

1E406 INDIVIDUAL ENQUIRY

DEPARTMENT OF CHEMICAL ENGINEERING

THE UNIVERSITY OF QUEENSLAND

“THE PROCESSING, MICROSTRUCTURE  
AND MECHANICAL PROPERTIES  
OF A SOFT SOLID FOOD”

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Dear Madam/Sir,

Please except this undergraduate Individual Enquiry. The work presented in this enquiry is, to the best of my knowledge and belief, original and my own work, except as otherwise acknowledged in the text. I have not submitted this material, either whole or in part, for a degree at this university or any other institution.

Sincerely,

Michael Flint

**Abstract**

A comparison between microstructure, mechanical, rheological properties and processing behaviour of three different liquorice products. The goal of the study is to be able to map these properties to mouthfeel. For this study an Environment Scanning Electron Microscopy (ESEM) took images of the liquorice surface at room temperature. From images it is possible to see the liquorice structure difference between the to type process. Continued research into the microstructure of liquorice will broaden the knowledge of what exactly happen in the processing of liquorice.

Keyword(s): Mouthfeel, ESEM

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- Thanks to the Associate Professor John Drennan and the CMM Dept, UQ for all your time capturing the high quality Environmental Scanning Electron Microscopy.
- Thanks to John Ruhle, MMM Engineering Dept, UQ for the time using the MMM Engineering Instron Testing Machine.
- Thanks to Dr Tri Le, Chemistry Dept, UQ for the time using the DMTA machine.

**1.0 Table of Contents**

<b><u>TABLE OF CONTENTS</u></b> .....	<b>5</b>
<b><u>1.0 INTRODUCTION</u></b> .....	<b>10</b>
<b><u>2.0 BACKGROUND LITERATURE REVIEW</u></b> .....	<b>11</b>
<u>2.1 NATURE OF INGREDIENTS</u> .....	11
<u>2.2 MANUFACTURED METHOD</u> .....	13
<u>2.3 TEXTURE AND MOUTHFEEL</u> .....	14
<b><u>3.0 MATERIALS AND METHODS</u></b> .....	<b>16</b>
<u>3.1 MATERIALS AND SAMPLING PREPARATION</u> .....	16
<u>3.2 MOISTURE CONTENT ANALYSIS</u> .....	16
<u>3.3 MICROSCOPY</u> .....	17
<u>3.4 MECHANICAL TESTING</u> .....	17
<b><u>4.0 EXPERIMENTAL RESULTS AND DISCUSSION</u></b> .....	<b>19</b>
<u>4.1 LIQUORICE INGREDIENTS COMPARISON</u> .....	19
<u>4.2 KF COULOMETER MOISTURE CONTENT ANALYSIS</u> .....	20
<u>4.3 MICROSCOPY</u> .....	21
<u>4.4 MECHANICAL TESTING</u> .....	27
<b><u>5.0 RECOMMENDATIONS FOR FURTHER STUDY</u></b> .....	<b>30</b>
<b><u>6.0 CONCLUSION</u></b> .....	<b>31</b>
<b><u>7.0 REFERENCES AND READINGS</u></b> .....	<b>32</b>

## **2.0 Introduction**

At present Cadbury uses a batch process to manufacture pascall licorice. This process is hard to control and therefore produces inconsistent results. Cadbury would prefer to use a continuous extrusion method however they fear that this type of method could affect the quality of their product.

The purpose of this project is to initiate collaborative research on the correlation between microstructure, rheology and processing behaviour and how these properties relate to the sensory aspects of a soft solid food product, such as liquorice.

The objective of the project was to compare the microstructure, mechanical, rheological properties and processing behaviour of three different liquorice products: Betta, Kenman and Cadbury Pascall.

