previous studies that polydextrose improved the texture of bread crumb and reduced staling when used as an additional ingredient. The possible explanation for the role of polydextrose in delaying bread staling might be attributed to its higher water absorption capacity.

It is thought that the primary effect of polydextrose in reducing the rate of staling in baked products is to dilute the starch components due to its highly water capacity which leads to increase the content of soluble carbohydrate thus reducing the available starch fractions for crystallization (Kilibwa and Niantic 2004). Since bread including 1% polydextrose showed the highest crust crispness at 4 and 24 hours after baking, crust water content presented in Table 3.10 and Figure 3.8 (A) supported this finding, where bread made with 1% polydextrose exhibited significantly lower water content than bread formulations at two time points, followed by Control bread. Experimentally, the crust water content demonstrated by different bread formulae shows that the higher crust water content, the less crust crispness (Roudaut, Dacremont et al. 1998, Fu, Tong et al. 2003)

It has been reported in several studies that polydextrose has a high water holding capacity and that it is this property causes to consider polydextrose as hydrocolloids (Guarda, Rosell et al. 2004, Laaman 2011). Theoretically, bread included 2% and 3% polydextrose would be expected to prevent the water from migration toward the crust due to its ability to bind water molecules, but this expectation was observed only with ratio of 1% polydextrose. It seems that the ratios of polydextrose of more than 1% have acted as water binding agent in both the crumb and crust as well. This finding was more obvious on bread weight, where bread included higher ratios of polydextrose exhibited higher weight 24 hours after baking as shown in Figure 3.9 (A). This study showed significant positive correlation between crust water content and crust thickness $R^2 = 0.84$, $P = 0.009$. The former and latter were negatively correlate with both experimental parameters SPL/Force$_{max}$ $R^2 = -0.88$, $P = 004$ and $R^2 = -0.69$, $P = 0.058$, regarding AUX/Force$_{max}$, $R^2 = -0.88$, $P = 0.004$ and $R^2 = -0.80$, $P = 0.018$ respectively at 24 hours as shown in Table 3.13.

3.5.2 Effect of sodium alginate

At the current time, the use of hydrocolloids has become a common practice in the baking industry. In this study, sodium alginate was added to white crusty bread to investigate its effect on bread crust crispness and related attributes.

In this study, it was hypothesised that the use of additive ingredients such as sodium alginate in bread recipe, will help in holding or binding water in the bread crumb and in minimizing water migration from the crumb to the crust during storage period, resulting in enhancing and maintaining crust crispness for longer.

Preliminary experiments in this work were conducted using 1%, 2% and 3% sodium alginate; however the results showed highly shrinking in bread volume reached to 10 – 15% compared to Control bread. In addition, the crumb was very wet after 24 hours after baking due to water being absorbed by sodium alginate (data not shown).

One of the most accepted reason of such event is attributed to the capability of sodium alginate to bind α-amylase present in the wheat flour, thereby effectively inhibiting the enzyme's activity. Since sodium alginate binds to α-amylase, it is expected that as more alginate is added, more enzyme will bind to which therefore causing further decrease in CO_2 production by yeast and subsequent lowering of the specific volume (Sharma, Sharma et al. 2000). It has been found that the effect of sodium alginate was not positive on bread volume comparing with other bread improver; this finding was in line the current study, specifically when sodium alginate was added in ratios more than 1% (Guarda, Rosell et al. 2004).

According to Kohajdová Z (2009) who reported that when sodium alginate used in small quantities (<1% (w/w) in flour) it is expected to increase water retention and loaf volume and to decrease firmness and starch retrogradation, the amount of sodium alginate was reduced to ratios 0.25%, 0.50% and 0.75% of flour weight which was also in line with a previous study by Kim, Jeon et al. (2008). Hydrocolloids, although added in small amounts, significantly influence the characteristics of the final products (Kohajdová and Karovičová 2009, Mandala, Polaki et al. 2009).

As expected, the addition of sodium alginate to bread dough significantly enhanced its crust crispness compared with Control bread at 4 and 24 hours after baking (Table 3.3 and 3.4). Bread made with different ratios of sodium alginate showed higher crust crispness from Control, while the differences between each other were not significant. Sensory crust crispness analysis supported instrumental measurements, where the panel could easily recognise the different between treated and Control bread and scored treated bread highly as shown in Figure 3.5 (B). This result was in agreement with a study performed by Kim, Jeon et al. (2008) on one type of Korean traditional confectionery called Yugwa base. Here they found that the use of sodium alginate in ratios 0.1%, 0.5%, 1.0% and 3.0 % (flour weight) resulted in increase of sensory crispness. Mandala, Polaki et al. (2009) reported that moisture redistribution during storage could be a factor strongly influencing crust firmness and consequently bread staling (crust softening is an indication of staling).

The inclusion of bread with sodium alginate leads to a decrease in the crumb firmness, and this decrease in crumb firmness corresponded with the ratio of sodium alginate added. In other words, crumb hardness decreased as amount of sodium alginate increased both at 4 and 24 hours after baking as shown in Figure 3.6 (B) and 3.7 (B). However, there needs to be a balance in the amount of sodium alginate added. A very high amount may give high consistency, water absorption and weight, however, bread crust crispness and crumb softness will be poor. Hence, the optimum amount will be a level which gives good crumb softness and better crust crispness. It has been recommended by manufacturer's (ISPCorp, Singapore) that the dosage of 0.25% (flour basis) for sodium alginate is suitable to give the dough better tolerance and coherence (Selomulyo, Vania Octaviani et al. 2007). The effect obtained with sodium alginate addition was in line with Guarda et al. (2004) who used sodium alginate in the amount of 0.1% (w/w, flour basis), however it differs in some extent with the previous findings of Rosell et al. (2001a) who was working with 0.5% sodium alginate addition. One of the possible explanations of the effect of sodium alginate on retarding crumb firmness is attributed to its ability to reduce of gluten– starch interactions (Davidou 1996). A different study conducted by Kulp and Ponte (1981) showed that sodium alginate shares water with both starch and gluten, thus the amount of free water will decrease, therefore the rate of water migration will be hindered and the crumb retains it softness for longer.

In this study, the main reason of using sodium alginate is its ability of holding or binding water in bread crumb and in minimizing water migration from crumb to crust during storage period. As expected, water absorption was increased by the addition of sodium alginate. The highest absorption amount was observed when adding sodium alginate at 0.5 and 0.75% as illustrated in Figure 3.8 (B). These results were in agreement with Friend, Waniska, and Rooney (1993) and Rosell et al. (2001a, b). They attributed these observations to the chemical structure of hydrocolloids which are characterised by their high content of hydroxyl groups. This structure allows more water interactions through hydrogen bonding (Guarda, Rosell et al. 2004). This impact was obviously reflected on the weight of bread particularly at 24 hours after baking, where bread weight increased as the amount of sodium alginate increased as shown in Figure 3.9 (B). This finding was in agreement with V.O. Selomulyo et al. (2007) who found that the weight increased as more hydrocolloids were added to the flour mixture, but the dough development time and stability decreased as the percentage of hydrocolloids increased.

Another agreement was observed with the study conducted by Rosell et al. (2001) who also reported increased water absorption increases with the addition of sodium alginate.

These seemed to indicate that at higher dosage of sodium alginate has a higher water binding capacity than lower dosages, thus dough containing higher dosage of sodium alginate exhibited a significantly higher weight than that the fewer doses. However, Sharma et al. (2000) reported that the extent of binding will increase only up to a certain level before it levels off and decreases.

3.5.3 Effect of enzyme dough conditioner (EDC)

A dough conditioner containing alpha amylase as a functional ingredient was selected on the basis of the known effect of alpha amylase on bread qualities such as bread crumb softness and bread volume as reported by Primo Martin, et al. (2008), while its effect on bread crust quality has only been studied by few researchers. Effects of EDC were assessed in terms of its effect on bread crust crispness, crumb firmness, crust water content and in relation to the sensory parameters. As expected, the addition of EDC in different ratios increased the number of force at failure and both the sound and force peaks and therefore, the value of crust crispness measured by instrument was significantly higher from Control bread at 24 hours after baking as presented in Table 3.3 and 3.4. This increase correlated well with a sensory crust evaluation $R^2 = 0.60$ (Figure 3.5 (C) and Table 3.13). A previous study conducted by Primo-Martín et al. (2008) was in line with the current study in terms of force at failure, where they revealed that lipase, amylase and glucose oxidase addition to the dough increased the force required to fracture bread crust. In the contrast, Primo-Martin, et al. (2006) who sprayed purified alpha-amylase (1 g/30 ml water) over the surface of the dough after proofing, found that treating the crust with alpha-amylase did not improve crispness retention.

It is generally accepted that crispness of baked goods decreases if the water content increases (Luyten, Plijter et al. 2004). In this study, further attention was paid to investigate the effect of crust water content on crust crispness retention through studying the correlation between sensory and instrumental crispness values and water content of the crusts (Table 3.13). A negative relationship was found when correlating both crispness experimental parameters and sensory crispness with crust water content (Table 3.13). This finding was supported by the study conducted by Primo-Martin, et al. (2006), who found that crispness correlates with lower water content and high moisture content results in a less crispy product.

It is still open to debate if the observed changes on bread crust crispness are due to a direct effect of the EDC on a component of flour or that they occur through an indirect effect by the interaction with other bread ingredients.

Bread crumb firmness was also affected by EDC addition, where treated bread was significantly softer than Control bread both at 4 and 24 hours after baking (Figure 3.6 (C) and Table 3.8, 3.9). The effect of alpha-amylase on bread crumb firmness was similarly detected both using experimental parameters and by sensory evaluation, where bread crumb showed more softness as the amount of EDC increased. The explanation which can be provided here is that crumb hardness showed by untreated bread is a result of increasing interactions, presumably by hydrogen bonding, between the swollen starch granule and the protein fibrils of the gluten matrix (Gerrard, Every et al. 1997). Martin and Hoseney (1991) demonstrated that the mechanism of bread firming is caused due to starch-gluten interaction, and that α-amylase interferes with this mechanism by releasing dextrins that prevent these starch-gluten interactions from forming. On the other hand, Luchian et al. (2010) reported that amylases have a limited effect against aging, because of their limited thermo stability and because they are inactivated before gelatinization of starch occurs during baking.

This work showed that the crust water content was influenced by recipe with EDC, where bread included EDC showed significantly lower crust water content particularly bread included 1% EDC. There is no definitive explanation which can be provided to illustrate this observation due to the lack of the suitable methodology needed for further quantification to the morphology of the crust. It seems that the recipe of bread dough with EDC modified water absorption properties of the flour components in the final product (Primo Martin, Beukelaer et al. 2008). However, previous work performed by Van Nieuwenhuijzen et al. (2007) showed no significant different in crust water content between bread included different enzymes such as amylase, lipase and xylanase comparing with the Control.

The bread weight of bread containing EDC was not found to be significantly different from Control breads after 4 hours of baking (Table 3.11 and Figure 3.9 (C)); however after 24 hours bread included 3% EDC showed significantly higher weight than other recipes.

3.5.4 Effect of citrus fibre

Awareness of the benefits associated with fiber is increasing and, therefore, citrus fibre could be used either for manufacturing new or improving existing bread formulations. The inclusion of citrus fibre was mainly to assess its effect on bread crust crispness and crumb firmness. Furthermore enriched bread with higher dietary fiber content could be the best way to increase the fiber intake (Mandala, Polaki et al. 2009)

Although citrus fibre additions, in general, had pronounced effects on dough properties such as, mixing and handling in comparison with Control, however, no pronounced effect on instrumental bread crust crispness represented by both SPL/Force$_{max}$ and AUX/Force$_{max}$ was detected both at 4 and 24 hours post baking (Table 3.3 and 3.4). Similar results were shown by sensory evaluation conducted by ten expert panels, where the panel did not detect any significant different between treated by different ratios of citrus fibre and Control bread as shown in Figure 3.5 (D).

For bread crumb firmness, bread included 2% and 3% citrus fibre had a significantly firmer crumb texture than control and bread included 1% citrus fibre. Both instrumental parameters and sensorial analysis showed that Control bread was softer than made with citrus fibre (Figure 3.3.7 (D) and Table 3.7). This result agrees with that found by Gómez, M. et al. (2003) with different kinds of dietary fibres orange, pea, cocoa, coffee, wheat and microcrystalline cellulose. They generally found that the recipe of bread made with ≥2% fibre had significantly firmer crumb than Control bread. Similar observations were shown by Abdul-Hamid (2000) and were attributed that to the thickening of the walls surrounding the air bubbles in the crumb. Unexpectedly, the current study showed that the differences between treated and control bread pertaining crust water content was not significant. Dietary fibre is characterized with its water holding capacity due to greater number of hydroxyl group which exist in its structure and allow more water interaction through hydrogen bonding as reported by Voit (1989), and which therefore prevent water from migration from crumb to crust, so crust water content of treated bread was expected to show lower crust water content. In contrast, the ability of citrus fibre in holding water was noticed in bread weight both at 4 and 24 hours after baking (Figure 3.9 (D)), where the result showed that as the amount of citrus fibre increased the weight of the bread increased. However several studies conducted by others revealed that the increase in weight is always accompanied with volume reduction (Gómez, Ronda et al. 2003, Sangnark and Noomhorm 2004).

Finally, it could also be concluded that the different ratios of citrus fibre added did not show any influence on bread quality particularly crust crispness and crumb firmness since no significant differences were found.

3.5.5 Effect of mono and di-glycerides (M&D-G)

Mono and Di-glycerides E741 (M&D-G) are considered as one of the most frequently used group of emulsifiers in food industry, which are known as dough improvers/ conditioners, and anti-staling agents or crumb softeners (Kohajdová Z 2009). From the literature, it is reported that Diacetyl tartaric acid of mono-diglycerides (DATEM) has a positive effect on crusty bread (Sluimer 2005); therefore it was expected that M&D-G would also modify the structure of bread crust (crispness). Regarding the effect of using different ratios of M&D-G on bread crust crispness, results obtained from the current study were contrary to the expectations. Both experimental parameters and sensory evaluation indicated that the differences between bread recipes were not significant as shown in Table 3.3 and 3.4.

A study conducted by Primo-Martin et al. (2008) showed that the samples made with DATEM at 300 mg/100g exhibited highly significant maximum sound pressure from Control sample. As a single parameter the current study was in line with previous studies particularly 4 hours after baking, but 24 hours after baking different bread formulae did not show any significant differences. Since the current study is mainly concerned about crust crispness at 24 hours after baking, it can be reported that the recipe of bread with M&D-G in amount more than 0.50% (Control) did not provide any improvement on bread crust crispness. For bread crumb firmness, the current study produced results which corroborate the findings of a great deal of the previous works in this field. The addition of M&D-G into the dough formulation produced bread with significantly reduced crumb hardness compared with the Control bread, where the latter is already contained M&D-G at of 0.5%. Here, the bread crumb showed less firmness as the amount of M&D-G increased at two different time points as illustrated in Table 3.7, 3.8 and 3.9.

There has been general consensus between the researchers in terms of the role of mono and diglycerides either as softener or anti-staling agents. The most accepted explanation was provided by Stampfli and Nersten (1995) who stated that the emulsifier creates a complex structure either with amylose or amylopectin resulting in inhibition of amylose or amylopectin from retrogradation.

Crust water content of different bread formulations did not exhibit any significant differences both at 4 and 24 hours after baking as shown in Table 3.10, indicating that M&D-G had no effect in preventing migration of water from crumb to crust. This finding was in line with previous study performed by Stampfli, et al. (1995) and Xu et al. (1992a), they found that bread included emulsifiers had greater moisture migration from the crumb to the crust than the control bread. They attributed this observation to the interaction occurring between the starch and the emulsifier, as a result of that starch cannot absorb water released from protein as Control bread, therefore released water would be migrate from wet crumb to dry crust. Another study conducted by Roundaut et al. (1998) showed by adding an emulsifier to bread led to decrease the water migration, likely due to hindering of migration of water into solid matrix. Unexpected significant differences in bread weight were detected between bread formulations, where bread included 2 and 3% M&D-G showed significantly higher weight than others. Since the amount of crust water content between different bread formulations was comparable, the weight also was expected to be comparable, unless crust water content was equated from ambient air. Selomulyo et al. (2008) reported that bread included DATEM was significantly represented by the high crumb moisture content which reflected in bread weight.

3.5.6 Comparison different characteristic across different experiments

Regarding the experimental parameters which represent the instrumental crust crispness, the results were encouraging particularly for both experimental parameters as shown in Table 3.13. Both experimental parameters showed highly significant correlation with sensory analysis, but SPL/Force$_{max}$ could differentiate between time points while AUX/Force$_{max}$ mixed them together. Despite the latter gives results which in agreement with the former, however it seems measure different thing from crispness. It seems that SPL/Forcemax gives information about the staling rather than the crispness, while AUX/Force showed to be more reliable in reflecting the level of crispness.

The results obtained by using AUX/Force$_{max}$ data was divided into separate lines rather than showing one linear correlation. This observation was similarly showed when the correlation between sensory and instrumental crumb firmness, despite it conducted using a standard method which known its reliability. The reason of that is probably attributed to procedure adopted during the evaluation, where the samples were evaluated separately and thus the panellists found a difficulty to remember what score they gave last time.

Therefore further work in this particular will be done in this research to investigate the effect of using this procedure on the results obtained from earlier stages in this study.

For the correlations obtained by combining different parameter across different experiments was in line with those conducted for each ingredient and described through chapter 3. Furthermore, the distribution of several additives around trend line particularly those related to SPL/Force$_{max}$ and AUX/Force$_{max}$ as showed in graphs presented in section 3.8 Figure 3.12 (A and B), demonstrated that this experimental parameter can reliably be used to predict or determine bread crust crispness made by different additives.

3.6 Conclusion

Referring back to the original hypothesis set out for the current stage that the updated approach represented by both SPL/Force$_{max}$ and AUX/Force$_{max}$ would be able to quantify bread crust crispness of different bread formulae treated with the different ratios of selected additives. SPL/Force$_{max}$ showed to more suitable to quantify the changes occurred in bread crust with time lapse which known as the rate of staling. This was clearly reflected from graphs obtained at 4 and 24 hours post baking, while AUX/Force$_{max}$ showed to be more accurate than SPL/Force$_{max}$ in determining crust crispness. The trend of the graphs obtained from AUX/Force$_{max}$ at 4 and 24 hours as shown in Figures 3.4 was in line with sensory analysis measurements (Figure 3.5). The addition of hydrocolloids in form of polydextrose and sodium alginate had an effect on both crust crispness and crumb softness. Recipes treated with 1% of polydextrose and 0.25% sodium alginate had significantly higher crust crispness and crumb softer than other recipes at 4 and 24 hours post baking.

Neither the treatment by using mono and di-glycerides nor the addition of citrus fiber had any significant effect on bread crust crispness; however the effect of adding extra amount of mono & di-glycerides was obvious on bread tested at 4 and 24 hours post baking.

EDC at ratio 1% had a significant effect on bread crust crispness; however more than 1% EDC resulted in sticky dough.

Chapter 4 Integration of sensory and objective measurements of crust crispness and crumb firmness of bread evaluated at the same time compared with separate evaluation

Most consumers consider sensory quality as the most important characteristic of crispy products, and are willing to pay for products that they believe crisper. Bread crust crispness is one of the most important and desirable characteristics that signify freshness and high quality in white crusty bread. Though many approaches to instrumental measurement of crispness have been made, the best measurements are still inconclusive (Castro-Prada, Luyten et al. 2007, Primo Martin, Beukelaer et al. 2008).

The use of the ratio between maximum sound pressure (SPL) and Maximum Force ($Force_{max}$), and the ratio between number of sound peaks (AUX) and $Force_{max}$ have not previously been directly used to express product crispness either for bakery products or other food products. Although many studies have provided extensive information about the correlations between mechanical and acoustic parameters as a single factor with sensory crispness analysis, combinations between two or more factors have not been described before as previously described in chapters 2 and 3 in the current study. Vanheck (1998) used the ratio between number of force peaks and the distance of the penetration. He found that the result was correlated with the firmness and which in turn related the crispness in somehow. It is known that it is particularly difficult to compare sensory quality over several hours or days, when standardised references are not available (Thybo, Bechmann et al. 2005), as is the case for crust crispness. Although both objective and sensory evaluations in chapters 2 and 3 were baked and measured separately, the results mostly corresponded to the same samples in terms of the highest and the worst crust crispness. SPL/$Force_{max}$ showed an improved capability for differentiation between bread tested at two time points (4 & 24 hours) after baking as shown in Figures 3.2, 3.11, 3,20, 3.29 and 3.38. Therefore, the current assumption is that the evaluations of bread crust crispness and crumb firmness at 4 and 24 hours post bake using two different bread formulae in terms of their crust crispness and crumb softness would reveal a better understanding of method reliability for the determination of bread crust crispness.

The hypothesis for this chapter is that separate time evaluation would not affect the reliability of both the experimental parameters and sensory measurements in determining bread crust crispness predominately and crumb firmness.

Therefore, the main aims of the current chapter are:

- Test that panellists cannot remember the previous evaluation of the same sample when tested at spaced intervals.
- Assess the effect of separate evaluation time on the curve trend of both SPL/Force$_{max}$ and number of sound peaks/Force$_{max}$ and therefore its effect on the conclusion made in previous experiments of the current study.
- Comparison of experimental parameters in terms of ability to reflect bread crust crispness in comparison with organoleptic analysis and determining which of instrumental methods should be adopted as a reliable crust crispness indicator.

4.1 Material and methods

A pre-ferment bread recipe was chosen to be the control in this experiment due to its characteristics both in terms of crust crispness and crumb softness as mentioned in chapters 2 & 3. In addition a modified recipe was also used in this part of the study and called ‘Traditional bread’. The latter is named due to the recipe lacking additives such as enzymes and acetic acid, crumb softer and emulsifier, which are otherwise known for their role for the enhancement of bread crumb softness and crust crispness as shown in Table 4.1. The experiment and the evaluations were carried out at Greggs plc facility. The ingredients for the Control and traditional recipe are presented in Table 4.1. Both bread formulae were prepared by using the straight dough method as previously described in chapter 2.

Table 4.1 Ingredients for Control and traditional bread

Ingredients	Control %	Traditional %
Bread Flour	100	100
Salt	1.4	1.4
Delta	0.98	0.98
Extra fresh	0.98	0
Gluten	1.53	1.53
Crumb soft	0.46	0
Fluid shortening	0.46	0
Pre-ferment 5%	5.0	0
Water	57.78	64.16
Yeast	2.28	2.29

The settings of the experiments regarding the mechanical, acoustic, crumb firmness and sensory analysis were different from the procedure explained in chapter 2 & 3. In these experiments both Control and traditional bread were baked at same time and therefore examined at next day the same time using both instrumental and sensory analysis.

4.1.1 Experimental procedure

The baked bread obtained from this stage was subjected to determination of physical (mechanical and acoustic) and sensory parameters at two different bread ages 4 & 24 hours after baking.

1. 5 loaves (980g per loaf) for each type of white crusty bread (Control and traditional) were obtained from each batch in the first day according to their recipe and placed in ambient (temperature 21± 2/ relative humidity 44 ±3%) conditions.
2. On the second day, another 5 loaves (980g per loaf) were baked and placed in ambient conditions for 4 hours.

3. Bread from both 4 and 24 hours post bake were simultaneously subjected to determination of physical (mechanical and acoustic) and sensory parameters.
4. The methods and procedure used to determine physical and sensory analysis were as explained in chapter 2.

At this stage, more consideration was given to the sensory evaluation capability of the panel for the differentiation between samples that differ in quality and age.

4.2 Results

4.2.1 Bread crust crispness and crumb firmness measured by sensory analysis

In this experiment 10 expert panel members were asked to score four half slices. Two halves representing Control bread at age 4 and 24 hours after baking, the other two halves were related to Traditional bread at the same post bake time. The criteria adopted to differentiate between samples were as explained in chapter two. The mean scores for sensory parameters obtained from ten panellists' evaluations for bread aged 4 and 24 hours are summarised in Table 4.2. The data showed normal distribution that allowed the use two-way ANOVA for assessment (Kuti, Hegyi et al. 2004).

The results regarding sensory bread crumb softness, crumb firmness and crust crispness (Table 4.2 and Figure 4.1 A, B and C) showed that the main effect of recipe was highly significant $P< 0.00$. This indicated that the difference between Control and Traditional bread formulae was extremely high. As expected, Control bread showed significantly higher score of crust crispness and crumb softness at two different time points than Traditional bread. The main effect of time was highly significant at three different attributed. The main effect of panel was not significant which indicates the consistency between panel and their ability to differentiate between different samples. For the interactions between panel and time, recipe and time, recipe and panel were not significant as illustrated in Table 4.2.

These results were in corresponding to that obtained from instrumental analysis. In comparison with results in chapter 2 (Figure 2.8 and 2.9) the trend of panel score was more reliable. As described in Chapter 2 and 3 the samples were evaluated within two separate days, and the panellists could not remember what score they awarded to the sample in day before, therefore their scores were dependent on the test time, therefore the results at two time points were more consistent.

Table 4.2 Mean values ± SE of the sensory parameters obtained from sensory evaluation for two different types of bread at two different ages 4 and 24 hours post baking

Recipes	Time	Softness	Crispness	Firmness
Control	4	14.1±0.21a	13.1±0.37a	0.9±0.21b
Traditional		10.8±0.39b	9.7±0.43b	4.2±0.37a
Control	24	7.6±0.31a	6.6±0.37a	7.4±0.38b
Traditional		4.9±0.44b	3.1±0.33b	10.1±0.49a
Recipe		< 0.001	< 0.001	< 0.001
Time		< 0.001	< 0.001	< 0.001
Panel		0.957	0.977	0.897
Recipe*Time		0.317	0.910	0.347
Recipe*Panel		0.989	0.988	0.959
Panel*Time		0.995	0.949	0.975

Averages of ten panellists, identical letters in the same column at each time point indicates that there is no significant difference at *P*>0.05.

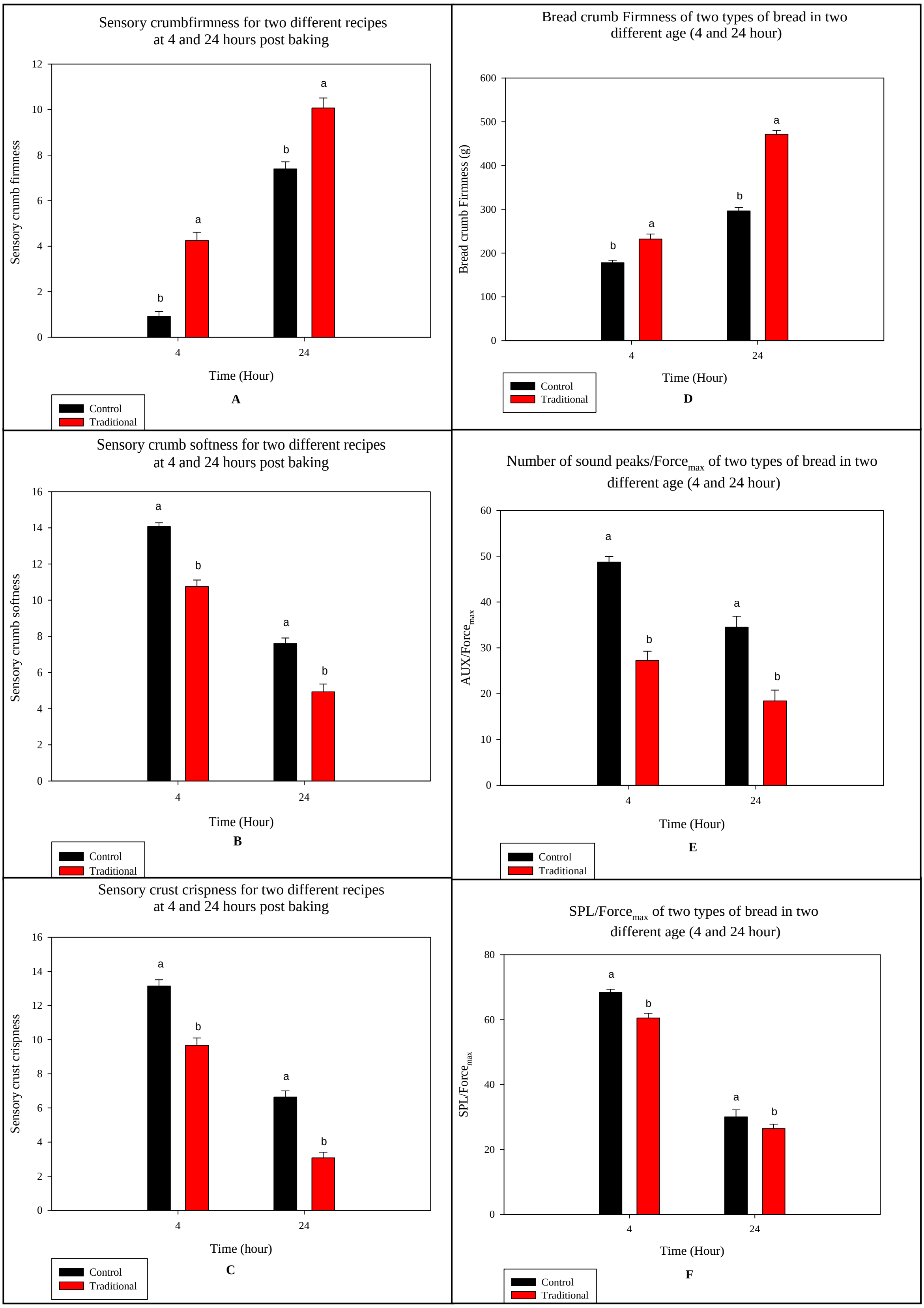

Figure 4.1 A, B and C, represents sensory parameters of two different type of bread, D, E and F represents instrumental measurements at 4 and 24 hours after baking.

For sensory measurements *n*= 10 replications, while instrumental measurements *n*= 15 replications. Identical letters in the same time point indicates that there is no significant difference at *P*>0.05.

4.2.2 Bread crust crispness and crumb firmness measured by instrument

Figure 4.1 (D, E and F) shows the differences between tested bread in terms of their crumb firmness and crust crispness represented by SPL/Force$_{max}$ and AUX/Force$_{max}$. It can be clearly seen from Table 4.3 that the main effects of recipe was highly significant $P<0.001$. Control bread either at age 4 or 24 hours after baking showed highly significant differences from Traditional bread.

SPL/Force$_{max}$ and AUX/Force$_{max}$ of Control bread showed significantly higher ($P<0.001$) from traditional bread at both time points. This indicated that the Control bread was crisper than traditional bread and the AUX/Force$_{max}$ was more comparable to results shown by the sensory analysis. This observation also appeared when AUX/Force$_{max}$ parameter was used to determine the effect of recipe on bread crust crispness and crumb firmness in Chapter 3.