### **3.0 Background Literature Review**

It is believed that by studying the microstructure, rheology and processing behaviours it could be possible to map the type of sensory feel a particular food will give inside the mouth. The purpose of this project was to study properties of liquorice, one of many soft solid foods. Liquorice (Licorice, liquorish) is a sweet candy, which is manufactured in different ways, shape and sizes. Liquorice can be produced as sheets for use in the liquorice allsorts candy lines or as rods and other shapes for sale as plain liquorice. Liquorice is a paste, which has a smooth but firm texture, when eaten it exhibits a relatively tough to chew. The texture of the liquorice is mainly due to the nature of the ingredients and method of treatment (Jackson, 1995).

#### **3.1 *Nature of Ingredients***

Flour, sugar and water make up the bulk of the ingredients in liquorice however liquorice extract (from the herb “glycyrrhiza glabra”) and other ingredients are added to give the liquorice it specific colour and taste qualities. When the bulk ingredients are mixed they form a viscous blend, when heat is added, a process called gelatinisation occurs. This process increases the viscosity of the mixture forming workable solid paste product that is known as liquorice. The main three ingredients are important as they control this gelatinisation process:

##### **3.1.1 *Flour***

A change in this percentage can regulate the gelatinisation temperature and degree of gelatinisation ‘the viscosity’ before, during and after cooking. This can influence the setting property of the starch gel after cooking. Changes in proportion can be obtained by replacement of certain quantities of flour by native or modified starches. The type of flour or starch are therefore one of the three variables to control the to degree of gelatinisation, (Jackson, 1986a)

##### **3.1.2 *Sugars***

The sugar is not only the sweetening agent of the liquorice, in the form of sucrose but it also provides body to the final product due to its crystallisation

property. The strength of the sugar solution is one of the key variables in the control of the degree of gelatinisation. The higher the concentration the sugar solution becomes the slower and less complete is the gelatinisation, or the higher the temperature has to be to obtain gelatinisation, (Jackson, 1986a).

### 3.1.3 *Water*

The quantity of water is the third important ingredient of liquorice. The quantity of water added to the slurry also varies the degree of gelatinisation. These three main ingredients therefore control the quality and type of the finished product, (Jackson, 1986a).

### 3.2 *Manufactured Method*

Liquorice can be manufactured in a batch or continuous processes. Figure 1 illustrates the batch production of liquorice in to sheets.

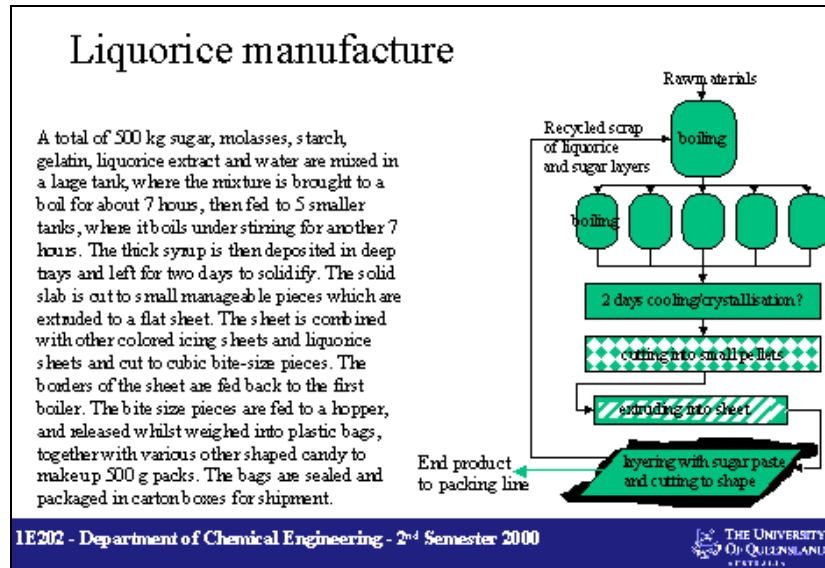


Figure 1. Batch Process liquorice Manufacture, (Rutgers, 2000)

For this process the raw ingredients are mixed and heated in a large tank. After a period of time the mixture is separated into several smaller tanks for further heating and mixing. After this stage, the syrup mixture is placed into pans to cool and solidify. The solid slabs are then broken into manageable pieces where it is extruded into the liquorice sheets. (Rutgers, 2000)

For batch process, this technique would be consider quite robust however they can tend to be quite labour intensive and hard to control the product quality therefore these types of batch process tend to be quite uneconomic. The preferable option is to use a continuous method for producing liquorice, thus minimising labour costs and minimising some variables associated with batch cooking. Although the quality of batch-cooked liquorice paste is considered to be superior to that produced by the continuous process. It is considered that the continuous methods produce a far more consistent and uniform quality (Jackson, 1995).