Table 4.3 Mean values ± SE of the instrumental measurements for two different types of bread at two different ages 4 and 24 hours post baking

Recipe	Time (hours)	SPL/Forcemax	AUX/Forcemax	Firmness
Control 1	4.00	68.4±1.12a	48.7±1.22a	178.1±6.4b
Traditional		60.5±1.5b	27.2±2.13b	232±12.1a
Control 1	24.00	30.1±1.36a	34.5±2.2a	296±5.6b
Traditional		26.5±1.32b	18.4±3.3b	471±9.5a
Recipe		< 0.001	< 0.001	< 0.001
Time		< 0.001	< 0.001	< 0.001
Recipe*Time		0.031	0.041	< 0.001

Averages of 15 replications, identical letters in the same column at each time point indicates that there is no significant difference at $P>0.05$.

The main effect of time was highly significant $P<0.001$ indicating that bread aged 4 hours was highly different from those aged 24 hours. The interaction between recipe and time was significant at the case of both experimental parameters to highly significant $P<0.001$ at the case of instrumental crumb firmness.

4.2.3 Integration of sensory and objective measurements

The preliminary results in this chapter regarding the sensory measurement of bread crust crispness and crumb firmness (Figure 4.1) showed that the differences between recipes had a higher significance than those from objective instrumental measurements. This suggests that sensory analysis was more efficient for evaluation of small textural differences compared with instrumental bread compression analysis.

Previous results in this work (Chapters 2 & 3) were obtained separately, the current stage of this work conducted in one time both instrumental and sensory measurements to determine the differences between both approaches particularly instrumental crispness using experimental parameters.

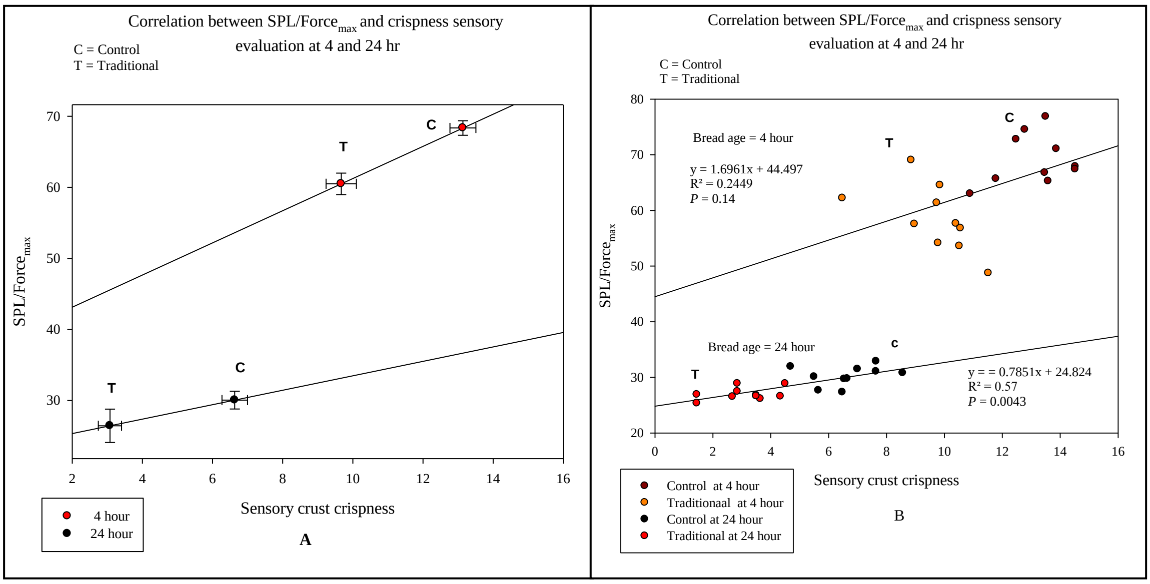

Figure 4.2(A and B) Correlation between SPL/Force$_{max}$ and sensory crust crispness for bread aged 4 and 24 hours after baking. R^2 and *P* value were calculated with the whole data set (*n*=20)

Correlations between both experimental parameters and sensory analysis at two time points were made and the results were plotted in Figure 4.2 and 4.3. The graph (A) plotted on the bases of average value of both type of bread, however significant of correlation coefficient (B) was calculated from the whole data set (*n* = 20). Both experimental parameters corresponded to the sensory characteristic. This correspondence was reflected in a high correlation at both time points.

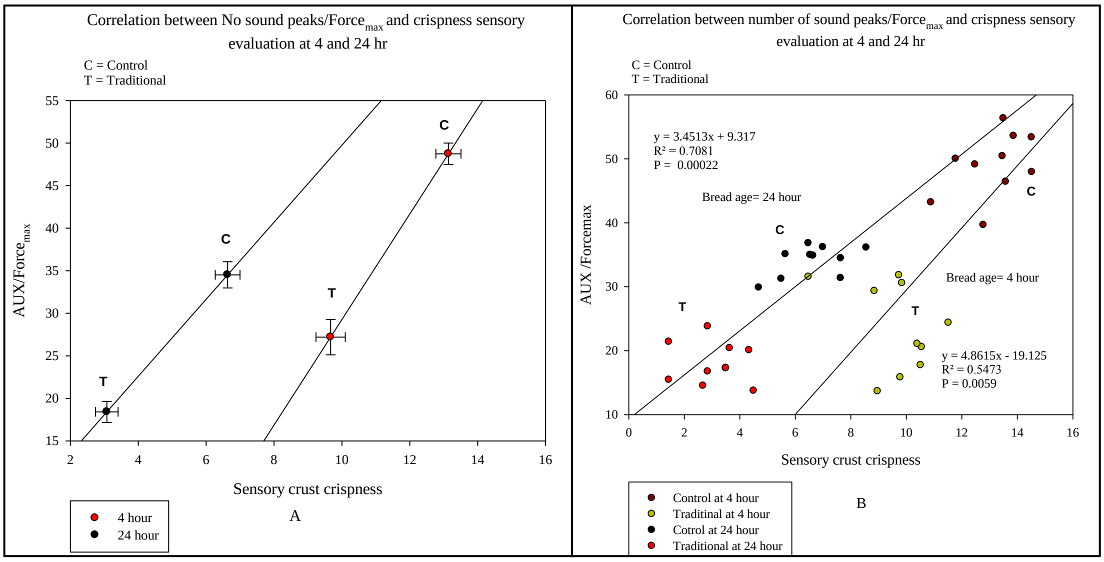

Figure 4.3 (A) Correlation between number of AUX/Force$_{max}$ and sensory crust crispness for bread aged 4 and 24 hours. R^2 and *P* value (B) were calculated with the whole data set (*n*=20).

A comparison between experimental parameters in terms of capability for determination of crust crispness showed that both experimental parameters could be used as crust crispness indicators. Results for both were in agreement in terms of determining which sample was crisper than the other at a certain time; however the trends between two time points varied as shown in Figure 4.2 and 4.3.

SPL/Force$_{max}$ showed non-significance correlation with sensory analysis at 4 hours $R^2 = 0.25$, $P = 0.14$, but this correlation was shown to be highly significant at 24 hours $R^2 = 0.57$, $P = 0.0043$. In the case of AUX/Force$_{max}$, the correlations with sensory analysis were highly significant at both time points $R^2 = 0.55$, $P = 0.0059$- $R^2 = 0.71$, $P = 0.00022$. SPL/Force$_{max}$ was more accurate due to its ability to differentiate crust crispness of tested bread on the basis of age or crust quality as shown in Figure 4.3. This Figure shows two distinct regions each of them representing different time points. Although, the AUX/Force$_{max}$ also showed difficulty in terms of discrimination between samples that fall between the best and worst ranking, it was in line with SPL/Force$_{max}$ and sensory analysis regarding the highest and lowest samples ranking.

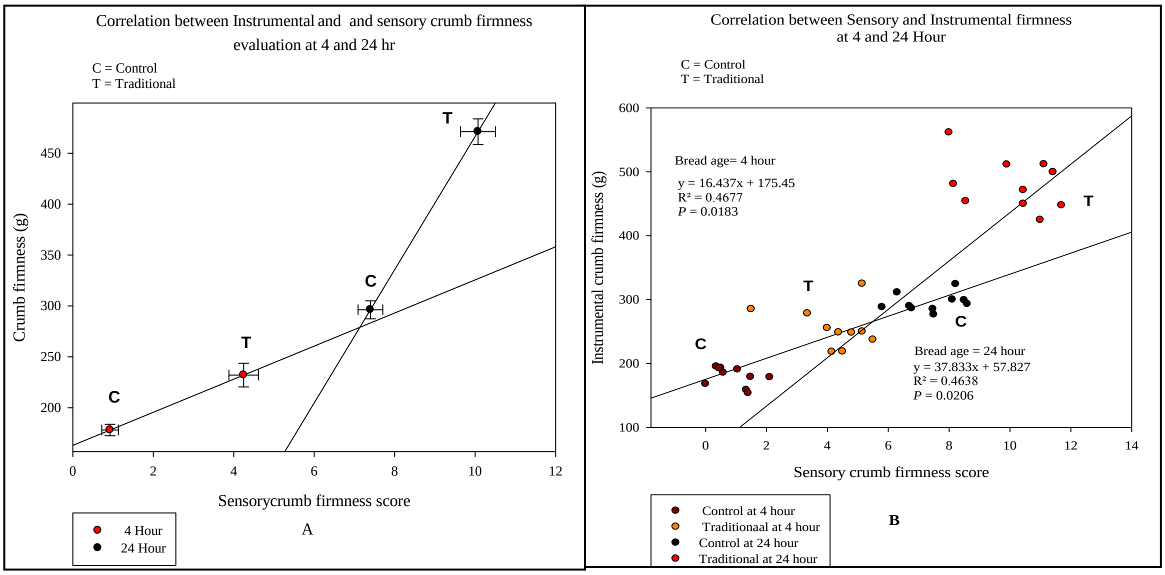

Figure 4.4(A) Correlation between instrumental and sensory crumb firmness for bread aged 4 and 24 hours. R^2 and *P* value (B) were calculated with the real data (*n*=20).

For bread crumb firmness, the differences between tested bread types at both test times were highly significant. The panellists showed high capability in discrimination between samples needing a compression force of 100 – 300g. This finding was observed through linear correlation between the first three points presented as shown in Figure 4.4, while the fourth point which represents the hardest crumb was out of line. Generally, the correspondence between instrumental and sensory crumb firmness was noticeable, and reflected in both agreement in the samples sequence and the high correlation coefficient obtained R^2 = 0.47, *P* = 0.018 and R^2 = 0.46, *P* = 0.021 at both 4 and 24 hours respectively.

4.2 Discussion

Sensory evaluation is the last quality measure determined by the human senses when consuming food. However, it is difficult to compare sensory quality with instrumental measurements at different times, due to the difficulty for the assessors to precisely remember a reference level either several days or weeks after the initial tests. Since all experiments presented both in chapters 2 and 3 were conducted separately and within two different time points, the samples in the current experiment were baked at the same times for two consecutive days and the evaluation of the samples for both types of bread either in age 4 or 24 hours after baking carried out in one session.

As expected, the current work showed that in the absence of score references, the trend of sensory evaluation conducted at different time points were independently scored. These observations can be clearly seen from results obtained in chapters 2 and 3 regarding sensory evaluations that the scores awarded to a samples at 24 hours after baking were comparable if not identical to their scores at 4 hours after baking, where the score was expected to be lower as the bread became older. The possible explanation of this observation is that the assessors could consistently score fresh bread samples on first day, but next day there was difficulty in differentiating them either due to the difficulty to remember what exactly they scored last time or bread still appeared fresh. As a result of that the scores between two different days were comparable. This finding was in line with a previous study conducted on Tomato samples by Thybo et al. (2005). The present results showed that the curves of both SPL/Force$_{max}$ and AUX/Force$_{max}$ were similar to those found in experiments conducted separately. However the latter experiments defined the differences between different samples of different ages with much better efficiency (Figure 4.2 and 4.3).

4.3 Conclusion

Both approach used in previous chapters or the method as presented in the current chapter can be used in determining bread crust crispness as both produced similar results. The experimental texture analyser settings using SPL/Force$_{max}$ and AUX/Force$_{max}$ clearly reflect sensory measures, as demonstrated by the high correlations obtained. However, SPL/Force$_{max}$ was shown to be more accurate than AUX/Force$_{max}$ in determining the changes occurring on the bread with the lapse of time which known as the staling of crust. It has been known that both bread crumb and bread crust are exposed to several changes such as water migration from crumb to crust which has high effect in increasing crust thickness which in turn would highly and rapidly affect bread crust crispness. SPL/Force$_{max}$ as presented in Figure 4.2 could follow and present these changes as two separate lines. AUX/Force$_{max}$ was more accurate in determining the level of crust crispness at different time points. Regardless the staling of bread crust, some types of bread that contain additives ingredients at age of 24 hours showed to be similar to those baked without additives at age of 4 hours as demonstrated by both by AUX/Force$_{max}$ and sensory analysis. AUX/Force$_{max}$ showed to be able express the level of crust crispness more efficiently than SPL/Force$_{max}$ does. This finding was confirmed both at the current chapter and with those conducted to assess the effect of selected additives content on bread crust crispness and crumb firmness as presented in chapter 3.

Chapter 5: General discussion, conclusion and future recommendation

Bread crust crispness is one of the most important sensory attributes on which consumers base their appreciation of different types of bread. However, a rapid loss of sensory crispness is inevitable because of water migrating from wet crumb to the dry crust (Luyten, Plijter et al. 2004). High quality of fresh bread is characterized by a soft moist crumb, and a dry outer crust, which is crispy. Bread crust is considered as crispy if it shows consecutive break and sound release under low force (Luyten, Plijter et al. 2004, van Vliet, Visser et al. 2007, Primo-Martin, Szer et al. 2009). After baking, the crust water content is very low, giving a crispy facture. However, water migration between crumb, crust, and surrounding air increases the water content of the crust. This rapid increase of the water content leads to a fast loss of crispness. Although sensory analysis gives a more complete description of the crust of tested bread, there has been a great interesting in developing instrumental techniques to assess bread crust crispness. Instrumental techniques provide some advantages, particularly in industrial environments where quick and easy-to-use methods are in great demand and economically more profitable (Roudaut, Dacremont et al. 2002). So far, there is no reliable objective method that can accurately measure and quantify bread crust crispness at different time points in the literature, as far as we are aware. Therefore, it is beneficial to think about the ideal approach which allows determining and tracking the changes occurred within different time points. Such finding would facilitate and help research to extend crispness retention. However, only a few approaches relating to the determination of bread crust crispness have been described so far (Primo-Martin, Pijpekamp et al. 2006, Primo-Martin, Castro-Prada et al. 2008, Primo Martin, Beukelaer et al. 2008). These approaches were reported in detail in chapter 1.

The first stage of this study was aimed at determining which, if any, mechanical and acoustic parameters best characterise bread crust crispness. To achieve this aim five different bread recipes were assessed (Pre-ferment, Overnight sponge, Overnight liquid sponge, Panarome and White bloomer bread (standard)). In this study, the combination between mechanical and acoustic parameters were investigated and used for bread crust crispness evaluation. An acoustic envelop detector (AED) was used to measure the acoustic properties, while a texture analyser was used to measure the mechanical properties of different bread formulae at four different time points 4, 24, 48 and 72 hours post baking. Previous studies on bread crust crispness were conducted mainly either in a single or a short time points (30 min- 5 hours). Studies of the crust crispness within 72 hours after baking have not previously been discussed, as far as we are aware.

In the current study, it has been found that the number of sound peaks and the sound pressure level (intensity) evaluated during crust measurement relate to crispness attributes. If these two parameters are higher, the product is also rated as crispier by sensory analysis (Chen, Karlsson et al. 2005, Castro-Prada, Luyten et al. 2007, Varela, Aguilera et al. 2008). Therefore these two parameters were measured during fracture at four time points (4, 24, 48 and 72 hours). Also it has been found that high maximum force suggests a leathery crust, this observation was also confirmed by the sensory panel where crispness ranking agrees well with the ranking from instrumental test results.

This study showed that crisper bread produced a greater sound peaks and a greater sound pressure level. Bread was considered crispy when only a high level of failure force is needed for initial crack and a low level of maximum force was necessary for entire fracture for a certain distance. Therefore maximum force was found to be a major factor in the discrimination of crispness of bread. The combination between mechanical and acoustic parameters in this study revealed that the ratio of both sound pressure level (SPL) and Number of sound peaks (AUX) with Maximum force ($\text{Force}_{\text{max}}$) can reliably be used as an indicator of bread crust crispness, as demonstrated by the high correlation obtained with sensory analysis as shown in chapter 2.

The current study showed that the crust moisture content increased as bread ages, due to water absorption from the atmosphere and by mass transport from neighbouring components of the crumb (Katz and Labuza 1981). It can be concluded that although factors like water content play a significant role either on bread crumb softness or crust crispness, other ingredients such as preferment, panarome liquid, greatly influenced the water migration through the crumb to the crust. However the actual influences of these ingredients on crust crispness retain remain unclear. The highest crust crispness and crumb softness were observed for preferment and panarome bread, likely due to the presence of preferment and panarome liquid in their formulation.

In general, overnight sponge and overnight liquid sponge recipes did not show significant differences from White bloomer bread (Control) regarding crust crispness at the four different time points. The bread crumb for preferment and panarome formulae firmed at a slower rate than did the bread either with different types of sponge or the control bread.

The slower firming rate and the lower final firmness for preferment and panarome liquid bread may attribute to their recipes. Both experimental parameters showed high capability to determine bread crust crispness as demonstrated by their correlation with sensory analysis, therefore both of them were adopted to measure crust crispness of different recipes treated with five different additives. The purpose of that was to validate their capability in determining crust crispness and also to recognise which of them are more accurate in determining bread crust crispness.

Referring back to the original hypothesis set out for stage 1, that the combination of the stable MicroSystems Texture Analyser (TA-XT plus) with an Acoustic Envelope Detector (AED) technique could reliably quantify crispness of bread crust supported by a much softer and moist crumb. And referring back to the original aims set out in section 1.6.1, it can be concluded that:

- The combination of acoustic recording with mechanical tests results in a more controlled and objective way of analysing sound emission and allows the extraction of a number of parameters for correlating to sensory measurements. The results of the current study suggest that the combination of the acoustical and mechanical measurements might predict better the crust crispness of bread crust (aim 1).
- Mechanical and acoustic parameters as measured by using Texture Analyser along with an AED were correlated highly with each other as well as with sensory analysis as shown in Table 2.6 and 2.7. The relationship between sensory crust crispness and instrumental parameters suggests that both SPL/Force$_{max}$ and AUX/Force$_{max}$ parameters can be used to measure and explain sensory crispness in bread crust. The former and latter had high correlation with sensory crispness at two time points (4 and 24 hours after baking) respectively $R^2 = 0.88$, $P = 0.052$- $R^2 = 0.90$, $P = 0.036$ and $R^2 = 0.80$, $P = 0.116$- $R^2 = 0.93$, $P= 0.024$.

- This indicates that sensory crispness could be reasonably well predicted by the both experimental parameters (aim 2).

In the last few years, the price of bread has continuously increased; however, its shelf-life is still limited due to the alterations in its properties which leading to loss of its crumb freshness and crust crispness and therefore effect on its desirability by consumers. These changes can be summarized in a single word, “staling”. Delaying such phenomenon is the biggest target for most of industrial and academic researchers. As previously illustrated in the literature review (Chapter 2) that the mechanism of bread staling is still ambiguous. Several views have been proposed with very few concrete conclusions for the staling of bread. It is not clear yet, which components of the bread, e.g., ingredient composition and water content, determine the rate of this process. In the second stage of this work (chapter 3) we focused on the effect of different types of additives influencing bread properties, especially on the crispness of the crust.

The hypotheses of this stage were, the treatment of bread dough by selected additives such as alginates, polysaccharides, dietary fibre and emulsifier would help to prevent or delay the migration of water from the wet core to the dry crust due to their high capacity to hold water, and, therefore bread crust will retain its crispness for longer. The second hypothesis was that the using of both experimental updated parameters from stage one would successful detect crust crispness of different bread formulae and could reflect the changes caused by adding different amounts of additives ingredients.

To test these hypotheses five different additives ingredients; polydextrose, sodium alginate, enzymes dough conditioner, mono & di-glycerides and citrus fibre were added in three different ratios into bread dough. Some of these ingredients such as EDC and mono & di-glycerides were chosen due to their known positive effect on bread crumb softness and crust crispness. Sodium alginate and polydextrose were chosen due their highly water holding capacity. The former belongs only to hydrocolloidal group while the later was considered as hydrocolloid and dietary fibre as well. Citrus fiber was mainly chosen due its ability to extend bread shelf-life, absorbing water and for its potential to increase dietary fibre intake. A significant enhancement was observed in both crust crispness and crumb softness when polydextrose added in ratio of 1%. The ratios above 1% polydextrose had a negative effect on both properties comparing with Control bread. Similar effects were found when sodium alginate was added in ratio of 0.25%, however the ratio over 0.25% showed comparable results to the Control bread.

In the ratio of 1% enzymes dough conditioner (EDC) as a function of alpha amylase was found to be effective in reducing firmness and improving crust crispness compared with control bread at the two different measurement time points. It was also observed the addition of EDC in ratios more than 1% produced slightly sticky, softer dough, while the ratio of 1% produced slightly dry, firmer dough. For mono & di-glycerides and citrus fiber, the results showed that their effects on crust crispness were not significantly different from control bread; however their effect on bread crumb softness was opposite to each other. Bread crumb softness was shown to be softer as the amount of mono & di-glycerides increased, while it was shown to be harder as the amount of citrus fiber increase.

Referring back to the original hypothesis set out for stage 2 that the updated approach would be able to quantify bread crust crispness of different bread formulae treated with the different ratios of additive ingredients. And according to the aims set out in section 1.6, it can be concluded that:

- Both updated parameters SPL/force$_{max}$ and AUX/Force$_{max}$ clearly reflect sensory measures, as demonstrated by the high correlations obtained during using both updated parameters to determine the effect of different modified ingredients on bread crust crispness as illustrated in chapter 3 (aim 3).
- Considering the effectiveness of adding hydrocolloids on both crust crispness and crumb softness, it was observed both characteristics were significantly enhanced compared with the control bread when 1% of polydextrose and 0.25% sodium alginate were added to the bread dough (aim 4).
- No effect of emulsifier treatment on bread crust crispness nor for the addition of citrus fiber (dietary fibre), however the crumb was shown to be softer as the amount of mono & di-glycerides increased while the crumb was shown to be harder as the amount citrus fiber increase .
- Enzymes dough conditioner (EDC) at three different amounts had a positive effect on bread crust crispness; however bread crumb was shown to be stickier in ratios more than 1% which resulted in difficulty in the handling process.
- Finally, it can be concluded that the results obtained both from stage one and two of the current work supported the hypotheses initially mentioned in this chapter.

Finally, the current study revealed that SPL/Force$_{max}$ and AUX/Force$_{max}$ clearly reflected sensory measures, and could reliably be used for determination of bread crust crispness either for samples baked at a similar or at separate times as demonstrated in chapter 4. SPL/Force$_{max}$ was shown to be more accurate than the AUX/Force$_{max}$ in determining the changes occurred in the bread which known as staling of crust, however AUX/Force$_{max}$ appeared to be more relevant to determine the level of crust crispness as revealed by results obtained from different experiments conducted in chapter 3.we do recommend using both of the experimental parameters to provide strength to the results obtained.

5.1 Recommendation and Future work

Further research is necessary regarding the effects of polydextrose, sodium alginate and EDC to determine the optimal amount of these ingredients to ensure a better crispy product. More attention should be paid to study the morphology of bread due to its important role in water uptake also for the perception of crispness by using relative techniques such as Coarsening in Solid Liquid Mixtures (CSLM), X-ray and mercury porosimetry to measure the porosity. Further research on the analysis of the water uptake curves, the effect of experimental times for measurement and the different processes going in bread crust during water uptake could be useful to better understand the water migration mechanism. Further work on SPL/Force$_{max}$ and AUX/Force$_{max}$ is needed to precisely identify the proper using of both experimental parameters in either the quantification of crispness level or in determining the rate of staling of the bread.

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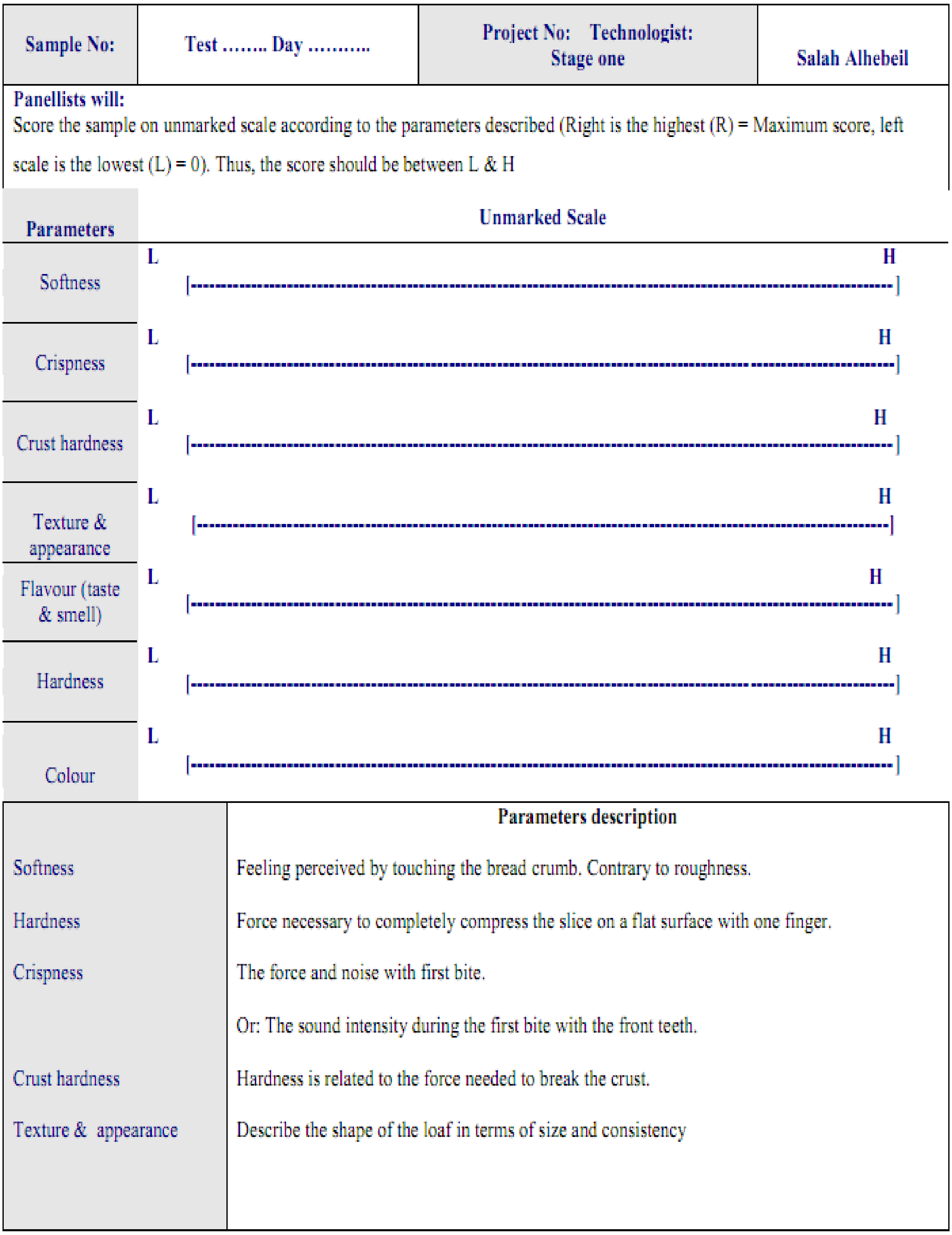
Chapter 7 Appendixes

Appendix 1 (Chapter 2)

Table 7.1 Sensory analysis form used to evaluate 5 different bread formulae at stage 1



Sample No:	**Test …….. Day ………..**	**Project No: Technologist:** **Stage one**	**Salah Alhebeil**

Panellists will:
Score the sample on unmarked scale according to the parameters described (Right is the highest (R) = Maximum score, left scale is the lowest (L) = 0). Thus, the score should be between L & H

Parameters	**Unmarked Scale**
Softness	**L** **H** |---|
Crispness	**L** **H** |---|
Crust hardness	**L** **H** |---|
Texture & appearance	**L** **H** |---|
Flavour (taste & smell)	**L** **H** |---|
Hardness	**L** **H** |---|
Colour	**L** **H** |---|

	Parameters description
Softness	Feeling perceived by touching the bread crumb. Contrary to roughness.
Hardness	Force necessary to completely compress the slice on a flat surface with one finger.
Crispness	The force and noise with first bite. Or: The sound intensity during the first bite with the front teeth.
Crust hardness	Hardness is related to the force needed to break the crust.
Texture & appearance	Describe the shape of the loaf in terms of size and consistency

Appendix 2 (Chapter 2)

Table 7.2 Mean values ± SE and the main effect and interaction of the sensory parameters extracted from sensory evaluation for five different bread recipes at 4 and 24 hours after baking

Recipes		Time (hours)	Main effect		Interaction	Time (hours)	Main effect		Interaction
Recipe		48.00	Recipe	Panel	Recipe*Panel	72.00	Recipe	Panel	Recipe*Panel
O.N.L.Sponge	S.C.F	12.4±0.25b	<0.001	0.072	0.071	14.8±0.12a	0.012	0.153	0.672
O.N.Sponge		12.5±0.21b				14.5±0.19ab			
Panarome		12.2±0.26b				14.5±0.13b			
Pre-ferment		12.0±0.18b				14.4±0.24b			
White bloomer		14.4±0.11a				14.7±0.18ab			
Mean All		12.7				14.6			
O.N.L.Sponge	S.C.C	3.1±0.14b	0.006	0.999	0.289	1.2±0.24a	0.156	0.672	0.975
O.N.Sponge		3.3±0.15b				1.3±0.11a			
Panarome		3.2±0.17b				1.2±0.21a			
Pre-ferment		3.8±0.13a				1.4±0.15a			
White bloomer		3.2±0.13b				1.1±0.13a			
Mean All		3.3				1.3			
O.N.L.Sponge	S.C.H	11.8±0.23a	0.396	0.466	0.013	14.9±0.23	0.013	0.649	0.929
O.N.Sponge		11.6±0.32a				14.8±0.25			
Panarome		11.6±0.16a				14.5±0.16			
Pre-ferment		11.2±0.27a				14.5±0.13			
White bloomer		11.7±0.19a				14.6±0.28			
Mean All		11.6				14.7			

Table 7.3 Mean values of the instrumental parameters ± SE extracted from the force/distance curve for five different bread formulae.