### 3.3 *Texture and Mouthfeel*

The external appearance or the internal features can determine the quality of the liquorice. The internal features are the sensory aspect of the liquorice. The important sensory aspects are liquorice taste (sweetness) and mouthfeel. The external features can easily be manipulated using waxes and other coverings, while taste can be adjusted with sugar and fat ratios. Therefore mouthfeel becomes an important feature in liquorice candy manufacturing. Mouthfeel properties include hardness, stickiness, consistency and texture. These properties have been related back to mechanical (hardness), rheological (stickiness, consistency) and microstructural (texture) properties, which are measurable. Therefore for this project the aim was to determine the above mouth feel properties for different commercial liquorice.

Previous studies on liquorice have determined several textural parameters. Olkku and Rha (1975) developed a texture profile analysis, based on a mechanical test to evaluate the sensory feel of food texture. For this study they used a penetration test to model a bite mechanism of the mouth. For this study they used an Instron Universal Testing Machine to measure the force required to penetrate a plunger into commercial liquorice samples. This test is characterised by a) a force measuring instrument, b) penetration of the probe into the food causing irreversible crushing or flowing of the food, c) the depth of penetration is usually held constant (Bourne, 1982). A plot showing force versus displacement and/or plot showing force versus time can be generated. From their results parameter such as hardness, fracturability, cohesiveness, springiness, gumminess, chewiness and adhesiveness were derived. Hardness is the maximum force that occurs at any time during the first compression cycle or 'first bite'. The yield point is represented by the change in the slope. This change represents the beginning of penetration in the food this is related to the fracturability parameter. (Bourne, 1982).

The puncture probe consists of a tapered plunger with a flat disk 2mm in diameter. The forty-five degree angle on the plate is used to reduce the effect of friction on the sides of the probe (Olkku, 1975). This probe is mounted on

the Instron Universal Testing Machine, which draws out a force-distance or force-time curves.

This was good start to determine the texture properties of liquorice however it has assumed that texture is only a function of mechanical properties. From this article it is not possible to make an informed decision on why the liquorice sample had these textural properties. By comparing the microstructure of a sample with these texture parameters it could be possible to make decision on why a sample has particular texture properties and therefore a particular mouthfeel.

Background studies into liquorice microstructure could not be found however liquorice consists of large quantities of flour and water so it was thought that the microstructure relationship between dough and liquorice could be similar. Several studies into the microstructural changes as dough is processed and baked were thought to be a useful guide in explaining the difference in the microstructural of liquorice samples. Autio and Laurikainen (1997) studied the relationship between flour/dough microstructure and dough handling and baking properties. In this study they examine the effects of ingredients, processing and baking have on the microstructure, (McDonough et al. 1996) studied the microstructural changes in the wheat flour tortillas during baking. This article is useful as it points out various flour components visible with a scanning electron microscope. An Environmental Scanning Electron Microscope (ESEM) will be used to view the liquorice. The ESEM is a valuable tool for food products. There is no special sample preparation such as fixation, dehydration or deflating. The ESEM allows the sample to be viewed at any temperature and a fully hydrated state.

The comparison useful between rheological properties and microstructure is also useful. The liquorice rheology or rheology of candy type foods is a relative unexplored area nevertheless liquorice consists of large quantities of flour and water so it was thought that the properties of dough or soft pasty type foods could have a similar rheological properties.

## 4.0 Materials and Methods

### 4.1 *Materials and Sampling Preparation*

Three commercial liquorices were used (Betta, Kenman and Pascall brands). Multiple packets of liquorice needed to be purchase to ensure the quantity of samples required. The packets for each liquorice type were chosen so that all packets for the one liquorice type had the same use-by-date. It was assumed that the use-by-date for each liquorice returns the same manufactured date. During experiments five specimens from each sample were prepared. To prepare samples for mechanical testing a razor blade was used.

### 4.2 *Moisture Content Analysis*

A Mettler DL37 Karl Fischer coulometer was used to measure the moisture content. Five specimens for each type of liquorice were used. A specimen weighing 0.1g was taken from the core centre of the liquorice to minimize the effect of any surface drying of the liquorice sample.

The KF coulometer uses a standard method for the moisture measurements for liquids and solids. The accuracy and precision have been found to be high.

$$WC = \frac{0.4 \times F \times (V_S - V_B)}{W}$$

Where WC – Percentage water of sample  
F – Standardisation factor of reagent (mg Water/mL)  
W – Weight of Sample (g)  
V<sub>S</sub> – Volume of reagent used for sample (mL)  
V<sub>B</sub> – Volume of reagent used for blank (mL)

### **4.3**      *Microscopy*

#### *4.3.1*      *Light Microscopy*

Thin slices of liquorice samples were cut using a razor blade at 25°C. The thin slices were placed on a glass slide and viewed using normal and polarised light.

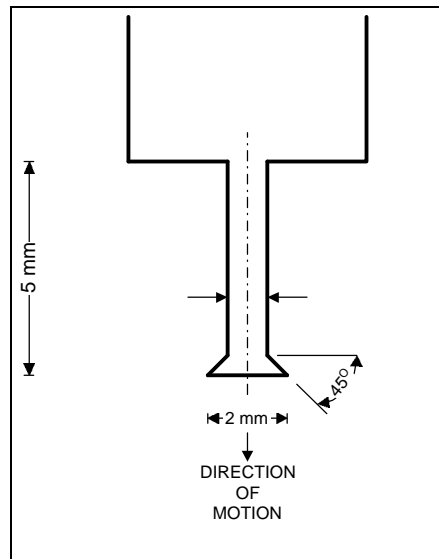
#### *4.3.2*      *Scanning Electron Microscopy*

An Environmental Scanning Electron Microscope was used to take a range of pictures between the magnifications of 250 and 1200 courtesy of CMM Department, The University of Queensland. Samples were prepared using two different methods. Method one: The samples were cooled to -200°C and fractured in a latitudinal direction. The samples were then stored at room temperature (25°C) before being viewed under the microscope. Method two: The samples were fractured at room temperature in a latitudinal direction. With both methods the sample were viewed at room temperature.

### **4.4**      *Mechanical Testing*

#### *4.4.1*      *Penetration Testing*

Olkku and Rhu (1975) penetration testing method was used. This test used a Universal Instron Testing Machine; model 5584 located in MMM Engineering Dept., UQ. A load cell of 100N using series IX software to record the force required to push a punch (Figure 2) into the liquorice sample. The depth of the probe penetration was kept constant at 1.5 mm; the penetration direction was across the grain to simulate a bite into the liquorice. The plunger used is a 45° tapered plunger punch with a 2 mm base diameter. The plunger speeds used were 1, 10 and 100 mm/min. The Instron was set on a two-cycle penetration test. At each speed five specimens were tested for each sample. For each sample a razor blade used to cut a flat surface in the liquorice for the plunger to penetrate to remove any surface coating e.g. surface wax. To stop the liquorice sample movement, during the upstrokes, double-sided tape fastened each sample to the flat bed. For all tests temperature and humidity conditions were controlled at 25°C and 60% humidity.



**Figure 2: Tapered Plunger**

#### 4.4.2 *Tensile Testing*

This test used a Universal Instron Testing Machine; model 5584 located in MMM Engineering Dept., UQ. A load cell of 100N using series IX software to record the force required to break the liquorice. The liquorice was stretched at 5 mm/min. All samples were measured and the length, width and thickness were entered into the computer each time. For all tests temperature and humidity conditions were controlled at 25°C and 60% humidity.