	Mechanical and acoustic parameters									
		Acoustic parameters		Mechanical parameters					Instrumental Crispness parameters	
Treatments	Time (hr)	No of sound peaks (AUX)	SPL (dB)	Area (Kg.mm)	Force peaks	Force $_{Max}$ (kg)	F. Failure kg	Firmness (g)	SPL/Force	AUX/Force
O.N.L.Sponge	48	119.4±1.8b	81.7±0.49ab	65.1±1.4b	14.3±0.55a	3.6±0.16b	3.114±0.0061ab	539±10.6a	22.8±0.44bc	33.3±0.74c
O.N.Sponge		130.6±2.7a	82.0±0.32ab	65.6±2.1b	13.7±0.74a	3.8±0.12ab	3.113±0.0025ab	468±9.4b	22.1±0.63bc	35.4±1.6bc
Panarome		126.6±3.1ab	81.1±0.47bc	56.1±3.4c	12.1±0.62a	3.3±0.16bc	3.131±0.0069a	429±10.4c	25.8±1.7ab	40.5±2.9ab
Pre-ferment		129.3±1.2a	83.15±0.46a	56.0±2.0c	13.2±0.63a	3.1±0.12c	3.129±0.00267a	422±5.1c	27.4±1.1a	42.7±2.0a
White bloomer		104.7±1.6c	79.9±0.36c	78.1±1.5a	12.7±0.89a	4.2±0.12a	3.104±0.0069b	423±7.0c	19.1±0.47c	25.1±0.72d
Mean All		122.1	81.6	64.2	13.2	3.6	3.118	456	23.5	35.4
Significance		< 0.001	< 0.001	< 0.001	0.201	< 0.001	0.002	< 0.001	< 0.001	< 0.001
O.N.L.Sponge	72	124.7±3.80ab	81.7±0.49ab	82.4±3.2b	14.1±0.90a	4.53±0.17ab	4.126±0.0059ab	682.9±10.1a	18.3±0.71ab	28±1.17b
O.N.Sponge		118.1±3.06bc	82.0±0.32ab	80.1±5.1bc	14.7±0.47a	4.65±0.26ab	4.125±0.0028ab	520±11.2b	18.5±1.1ab	26.5±1.63b
Panarome		111.3±2.52c	81.1±0.47bc	65.0±5.3c	13.5±0.53a	4.16±0.28b	4.143±0.0069a	521±13.5b	20.9±1.6a	28.4±1.76b
Pre-ferment		131.4±1.45a	83.15±0.46a	67.6±3.1bc	14.3±0.37a	3.89±0.14b	4.142±0.0027a	456±5.9c	22.1±0.87a	34.5±1.50a
White bloomer		119.3±2.21bc	79.9±0.36c	100.0±2.9a	14.3±0.37a	5.29±0.12a	4.116±0.0068b	524±9.0b	15.6±1.54	22.8±0.79b
Mean All		120.99	81.6	79	17.177	4.5	4.131	541	19	28
Significance		< 0.001	< 0.001	< 0.001	0.814	< 0.001	0.0010	< 0.001	< 0.001	< 0.001

Table 7.4 (A) Mean values of the instrumental parameters and CV% extracted from the force/distance curve for five different bread formulae of trial 2.

Treatments	Time	AUX	SD	C.V%	SPL (dB)	SD	C.V%	Area	SD	C.V%
O.N.L.Sponge	4	47.5±1.5b	4.79	10.08	76.4±1.21a	3.91	5.11	23.6±1.21a	3.68	15.57
O.N.Sponge		44.5±1.9b	5.85	13.16	76.6±0.71a	2.21	2.88	25.3±1.92a	6.08	24.05
Panarome		57.3±1.3a	57.3	5.76	76.6±0.81a	2.47	3.23	22.1±1.54ab	4.87	22.1
Pre-ferment		56.9±0.67a	56.9	3.75	76.2±0.72a	2.28	2.99	17.9±1.41b	4.32	24.11
White bloomer		49.2±2.0b	49.2	12.63	71.1±1.4b	4.48	6.32	25.4±0.52a	1.66	6.51
Mean All		51.1		9.076	75.4		4.106	22.86		18.468
Significance		< 0.001			0.001			0.002		
O.N.L.Sponge	24	101.6±1.94b	6.13	6.04	80.2±0.47b	1.48	1.84	50.9±1.65ab	5.2	10.22
O.N.Sponge		99.3±1.11b	3.16	3.19	81.1±0.49b	1.56	1.92	44.8±1.28c	4.04	9.03
Panarome		113.1±2.09a	6.62	5.86	79.9±0.58b	1.82	2.28	45.0±1.31bc	4.15	9.22
Pre-ferment		115.6±1.28a	4.03	3.49	83.5±0.44a	1.4	1.68	43.5±1.44c	4.55	10.44
White bloomer		105.5±2.53b	8.00	7.59	79.6±0.53b	1.69	2.11	51.4±1.75a	5.52	10.74
Mean All		107.02		5.234	80.9		1.966	47.14		9.93
Significance		< 0.001			< 0.001			< 0.001		
O.N.L.Sponge	48	118.9±1.62ab	5.11	4.30	81.8±0.61ab	1.93	2.36	64.7±1.80ab	5.69	8.80
O.N.Sponge		129.7±3.64a	11.51	8.87	82.4±0.43a	1.35	1.63	66.6±2.84ab	9.00	13.51
Panarome		125.3±4.14a	13.11	10.46	80.7±0.73ab	2.31	2.86	56.7±3.82b	12.07	21.28
Pre-ferment		129.3±1.64a	5.19	4.01	82.9±0.54a	1.14	2.09	56.0±2.51b	7.92	14.15
White bloomer		108.2±1.41b	4.47	4.13	80.0±0.48b	1.52	1.89	69.5±2.11a	6.68	9.61
Mean All		122.28		6.354	81.55		2.166	62.69		13.47
Significance		< 0.001			0.004			0.002		
O.N.L.Sponge	72	126.8±1.69a	5.33	4.2	82.2±0.56b	1.76	2.14	83.8±2.76b	8.75	10.43
O.N.Sponge		117.7±3.55ab	11.22	9.53	83.1±0.39ab	1.22	1.47	78.2±6.31b	19.95	25.52
Panarome		113.2±3.10b	9.82	8.67	82..8±0.47b	1.47	1.77	71.55±1.71b	5.41	7.52
Pre-ferment		115.2±2.32b	7.35	6.38	84.7±0.36a	1.14	1.34	78.33±1.24b	3.93	5.01
White bloomer		121.5±2.28ab	7.21	5.94	83.9±0.36ab	1.14	1.35	98.2±1.21a	3.8	3.87
Mean All		118.88		6.944	83.35		1.614	82.1		10.47
Significance		< 0.001			0.002			< 0.001		

Table 7.4 (B) Mean values of the instrumental parameters and CV% extracted from the force/distance curve for five different bread formulae of trial 2.

Treatments	Time	Force peaks	SD	C.V%	Force $_{Max}$	SD	C.V%	F. Failure	SD	C.V%
O.N.L.Sponge	4	7.1±0.38ab	1.19	16.86	1.22±0.014ab	0.0437	3.56	1.18±0.028a	0.0872	7.36
O.N.Sponge		5.8±0.36b	1.14	19.57	1.30±0.041a	0.1307	13.13	1.16±0.016ab	0.0509	4.38
Panarome		8.3±0.26a	0.82	9.92	1.18±0.017ab	0.0542	4.6	1.10±0.013b	0.4	3.64
Pre-ferment		7.3±0.51ab	1.57	21.47	1.12±0.021b	0.0619	5.51	1.11±0.021b	0.0667	6.04
White bloomer		6.3±0.37b	1.16	18.4	1.24±0.078ab	0.2449	19.69	1.10±0.012b	0.0384	3.53
Mean All		6.96		17.244	1.21		9.298	1.13		4.99
Significance		< 0.001			0.021			0.002		
O.N.L.Sponge	24	10.4±0.37bc	1.17	11.29	2.7±0.117a	0.37	13.83	2.11±0.011a	0.0335	1.59
O.N.Sponge		10.5±0.31bc	0.97	9.26	2.5±0.077a	0.242	9.81	2.11±0.021a	0.0674	3.20
Panarome		11.9±0.43a	1.37	11.52	2.4±0.072ab	0.226	9.49	2.13±0.012a	0.0365	1.72
Pre-ferment		11.5±0.27ab	0.85	11.52	2.1±0.026b	0.083	3.93	2.14±0.011a	0.0285	1.33
White bloomer		9.3±0.34c	1.06	11.39	2.6±0.082a	0.259	10.01	2.09±0.012a	0.0366	1.75
Mean All		10.72		10.996	2.45		9.414	2.12		1.918
Significance		< 0.001			< 0.001			0.131		
O.N.L.Sponge	48	13.9±0.38a	1.20	8.61	3.6±0.071bc	0.221	6.15	3.11±0.014a	0.0446	1.43
O.N.Sponge		14.1±1.03a	3.25	23.03	3.8±0.149ab	0.47	12.33	3.12±0.016a	0.0494	1.58
Panarome		12.4±0.67a	2.17	17.50	3.3±0.187bc	0.593	17.83	3.15±0.009a	0.0285	0.90
Pre-ferment		13.9±0.53a	1.66	11.97	3.2±0.155c	0.491	15.55	3.14±0.003a	0.0108	0.34
White bloomer		12.7±1.04a	3.30	26.00	4.3±0.168a	0.53	12.27	3.11±0.005a	0.0167	0.54
Mean All		13.4		17.422	3.64		12.826	3.13		0.958
Significance		0.407			< 0.001			0.055		
O.N.L.Sponge	72	14.2±1.05a	3.33	23.43	4.7±0.157ab	0.497	10.48	4.2±0.016a	0.0517	1.25
O.N.Sponge		15.3±0.76a	2.41	15.73	4.6±0.297bc	0.939	20.00	4.1±0.010a	0.0319	0.77
Panarome		13.8±0.66a	2.10	15.2	4.2±0.111bc	0.351	8.37	4.2±0.010a	0.0321	0.77
Pre-ferment		14.5±0.50a	1.58	10.9	4.0±0.079c	0.253	6.30	4.2±0.009a	0.0272	0.66
White bloomer		14.1±0.51a	1.60	11.31	5.367±0.173a	0.548	10.22	4.1±0.008a	0.0247	0.6
Mean All		14.38		15.314	4.59		11.074	4.15		0.81
Significance		0.649			< 0.001			0.820		

Table 7.4 (C) Mean values of the instrumental parameters and CV% extracted from the force/distance curve for five different bread formulae of trial 2.

Treatments	Time	Firmness	SD	C.V%	SPL/Force	SD	C.V%	AUX/Force	SD	C.V%
O.N.L.Sponge	4	208±3.1a	9.9	4.76	62.4±1.49ab	4.72	7.65	38.8±1.3b	4.11	10.6
O.N.Sponge		202±4.4ab	13.94	6.9	60.0±2.33ab	7.36	12.27	34.8±1.77b	5.61	16.13
Panarome		192±1.9b	5.87	3.06	65.1±1.07ab	3.37	5.18	48.7±1.11a	3.52	7.23
Pre-ferment		173±5.9c	18.67	10.82	68.1±1.37a	4.32	6.34	50.9±1.28a	4.05	7.97
White bloomer		213±1.6a	5.12	2.4	59.1±3.87b	12.25	20.75	40.8±2.65b	8.37	20.49
Mean All		198		5.588	62.94		10.438	42.8		12.484
Significance		< 0.001			0.039			< 0.001		
O.N.L.Sponge	24	375±8.1a	25.38	6.79	30.4±1.17b	3.69	12.16	38.4±1.31c	4.15	10.82
O.N.Sponge		367±6.6ab	20.89	5.69	33.2±1.10b	3.49	10.53	40.6±1.38c	4.35	10.71
Panarome		335±5.2bc	16.49	4.93	33.8±1.06b	3.36	9.94	47.7±1.58b	4.99	10.45
Pre-ferment		307±6.7d	21.31	6.93	39.5±0.61a	1.91	4.83	54.6±1.13a	3.57	6.56
White bloomer		344±6.3bc	19.81	5.75	31.1±0.91b	2.88	9.26	41.2±1.74c	5.49	13.32
Mean All		346		6.018	33.57		9.344	44.52		10.372
Significance		< 0.001			< 0.001			< 0.001		
O.N.L.Sponge	48	490±5.75a	18.2	3.72	22.9±0.55abc	1.74	7.59	33.3±0.82ab	2.59	7.77
O.N.Sponge		471±7.39ab	23.38	4.94	21.9±0.31bc	2.57	11.74	34.7±2.18a	6.91	19.88
Panarome		425±13.5c	42.7	10.06	25.2±1.89ab	5.98	23.77	39.3±3.39a	10.71	27.27
Pre-ferment		430±5.13c	16.21	3.77	26.9±1.35a	4.28	15.92	42.1±2.45a	7.75	18.43
White bloomer		440±3.85bc	12.19	2.77	18.7±0.64c	2.01	10.73	25.3±0.95b	3.01	11.86
Mean All		451		5.052	23.12		13.95	34.9		17.042
Significance		< 0.001			< 0.001			< 0.001		
O.N.L.Sponge	72	681±10.6a	33.5	4.91	17.5±0.55bc	1.74	9.94	27.0±1.01ab	3.19	11.8
O.N.Sponge		527±13.6b	42.9	8.13	18.7±1.12ab	3.55	18.97	26.5±1.86ab	5.88	22.17
Panarome		512±15.9b	50.3	9.82	19.9±0.53ab	1.69	8.49	27.0±0.68ab	2.14	7.91
Pre-ferment		461±6.93c	21.92	4.75	21.2±0.44a	1.38	6.53	28.8±0.76a	2.41	8.38
White bloomer		527±10.3b	32.5	6.17	15.8±0.52c	1.64	10.44	22.8±0.54b	2.64	11.57
Mean All		541.8		6.756	18.6		10.874	26.44		12.366
Significance		< 0.001			< 0.001			0.009		

Table 7.4 (D) the correlations between sensory and instrumental parameters at 24 and 72 hours post baking

		S.C.F	*S.C.C*	*S.C.H*	*AUX*	*SPL*	*F. peaks*	*Area*	*F.max*	*F.Fauilar*	*I.C.F*	*SPL/Force*	*AUX/Force*
S.C.C	48	-0.496											
S.C.H		0.914	-0.208										
AUX		0.021	0.544	0.019									
SPL		-0.554	0.696	-0.563	0.771								
F. peaks		0.484	0.300	0.503	0.441	0.234							
Area		0.742	-0.686	0.429	-0.021	-0.290	0.449						
F.max		0.707	-0.776	0.419	-0.293	-0.481	0.352	0.960					
F.Fauilar		-0.778	0.695	-0.490	0.096	0.372	-0.466	-0.993	-0.978				
I.C.F		0.752	-0.460	0.761	-0.018	-0.625	-0.097	0.280	0.249	-0.304			
SPL/Force		-0.803	0.768	-0.540	0.250	0.529	-0.380	-0.962	-0.989	0.984	-0.375		
AUX/Forc		-0.631	0.859	-0.404	0.605	0.727	-0.121	-0.804	-0.934	0.849	-0.294	0.921	
S.C.C	72	-0.336											
S.C.H		0.457	-0.973										
AUX		-0.911	0.416	-0.535									
SPL		-0.819	0.697	-0.700	0.813								
F. peaks		-0.221	-0.090	0.227	0.156	0.443							
Area		0.937	-0.456	0.611	-0.848	-0.721	0.111						
F.max		0.910	-0.556	0.683	-0.784	-0.766	0.074	0.982					
F.Fauilar		-0.791	0.555	-0.717	0.713	0.596	-0.366	-0.954	-0.954				
I.C.F		-0.233	-0.538	0.596	0.036	0.129	0.826	0.072	0.082	-0.335			
SPL/Force		-0.865	0.622	-0.750	0.761	0.747	-0.159	-0.970	-0.993	0.974	-0.195		
AUX/Forc		-0.920	0.576	-0.717	0.888	0.786	-0.105	-0.985	-0.972	0.949	-0.163	0.972	

Appendix 3 (Chapter 3)

Table 7.5 Composition of enzyme dough conditioner (EDC)

EDC Composition		
Description:	%	Details:
Calcium Sulphate	35-45	Yeast food
Wheat Flour	30-40	
Emulsifier E481	5-15	Sodium estroyl 1-2 lactate
Vegetable Fat (containing carriers; Glucose Syrup, Pea Protein and Anti-Caking Agent E551)	5-15	
Flour Treatment Agent E300	< 3	Ascorbic acid
Enzymes	< 3	α Amylase
Wheat Starch (containing Sunflower Oil)	< 3	Added as dust suppressant

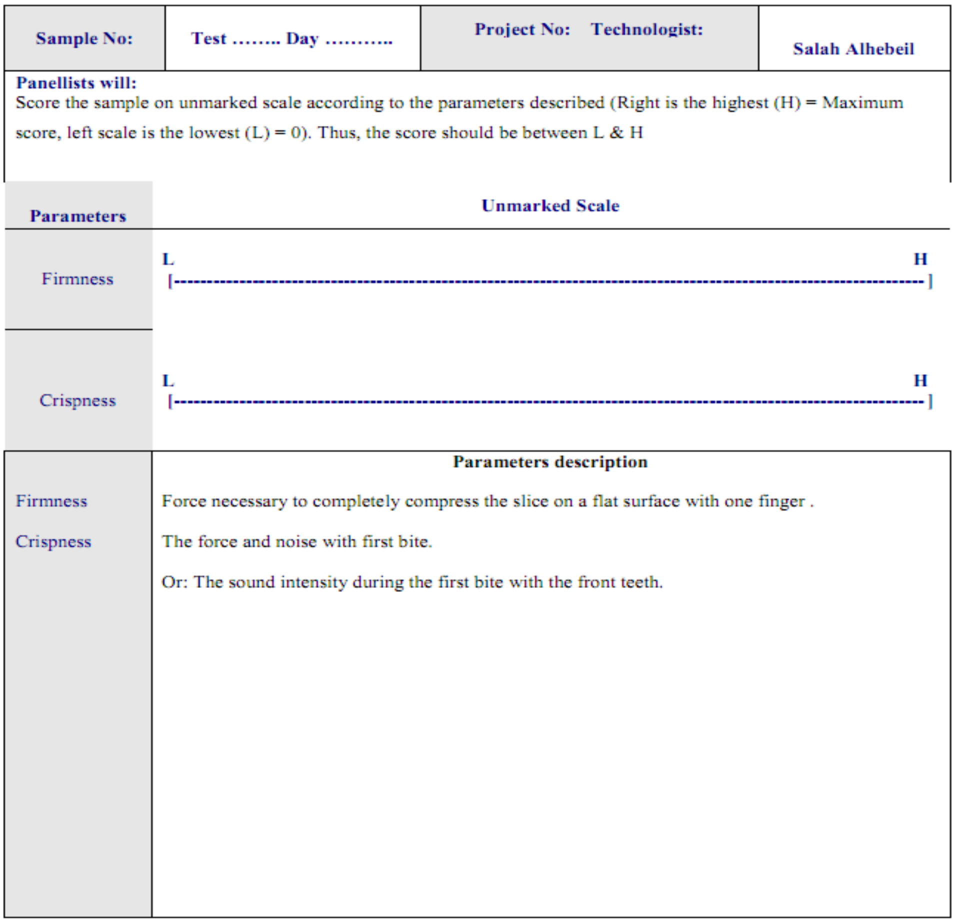
Table 7.6 Nutritional information and chemical composition of Mono & Di-Glycerides of Fatty Acids

NUTRITIONAL GROUP	PER 100g / 100ml
Energy (kJ)	3756.2
Energy (kcal)	894.3
Protein	0
Total Carbohydrate	0
- Sugar	
- Starch	
Total Fat	99.3
- Saturated	10.42
- Monounsaturated	61.56
- Polyunsaturated	27.48
- Trans Fatty Acids	
Salt	0
Sodium	0
Ash	0
Moisture	0.09
Dietary Fibre	0
Alcohol	0

Table 7.7 Nutritional information and chemical composition of citrus fibre

Nutritional group	PER 100g / 100ml
Energy (kJ)	908.5
Energy (kcal)	217
Protein	8.18 %
Total carbohydrate	81.3
Sugar	5.4
Total fat	1
Salt	0
Sodium	18.5 mg
Ash	2.7
Moisture	6.8
Dietary Fibre	70.8
Moisture level	8.90%

Table 7.8 Sensory analysis form used to evaluate the effect of ingredients additives on sensory at stage 2



Sample No:	**Test …….. Day ………..**	**Project No: Technologist:**	**Salah Alhebeil**

Panellists will:
Score the sample on unmarked scale according to the parameters described (Right is the highest (H) = Maximum score, left scale is the lowest (L) = 0). Thus, the score should be between L & H

Parameters	**Unmarked Scale**
Firmness	**L** **H** [---]
Crispness	**L** **H** [---]

	Parameters description
Firmness	Force necessary to completely compress the slice on a flat surface with one finger .
Crispness	The force and noise with first bite. Or: The sound intensity during the first bite with the front teeth.

Appendix 3 (Chapter 3)

Table 7.9 Mean values ±SE of mechanical and acoustic parameters extracted from bread made with polydextrose comparison with Control

Recipes	Trial	Time (hr)	No of sound peaks	No of Force peaks	Sound Pressure level (SPL)	Force Max	F. Failure	Crumb Firmness	SPL/Force	AUX/Force
Control	1.00	4.00	83.1±2.8a	8.3±0.4a	85.3±0.4a	1.4±0.02a	1.084±0.005a	192±8b	61.2±1.1ab	59.7±2.3b
Polydextrose 1%			86.8±2.5a	8.4±0.3a	86.0±0.3a	1.3±0.05a	1.086±0.017a	169±8b	68.2±3.2a	68.8±3.7a
Polydextrose 2%			42.6±1.4b	4.0±0.3b	81.9±0.9ab	1.4±0.03a	1.04±0.003b	258±8a	57.1±1.1b	29.8±1.3c
Polydextrose 3%			39.31.0b	3.4±0.2b	79.7±2.1b	1.40±.04a	1.035±0.004b	260±11a	57.0±2.1b	28.2±1.2c
Mean All			63.0	6.0	83.2	1.40	1.1	220	60.9	46.6
Control	2.00	4.00	65.3±2.4a	6.0±0.3a	84.8±0.5a	1.1±0.03ab	1.065±0.003a	169±3c	75.7±2.1a	58.4±2.7a
Polydextrose %1			69.4±3.0a	6.8±0.3a	84.8±0.3a	1.1±0.02b	1.07±0.004a	157±3c	79.8±1.2a	63.8±2.1a
Polydextrose %2			36.8±4.9b	3.7±0.5b	82.7±0.7a	1.2±0.02a	1.039±0.006b	209±4b	67.2±2.4b	28.9±3.0b
Polydextrose %3			20.7±1.0c	2.2±0.1c	74.1±2.2b	1.2±0.03a	1.019±0.004c	252±5a	60.4±2.6b	17.0±1.3c
Mean All			48.1	4.7	81.6	1.2	1.048	197.0	70.8	42.0
Control	1.00	24.00	94.8±5.1b	11.4±0.3a	85.6±0.2a	2.7±0.1ab	2.122±0.004a	308±8b	32.1±1.2b	36.0±3.0b
Polydextrose %1			108.5±1.6a	11.5±0.2a	86.4±0.4a	2.3±0.1b	2.124±0.003a	269±12c	37.9±0.9a	47.6±1.3a
Polydextrose %2			73.9±0.7c	7.6±0.4b	85.1±0.4a	2.9±0.1a	2.076±0.005b	389±6a	29.8±0.8b	25.9±0.8c
Polydextrose %3			71.0±1.9c	6.8±0.4b	85.8±0.7a	3.1±0.2a	2.072±0.004b	417±8a	28.7±1.7b	23.8±1.7c
Control	2.00	24.00	107.5±5.1a	10.9±0.5a	86.4±0.4a	2.2±0.1b	2.11±a0.005	301±7c	39.7±2.1a	49.3±3.2a
Polydextrose %1			106.4±4.0a	10.6±0.4a	87.2±0.4a	2.0±0.1b	2.11±0.004a	275±7c	44.6±2.1a	54.1±2.9a
Polydextrose %2			99.2±4.8a	9.7±0.5a	85.3±0.6ab	2.7±0.1a	2.102±0.005a	333±10b	32.2±1.3b	37.5±2.4b
Polydextrose %3			69.7±3.2b	6.9±0.3b	84.3±0.6b	2.8±0.1a	2.07±0.004b	440±7a	30.5±1.2b	25.1±1.3c
Mean All			95.7	9.5	85.8	2.4	2.1	337	36.8	41.5

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)

Table 7.10 Mean values ±SE of mechanical and acoustic parameters extracted from bread made with sodium alginate comparison with Control

Recipes	Trial	Time (hr)	No of sound peaks	No of Force peaks	Sound Pressure level (SPL)	Force Max	F. Failure	Crumb Firmness	SPL/Force	AUX/Force
Control	1.00	4.00	64.7±4.4a	5.7±0.49ab	83.2±1.1a	1.2±0.03b	1.12±0.056a	188±7ab	67.3±1.7ab	52.6±4.1ab
Alginate 0.25%			56.6±4.6a	5.6±0.45b	84.3±0.9a	1.2±0.03ab	1.06±0.004a	166±4bc	69.0±2.3ab	46.1±3.8b
Alginate 0.50%			56.9±5.1a	5.7±0.49ab	84.2±1.0a	1.4±0.05a	1.06±0.005a	204±6a	62.7±2.2b	41.36±3.0b
Alginate 0.75%			74.8±5.9a	7.6±0.64a	83.7±0.6a	1.2±0.05ab	1.084±0.006a	148±4c	71.9±3.2a	63.7±5.3a
Mean All			63.3	6.2	83.9	1.3	51.0	177	67.7	51.0
Control	2.00	4.00	57.0±3.3b	5.7±0.4b	85.5±1.4a	1.4±0.05a	1.064±0.004b	205±7a	63.7±2.2b	41.6±2.5b
Alginate 0.25%			87.2±4.4a	8.9±0.5a	85.7±0.6a	1.2±0.04b	1.11±0.005a	152±3c	74.9±2.9a	75.2±3.8a
Alginate 0.50%			61.9±3.6b	6.3±0.4b	85.1±0.6a	1.3±0.03ab	1.07±0.004b	176±4b	68.0±1.7ab	49.5±3.2b
Alginate 0.75%			58.7±4.6b	5.9±0.5b	85.5±1.1a	1.2±0.04ab	1.067±0.006b	180±4b	69.3±2.2ab	47.3±3.7b
Mean All			66.2	6.7	85.4	1.3	53.4	178	69.0	53.4
Control	1.00	24.00	107.6±3.1a	10.8±0.34a	86.2±0.4a	2.7±0.16a	2.11±0.004a	301±9a	31.9±1.1b	39.8±1.8a
Alginate 0.25%			111.7±3.8a	11.3±0.40a	86.3±0.3a	2.5±0.15ab	2.12±0.004a	243±11b	35.5±0.9ab	45.9±1.7a
Alginate 0.50%			100.1±4.5ab	10.0±0.46ab	86.2±0.3a	2.3±0.21b	2.11±0.004ab	292±10a	38.5±1.0a	44.8±2.5a
Alginate 0.75%			89.0±5.5b	8.9±0.53b	83.9±0.8b	2.4b±0.12	2.09±0.005b	240±6b	36.2±1.4a	39.0±3.1a
Mean All			102.1	11.8	85.6	2.5	42.4	269	35.5	42.4
Control	2.00	24.00	108.9±3.0a	11.1±0.3a	87.7±1.3ab	2.7±0.08a	2.11±0.003ab	307±8a	32.0±1.0b	40.3±1.6b
Alginate 0.25%			112.3±3.7a	11.3±0.4a	88.1±1.0a	2.2±0.02b	2.12±0.005a	246±9b	40.1±0.4a	51.1±1.7a
Alginate 0.50%			105.8±3.8a	10.6±0.5a	87.4±0.89ab	2.4±0.04b	2.11±0.005ab	258±9b	37.3±0.7a	45.0±1.5ab
Alginate 0.75%			98.3±6.0a	9.1b±0.6	86.2±0.78b	2.4±0.09b	2.10±0.006b	262±9b	37.0±1.3a	42.6±3.1b
Mean All			106.3	10.5	87.3	2.4	44.7	268	36.7	44.7

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)

Table 7.11 Mean values ±SE of mechanical and acoustic parameters extracted from bread made with EDC comparison with Control

Recipes	Trial	Time (hr)	No of sound peaks	No of Force peaks	Sound Pressure level (SPL)	Force Max	F. Failure	Crumb Firmness	AUX/Force	SPL/Force
Control	1.00	4.00	51.5±3.2b	5.3±0.3b	82.1±0.57a	1.36±0.04a	1.059±0.003a	172±7a	37.7±2.0	61.2±2.2b
EDC 1%			68.7±4.1a	6.8±0.4a	83.3±0.36a	1.19±0.05b	1.07±0.004a	154±4b	58.7±4.1	71.6±3.2a
EDC 2%			61.2±2.3ab	6.1±0.2ab	83.1±0.53a	1.25±0.03ab	1.062±0.002a	151±3b	49.7±2.5	67.2±1.7ab
EDC 3%			56.7±4.6ab	5.6±0.4ab	82.1±0.57a	1.24±0.35ab	1.066±0.004a	148±4b	46.1±3.8	67.1±1.9ab
Mean All			59.5	6.0	82.5	1.3	1.1	156	48.1	66.7
Control	2.00	4.00	57.0±3.3b	5.7±0.5b	83.3±0.43ab	1.36±0.05a	1.07±0.004b	178±6a	42.1±2.4b	62.1±2.2b
EDC 1%			77.3±2.5a	7.6±0.3a	85.0±0.42a	1.12±0.04b	1.09±0.003a	151±4b	67.5±3.3a	74.4±3.1a
EDC 2%			60.7±3.1b	6.0±0.3b	83.3±0.68ab	1.36±0.03ab	1.07±0.004b	144±5b	48.3±2.4b	66.5±1.5ab
EDC 3%			53.1±3.2b	5.1±0.4b	82.0±0.72b	1.25±0.04ab	1.06±0.003b	140±4b	42.7±2.4b	66.4±1.9ab
Mean All			62.0		83.4	1.2	1.1	153	50.1	67.3
Control	1.00	24.00	88.4±4.7b	8.5±0.4b	85.0±0.24a	2.29±0.09a	2.098±0.0043a	295±10a	38.9±2.1	37.8±1.5b
EDC 1%			101.1±2.4a	9.9±0.3a	86.4±0.64a	1.85±0.06b	2.11±0.004a	276±9a	55.2±1.9	47.3±1.6a
EDC 2%			98.0±1.3ab	9.6±0.1a	85.4±0.42a	1.84±0.09b	2.11±0.0034a	275±7a	54.0±1.6	47.2±1.6a
EDC 3%			91.7±1.5ab	9.1±0.2ab	85.4±0.31a	1.86±0.043b	2.096±0.0045a	232±8b	49.6±1.4	46.1±1.1a
Mean All			94.8	9.3	85.6	2.0	2.1	270	49.4	44.6
Control	2.00	24.00	87.9±4.6a	8.7±0.7b	86.02±0.59a	2.25±0.049ab	2.09±0.006a	295±9a	39.2±1.9b	38.5±0.9ab
EDC 1%			96.1±1.9a	9.7±0.2a	86.9±0.37a	2.10±0.06b	2.10±0.004a	270±8ab	46.3±1.9a	41.8±1.4a
EDC 2%			92.5±1.5a	9.2±0.3ab	86.5±0.45a	2.24±0.07ab	2.10±0.005a	269±9ab	41.7±1.2ab	39.0±0.9ab
EDC 3%			89.6±1.4a	9.0±0.4ab	86.8±0.39a	2.36±0.34a	2.09±0.0041a	263±6b	38.1±0.6b	36.9±0.5b
Mean All			91.5	9.2		2.2	2.1	274	41.3	39.0

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)

Table 7.12 Mean values ±SE of mechanical and acoustic parameters extracted from bread made with citrus fibre comparison with Control

Recipes	Trial	Time (hr)	No of sound peaks	No of Force peaks	Sound Pressure level (SPL)	Force Max	F. Fauilar	Crumb Firmness	SPL/Force	AUX/Force
Control	1.00	4.00	59.2±2.5a	5.9±0.26a	80.6±0.63a	1.22±0.012a	1.07±0.004a	167±5c	66.2±1.0a	48.5±1.9a
Citrus fibre 1%			59.8±1.2a	6.0±0.17a	81.1±0.76a	1.23±0.034a	1.07±0.002a	174±2bc	66.4±1.9a	49.1±2.0a
Citrus fibre 2%			62.7±2.6a	6.2±0.28a	81.9±0.56a	1.25±0.028a	1.07±0.003a	181±2ab	66.2±1.7a	50.7±2.5a
Citrus fibre 3%			60.5±3.1a	5.8±0.28a	80.5±0.64a	1.22±0.029a	1.06±0.003a	186±3a	66.4±1.5a	49.9±2.8a
Mean All			60.5	6.0	81.0	1.2	1.1	166	66.3	49.6
Control	2.00	4.00	62.2±3.1a	6.3±0.30a	82.3±0.42a	1.32±0.016a	1.07±0.003a	170±3c	62.4±0.9b	47.1±2.1a
Citrus fibre 1%			60.3±1.9a	6.0±0.17a	81.9±0.31a	1.26±0.014ab	1.09±0.036a	178±2c	65.1±0.6ab	48.1±1.8a
Citrus fibre 2%			59.7±3.2a	5.9±0.32a	81.7±0.74a	1.22±0.019b	1.07±0.003a	193±5b	67.4±1.1a	49.5±3.0a
Citrus fibre 3%			60.7±2.3a	6.0±0.26a	78.5±1.1b	1.24±0.017b	1.06±0.004a	217±5a	63.7±1.4ab	49.1±1.9a
Mean All			60.7	6.1	81.1	1.3	1.1	190	64.5	48.4
Control	1.00	24.00	89.1±1.4a	8.9±0.36a	85.1±0.44bc	2.26±0.065a	2.09±0.005a	296±9c	38.0±1.2ab	40.0±2.4a
Citrus fibre 1%			93.1±4.7a	9.2±0.45a	87.3±0.33a	2.18±0.075a	2.10±0.004a	311±36bc	40.5±1.1a	43.2±a
Citrus fibre 2%			88.6±2.2a	8.9±0.25a	85.7±0.45b	2.29±0.029a	2.09±0.003a	323±5ab	37.6±0.6ab	38.8±a
Citrus fibre 3%			91.5±1.4a	9.0±0.17a	83.86±0.46c	2.35±0.030a	2.10±0.003a	338±2a	35.7±0.5b	38.9±0.6a
Mean All			90.6	9.0	85.5	2.3	2.1	317	38.0	40.2
Control	2.00	24.00	87.7±3.5a	9.2±0.38a	85.9±0.53bc	2.31±0.059a	2.09±0.004a	308±6c	37.6±1.1b	38.6±3.3a
Citrus fibre 1%			89.9±1.5a	9.3±0.21a	88.7±0.39a	2.15±0.032b	2.11±0.0025a	315±4bc	41.4±0.6a	42.1±1.1a
Citrus fibre 2%			93.0±2.0a	9.5±0.19a	86.8±0.46ab	2.30±0.033ab	2.10±0.0023a	327±b	37.9±0.6b	40.7±1.2a
Citrus fibre 3%			90.8±1.9a	9.2±0.22a	84.5±0.65c	2.33±0.032a	2.03±0.066a	346±2a	36.3±0.5b	39.1±2.3a
Mean All			90.4	9.3	86.5	2.3	2.1	323	38.3	40.1

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)

Table 7.13 Mean values ±SE of mechanical and acoustic parameters extracted from bread made with M&D-G comparison with Control

Recipes	Trial	Time (hr)	No of sound peaks	No of Force peaks	Sound Pressure level (SPL)	Force Max	F. failure	Crumb Firmness	SPL/Force	AUX/Force
Control	1.00	4.00	60.9±1.7a	6.3±0.15a	80.3±0.90b	1.18±0.015a	1.07±0.0029a	181±4a	68.1±1.3a	51.6±1.6a
Emulsifier 1%			59.6±1.8a	6.2±0.18a	84.2±0.45a	1.20±0.014a	1.06±0.0045a	171±5ab	70.2±0.9a	49.6±1.3a
Emulsifier 2%			58.1±1.6a	5.9±0.18a	81.4±1.81ab	1.18±0.020a	1.07±0.012a	168±6b	69.3±1.9a	49.3±1.3a
Emulsifier 3%			60.7±1.9a	6.1±0.23a	80.7±1.11ab	1.2±0.009a	1.07±0.0089a	147±8c	66.8±1.3a	50.2±1.5a
Mean All			59.8	6.1	81.7	1.2	1.1	167	68.6	50.2a
Control	2.00	4.00	66.9±1.7a	6.7±0.19a	81.7±0.53a	1.18±0.019a	1.07±0.0035a	191±5a	69.8±1.4a	57.1±1.8a
Emulsifier 1%			62.9±2.3a	6.5±0.26a	82.7±0.44a	1.22±0.012a	1.06±0.0055a	175±4b	67.7±0.9a	51.5±1.8a
Emulsifier 2%			64.1±1.6a	6.4±0.19a	82.7±0.73a	1.20±0.020a	1.07±0.0123a	150±5c	69.0±1.4a	53.4±1.3a
Emulsifier 3%			66.2±1.0a	6.5±0.14a	83.0±0.84a	1.17±0.009a	1.06±0.0089a	141±4c	70.9±0.8a	56.6±1.0a
Mean All			65.0	6.5	82.5	1.2	1.1	164	69.4	54.6
Control	1.00	24.00	96.3±1.9a	9.6±0.24a	85.5±0.67a	2.19±0.024a	2.11±0.0040a	303±6a	39.1±0.6a	44.0±1.2a
Emulsifier 1%			96.6±2.4a	9.6±0.27a	85.1±0.34a	2.19±0.045a	2.10±0.0052a	283±4ab	39.0±0.9a	44.3±1.2a
Emulsifier 2%			94.3±2.5a	9.3±0.29a	84.8±0.57a	2.11±0.034a	2.09±0.0042a	277±8b	40.4±0.8a	44.9±1.6a
Emulsifier 3%			97.7±4.6a	9.5±0.40a	86.3±0.33a	2.18±0.029a	2.11±0.0214a	262±8b	39.6±0.9a	44.9±2.3a
Mean All			96.2	9.5	85.4	2.2	2.1	281	39.5	44.5
Control	2.00	24.00	92.0±2.6b	8.9±0.32b	85.7±0.59a	2.10±0.024a	2.09±0.012b	301±7a	40.9±0.5a	44.0±1.4a
Emulsifier 1%			100.5±1.9a	9.9±0.22ab	85.6±0.42a	2.11±0.042a	2.10±0.0142ab	254±8b	40.9±1.0a	48.1±1.7a
Emulsifier 2%			102.1±2.9a	10.2±0.33a	86.1±0.63a	2.14±0.021a	2.11±0.0089a	255±8b	40.4±0.5a	47.9±1.5a
Emulsifier 3%			105.5±3.1ab	10.5±0.29a	86.1±0.39a	2.16±0.028a	2.11±0.012a	232±6b	40.0±0.6a	49.1±1.7a
Mean All			100.0	9.9	85.9	2.1	2.1	261	40.6	47.3

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05

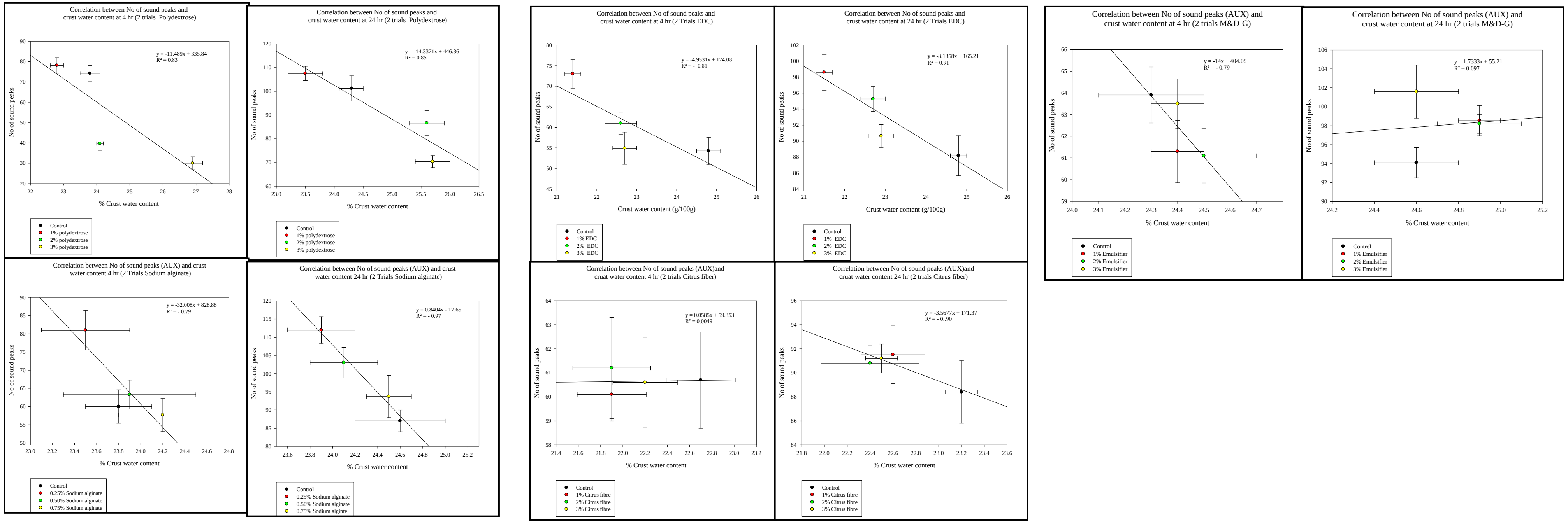


Figure 7.1 Correlation between crust water content and number of sound peaks (AUX) for five different additives at 4 and 24 hours after baking

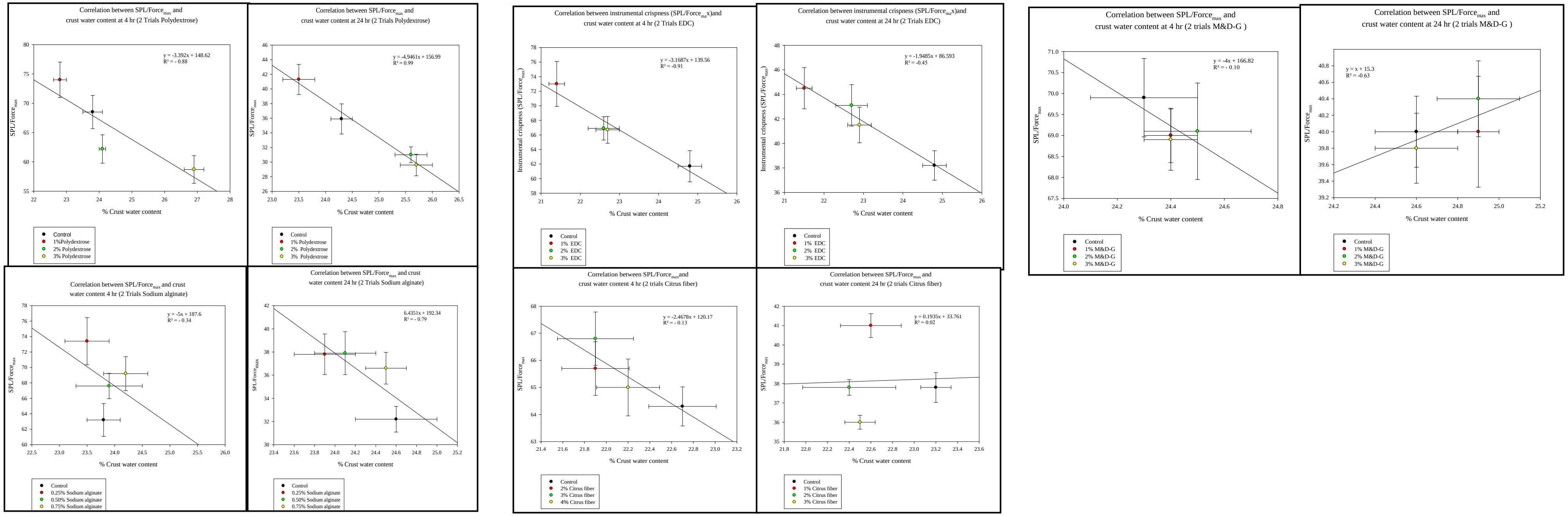


Figure 7.2 Correlation between crust water content and SPL/Force$_{max}$ for five different additives at 4 and 24 hours after bakin

Appendix 4 (Chapter 3)

Table 7.14 source of variance of bread crust crispness made with polydextrose and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
SPL/Force$_{max}$		4		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3.00	21.12	0.000	23.82	0.000
Trials	1.00	45.03	0.000	17.99	0.000
Recipes*Trails	3.00	2.49	0.067	1.83	0.149
Error	72.00				
Total	79.0				
AUX/Force					
Recipes	3.00	166.80	0.00	54.15	0.000
Trials	1.00	7.46	0.00	26.46	0.000
Recipes*Trails	3.00	2.01	0.12	2.93	0.039
Error	72.00				
Total	79.00				

SPL/Force$_{max}$		4			24	
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	61.2cd	75.7ab	68.5*b*	32.1	39.7	35.9*b*
Polydextrose 1%	68.2bc	79.8a	74.0*a*	37.9	44.6	41.3*a*
Polydextrose 2%	57.1d	67.2bc	62.2*c*	29.9	32.2	31.0*c*
Polydextrose 3%	57.0d	60.4cd	58.7*c*	28.7	30.5	29.6*c*
Mean All	60.9B	70.8A	65.8	32.1B	36.8A	34.4
SEM		1.1			0.79	
Significance		NS			NS	

AUX/Force		4			24	
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	59.7a	58.4a	59.0*b*	36.0b	49.3a	42.7*b*
Polydextrose 1%	68.8a	63.8a	66.3*a*	47.6a	54.1a	50.9*a*
Polydextrose 2%	29.8b	28.9b	29.4*c*	25.9c	37.5b	31.7*c*
Polydextrose 3%	28.2b	17.0c	22.6*d*	23.8c	25.1c	24.5*d*
Mean All	46.6A	42.0B	44.3	33.3B	41.5A	37.4
SEM		0.577			1.47	
Significance		NS			*	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.15 source of variance of bread crumb firmness made with polydextrose and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
Firmness		4		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3.00	86.46	0.00	54.15	0.000
Trials	1.00	23.53	0.00	26.46	0.153
Recipes*Trails	3.00	3.85	0.01	2.93	0.000
Error	72.00				
Total	79.00				

Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	192bc	169cd	181*c*	308cd	301cde	304*c*
Polydextrose 1%	169cd	157d	163*c*	269e	275de	272*d*
Polydextrose 2%	258a	209b	234*b*	390b	334c	362*b*
Polydextrose 3%	260a	252a	256*a*	417ab	440a	429*a*
Mean All	220A	197B	208	346A	337A	342
SEM		5.07			7.47	
Significance		***			***	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.16 source of variance of bread crust crispness made with sodium alginate and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
SPL/Force		*4*		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	6.48	0.000	13.28	0.000
Trials	1	0.55	0.462	0.11	0.000
Recipes*Trails	3	0.13	0.943	0.05	0.149
Error	112				
Total	119				
AUX/Force		*4*		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	20.89	0.000	6.28	0.001
Trials	1	0.83	0.365	0.13	0.132
Recipes*Trails	3	1.40	0.247	0.61	0.605
Error	112				
Total	119				

SPL/Force		*4*			24	
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Sodium Alginate 0.25%	71.9	74.9	73.4a	35.5	40.1	37.8*a*
Sodium Alginate 0.50%	67.3	68.0	67.6ab	38.5	37.3	37.9*a*
Sodium Alginate 0.75%	69.0	69.3	69.2ab	36.2	37.0	36.6*a*
Control	62.7	63.7	63.2b	31.9	32.0	32.2*b*
Mean All	67.7A	69.0A	68.4	35.5A	36.7A	36.1
SEM		0.9			0.43	
Significance		*NS*			NS	

AUX/Force		*4*			24	
Recipes	Trial 1	Trial 2	All	Trial 1	Trial 2	All
Sodium Alginate 0.25%	63.7	75.2	69.4a	45.9	51.1	48.5*a*
Sodium Alginate 0.50%	52.6	49.5	51.1b	44.8	45.0	44.9*ab*
Sodium Alginate 0.75%	46.1	47.3	46.7b	39.0	42.6	40.8*b*
Control	41.4	41.6	41.5b	39.8	40.3	40.0*b*
Mean All	51.0A	53.4A	52.2	35.5A	44.7A	43.5
SEM		1.6			0.8	
Significance		NS			NS	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.17 Source of variance of bread crumb firmness made with sodium alginate and measured by instrument and the main effect and f interaction between recipes and trials

	Time after baking (hours)				
		4		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	37.04	0.00	18.20	0.000
Trials	1	0.18	0.67	0.01	0.929
Recipes*Trails	3	2.12	0.10	3.36	0.021
Error	112				
Total	119				

Firmness	4			24		
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Sodium Alginate 0.25%	148	152	150*c*	243	246	244*c*
Sodium Alginate 0.50%	188	176	182*b*	292	258	275*b*
Sodium Alginate 0.75%	166	180	173*b*	240	262	250*c*
Control	204	204	204*a*	301	307	304*a*
Mean All	177A	178A	177	269A	268A	269
SEM		2.60			3.88	
Significance		NS			NS	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.18 Source of variance of bread crust crispness made with EDC and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
SPL/Force		4		24	
SOV SPL/Force	DF	*F*	*P*	*F*	*P*
Recipes	3	8.30	0.000	9.78	0.000
Trials	1	0.12	0.730	40.37	0.000
Recipes*Trails	3	0.27	0.845	6.46	0.000
Error	112				
Total	119				

AUX/Force		4		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	23.57	0.00	19.02	0.000
Trials	1	1.00	0.32	48.63	0.000
Recipes*Trails	3	1.80	0.15	6.15	0.001
Error	112				
Total	119				

SPL/Force		4			24	
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
EDC 1%	71.6	74.4	73.0*a*	47.3a	41.8bc	44.5*a*
EDC 2%	67.2	66.5	66.9*b*	47.2a	39.0c	43.1*a*
EDC 3%	67.1	66.4	66.7*b*	46.1ab	36.9c	41.5*a*
Control	61.2	62.1	61.7*b*	37.8c	38.5c	38.2b
Mean All	66.7A	67.3A	67.1	44.6A	39.0B	41.8
SEM		0.86			0.56	
Significance		NS			***	

AUX/Force		4			24	
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
EDC 1%	58.7	67.5	63.1*a*	55.2a	46.3bc	50.7*a*
EDC 2%	49.6	48.3	48.9*b*	54.0a	41.7cd	47.8*ab*
EDC 3%	46.1	42.7	44.4*bc*	49.6ab	38.1d	43.9*b*
Control	37.7	42.1	39.9*c*	38.9d	39.2cd	39.0*c*
Mean All	48.1A	50.1A	49.1	49.4A	41.3B	45.4
SEM		1.3			0.8	
Significance		NS			***	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.19 Source of variance of bread crumb firmness made with EDC and measured by instrument and the main effect and f interaction between recipes and trials

	Time after baking (hours)				
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	17.63	0.00	10.69	0.000
Trials	1	0.83	0.37	0.64	0.425
Recipes*Trails	3	0.92	0.43	2.24	0.088
Error	112				
Total	119				

	4			24		
Recipes	Trial 1	Trial 2	All	Trial 1	Trial 2	All
EDC 1%	154	151	152*b*	276	270	273*ab*
EDC 2%	151	144	148*b*	274	269	272*b*
EDC 3%	148	141	144*b*	232	263	248*c*
Control	172	178	175*a*	294	295	295*a*
Mean All	156A	153A	154	270A	274A	272
SEM		1.94			3.30	
Significance		NS			NS	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant.
NS = non-significant

Table 7.20 Source of variance of bread crust crispness made with citrus fibre and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
SPL/Force$_{max}$		4		24	
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	1.33	0.269	13.16	0.000
Trials	1	3.10	0.081	0.41	0.522
Recipes*Trails	3	1.36	0.260	0.26	0.855
Error	112				
Total	119				

AUX/ Force$_{max}$					
SOV	DF	*F*	*P*	*F*	*P*
Recipes	3	0.39	0.76	2.09	0.105
Trials	1	0.47	0.49	0.01	0.908
Recipes*Trails	3	0.01	1.00	0.41	0.747
Error	112				
Total	119				

SPL/ Force$_{max}$	4			24		
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Citrus 1%	66.4	65.1	65.7a	40.5a	41.4a	41.0*a*
Citrus 2%	66.2	67.4	66.8a	37.6ab	37.9b	37.8*b*
Citrus 3%	66.4	63.7	65.0a	35.7b	36.3b	36.0*b*
Control	66.2	62.4	64.3a	38.0ab	37.6b	37.8*b*
Mean All	66.3A	64.5A	65.5	38.0A	38.3A	38.1
SEM		0.47			0.32	
Significance		NS			NS	

AUX/ Force$_{max}$	4			24		
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Citrus 1%	49.1	48.1	48.6*a*	43.2a	42.1a	42.6*a*
Citrus 2%	50.7	49.5	50.1*a*	38.8a	40.7a	39.7*a*
Citrus 3%	49.9	49.1	49.5*a*	38.9a	39.1a	39.0*a*
Control	48.5	47.1	47.8*a*	40.0a	38.6a	39.2*a*
Mean All	49.6A	48.4A	49.0	40.2A	40.1A	40.2
SEM		0.8			0.6	
Significance		NS			***	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.21 Source of variance of bread crumb firmness made with citrus fibre and measured by instrument and the main effect and f interaction between recipes and trials

	Time after baking (hours)					
		4			24	
SOV	DF	*F*	*P*	*F*		*P*
Recipes	3	35.02	0.00	24.36		0.000
Trials	1	26.87	0.00	3.54		0.062
Recipes*Trails	3	7.58	0.00	0.27		0.847
Error	112					
Total	119					
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Citrus 1%	174cd	178cd	176*c*	311	315	313*bc*
Citrus 2%	181bcd	193b	187*b*	323	327	325*b*
Citrus 3%	186bc	217a	201*a*	338	346	342*a*
Control	167d	170d	169*c*	296	308	302*c*
Mean All	166B	190A	183	317A	323A	321
SEM		4.50			5.50	
Significance		***			NS	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.22 Source of variance of bread crust crispness made with M&D-G and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)			
SOV		4		24	
SPL/Force$_{max}$	DF	*F*	*P*	*F*	*P*
Recipes	3	0.01	0.992	0.21	0.895
Trials	1	0.76	0.384	4.25	0.042
Recipes*Trails	3	2.53	0.061	0.93	0.429
Error	112				
Total	119				
AUX/ Force$_{max}$					
Recipes	3	2.92	0.057	1.25	0.296
Trials	1	18.44	0.000	5.45	0.021
Recipes*Trails	3	0.87	0.46	0.67	0.57
Error	112				
Total	119				

SPL/ Force$_{max}$						
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	68.1	69.8	69.9*a*	39.1	40.6	40.0*a*
Emulsifier 1%	70.2	67.6	69.0*a*	39	40.9	40.0*a*
Emulsifier 2%	69.3	69	69.1*a*	40.4	40.4	40.4*a*
Emulsifier 3%	66.8	70.9	68.9*a*	39.6	40	39.8*a*
Mean All	68.6A	69.4A	69	39.5B	40.1A	40
SEM		0.44			0.25	
Significance		NS				
AUX/ Force$_{max}$						
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	51.6	57.1	54.3a	44.0a	44	44.0*a*
Emulsifier 1%	49.6	51.5	50.5a	44.3a	48.1	46.2*a*
Emulsifier 2%	49.3	53.4	51.3a	44.9a	47.9	46.4*a*
Emulsifier 3%	50.2	56.6	53.4a	44.9a	49.1	47.0*a*
Mean All	50.2B	54.6A	52.4	44.5B	47.3A	45.9*a*
SEM	0.5			0.6		
Significance		NS			NS	

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Table 7.23 Source of variance of bread crumb firmness made with M&D-G and measured by instrument and the main effect and f interaction between recipes and trials

		Time after baking (hours)				
		4			24	
SOV	DF	*F*	*P*		*F*	*P*
Recipes	3	45.28	0.000		20.44	0.000
Trials	1	0.89	0.347		17.39	0.000
Recipes*Trails	3	5.13	0.002		1.68	0.175
Error	112					
Total	119					
Recipes	Trial 1	Trial 2	Average	Trial 1	Trial 2	Average
Control	181ab	191a	186*a*	303a	301a	302*a*
Emulsifier 1%	171b	175ab	173*b*	283ab	254b	268*b*
Emulsifier 2%	168b	150c	159*c*	277b	255b	266*bc*
Emulsifier 3%	147c	141c	144*d*	262b	232b	248*c*
Mean All	167A	164A	165	281A	261B	271
SEM		2.00			3.20	
Significance		***				

Identical letters in the same column indicates that there is no significant difference at (*P*>0.05)
*** = highly significant. NS = non-significant

Appendix 5

Method for Determination of Firmness in Bread and Bakery Products According to the AACC method (74-09)

AIM: Method for the determination of firmness in bread and bakery products, using the Texture Analyser TA-XT Plus with the AACC (American Association of Cereal Chemists) Method 74-09.01. Firmness being defined as the force in g /Kg or Newtons required for uniaxial compression of the product by a preset distance eg 25%.

EQUIPMENT REQUIRED:

Texture analyser TA.XT Plus
AACC cylinder probe with 36 mm radius
Bread knife
Chopping board
2 kg calibration weight

SPECIAL SAFETY REQUIREMENTS: Good Laboratory Practice must be adhered to at all times. Refer to Quality Manual.

METHOD:

Sample preparation:

Slice the bread into slices of equal thickness of 25 ± 5mm. Use one slice for each test sample (discarding the end crust slice of the loaf). For 12.5mm thick slices, two slices should be stacked together for each test, discarding two or three end slices and end crust slices of the loaf.

Rolls, Buns and similar products may be carefully cut approximately into halves of the same height with separate measurements taken for the 'lid' and 'base'

Note: Samples with structural defects should be avoided.

Samples should be prepared and stored at a constant temperature of 20 - 25 ºC, unless requested otherwise.

Use an electric or sharp knife for sample preparation to minimise pre-test deformation.

1. Open Stable Microsystems Exponent, select a user, "Do not open a project" option, enter a password and click "Ok".

- Use Texture analyser chats for help to download appropriate method
- Drive C/Texture analyser/Bread Firmness AACC 74-09.01

2. Confirm safety notice reading by clicking ‘Yes’.
3. Select ‘File’, ‘Project’, ‘Open Project’, C drive/Projects 2010/Bread Firmness AACC 74-09.01 or from ‘Help’ option “Product testing Guide”, choose from Bakery Products AACC (74-09.01) Method, click on it to open, load project.
4. Click ‘TA’ icon – select ‘TA settings’

Ensure that the following settings are used for the AACC (74-09.01) method for bread and bakery products:

Settings Mode: Measure Force in Compression
Option: Return to start
Pre-test speed: 1.0 mm/s
Test speed: 1.7 mm/s
Post–test speed: 10.0 mm/s
Rupture test distance: 4.0%
Distance: 40 %
Force: 100.0 g
Time: 5.0 sec
Count: 5
Load cell: 5 kg
Temperature: 25°C
Trigger type: Auto
Force: 5g
Trigger Type: Auto -5g
Stop plot at: Trigger return
Auto target: x
Units: Force: Grams
Distance: % strain
Data Acquisition
Rate: 250pps

Macro settings:

Clear Graph results
Search Forwards
Go to Min.time
Go to Distance 25 %

Mark Value Force Firmness X

5. Ensure that the correct probe is attached to the Load Cell.
6. On Menu Bar select: ‘TA’.
7. Select ‘Force’, ‘Force Calibration’ should be carried out prior to each use, by selecting ‘Calibrate Force’.
8. Follow instructions as they appear, using the 2 kg calibrated weight for the force calibration.
9. Remove this weight and click on ‘Finish’ icon, if calibration successful –click ’Ok’, if it fails, repeat from ‘7’ as appropriate.
10. Note: If a test is manually stopped or aborted, the calibration must be repeated.
11. The Probe calibration should be carried out prior to each use, by selecting ‘Calibrate Height’ and by following the instructions, click ‘Ok’ if calibration successful .

Note: Lower the probe, so that it is close to the test surface to reduce test time.

Specify the distance that you want the probe to return to after sample compression, for each test-e.g.30 mm.

12. Click on T.A. – select ‘Run test’ window
13. Enter a File ID, Title,Batch number or date
14. Choose appropriate Path on a C drive /Texture analysis 2010
15. Ensuring that each sample is the same height, place the sample centrally under the cylinder probe, avoiding any irregular or non-representative areas of crumb.
16. Commence the test, clicking on ‘Run a test’.
17. The probe will move on to the sample and the test data will be generated
18. Go to process data, Macro, Run, to ensure that anchor was dropped at 40 % of distance.
19. Open the new file for the results by clicking ‘File’, then ‘new’ file, enter a name for the new file and then save by clicking on ‘Save as’ icon.

20. Insert to result file Average and S.D. by highlighting and clicking with the right mouse
21. Repeat the tests on a new sample by holding the ‘Ctrl’ key and pressing ‘Q’
22. Repeat tests as required, a minimum of 3 replicate tests should be carried out, however sample size should be >10 for better reproducibility.

23. Check the results file and put the date into the appropriate results sheet, save it and e- mail to the appropriate division as appropriate
24. To exit the Programme, click on ‘X’ in the top right hand corner of the screen.
25. Answer ‘YES’ to all questions regarding saving results and archive file and ‘NO’ to save changes to project.
26. The results from these tests must be recorded on the appropriate Raw Data Sheet together with the sample storage temperature (usually room temperature) and humidity. The latter measurements should be carried out using the Kestrel thermometer / hygrometer by rapidly swinging the instrument back and forth for at least 1 minute.

Calculations:

$$\text{Bread Firmness} = \text{Force (N)} \times \text{Distance (m)}$$
$$= \text{Nm}$$

$$\text{Standard Deviation} = \sqrt{\left(\frac{\sum (x - \text{mean})^2}{n - 1} \right)}$$

Where x = sample result
And n = number of samples

ACCURACY

For repeatability and reproducibility results, refer to Texture Analyser Accuracy data sheet.

Refer to Bread Firmness Chart for tolerances of acceptability for specific bread types.