#### 4.4.3 *Dynamic Mechanical Analysis*

This Dynamic Mechanical Analysis equipment was the Perkin-Elmer DMA7 located in Chemistry Dept, UQ. The storage modulus ( $G'$ ) and loss modulus ( $G''$ ) were obtained in the a parallel plate measurement system. These properties were measured in the perpendicular direction to the extrudate direction.

The plate diameter was 10mm and the test specimens were prepared in a cylindrical shape with the same diameter, 10mm. For all tests temperature and humidity conditions were controlled at 25°C and 60% humidity.

## 5.0 Experimental Results and Discussion

### 5.1 *Liquorice Ingredients Comparison*

Difference in the ingredients occurs in the colours, preservatives and flavours Figure 4.1 and Figure 4.2. The ingredients were taken from the liquorice packets. Colour and flavour difference occurred. For the Kenman brands only liquorice allsorts packets could be purchased variations in other ingredients is possible due to presence of liquorice allsorts. The colour, flavours and preservatives are only small quantities compared to the flour, sugar and water; therefore it is assumed that there are no major differences in the ingredients.

**Table 4.1: List of Ingredients common to the three liquorice brands**

<b>Pascall</b>	<b>Kenman</b>	<b>Betta</b>
Wheat flour	Wheat flour	Wheat flour
Sugar	Sugar	Sugar
Molasses	Molasses	Molasses
Vegetable fat	Vegetable fat	Vegetable fat
Liquorice extract	Liquorice extract	Liquorice powder
Water	Water	Water
Glucose Syrup	Glucose syrup	Glucose invert syrup

**Table 4.2: List of other ingredients the three liquorice brands**

<b>Pascall</b>	<b>Kenman</b>	<b>Betta</b>
Salt		
Gelatine		
Humectant		
Colours: 102 Tartrazine 110 Sunset Yellow 123 Amaranth 133 Brilliant Blue 150 Caramel	Colours: 102 Tartrazine 129 Allura red AC 133 Brilliant Blue	Colours: 150 Caramel
Preservative: 200 Sorbic acid 420 Sorbitol	Preservative: 202 Potassium Sorbate	
	Flavours: Treacle Emulsifier 471 Mono and di-glycerides of fatty acids	Flavours: Emulsifier 471 Mono and di-glycerides of fatty acids Aniseed

## 5.2 *KF Coulometer Moisture Content Analysis*

Comparing the moisture content of three licorice samples see Figure 3. The final water content for the Betta and Kenman brands are quite variable due to large standard deviations. There was no significant difference between the Pascall and Kenman brands. There was a slight moisture content difference between Pascall and Betta. Therefore it is inconclusive that the final moisture content is a result of different processing methods.

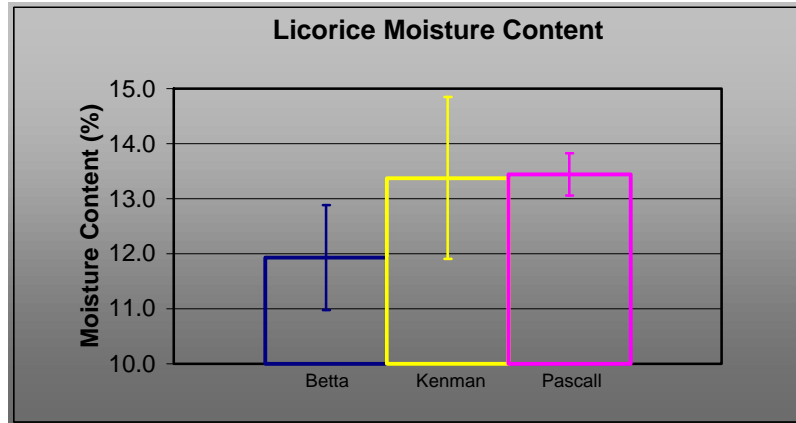


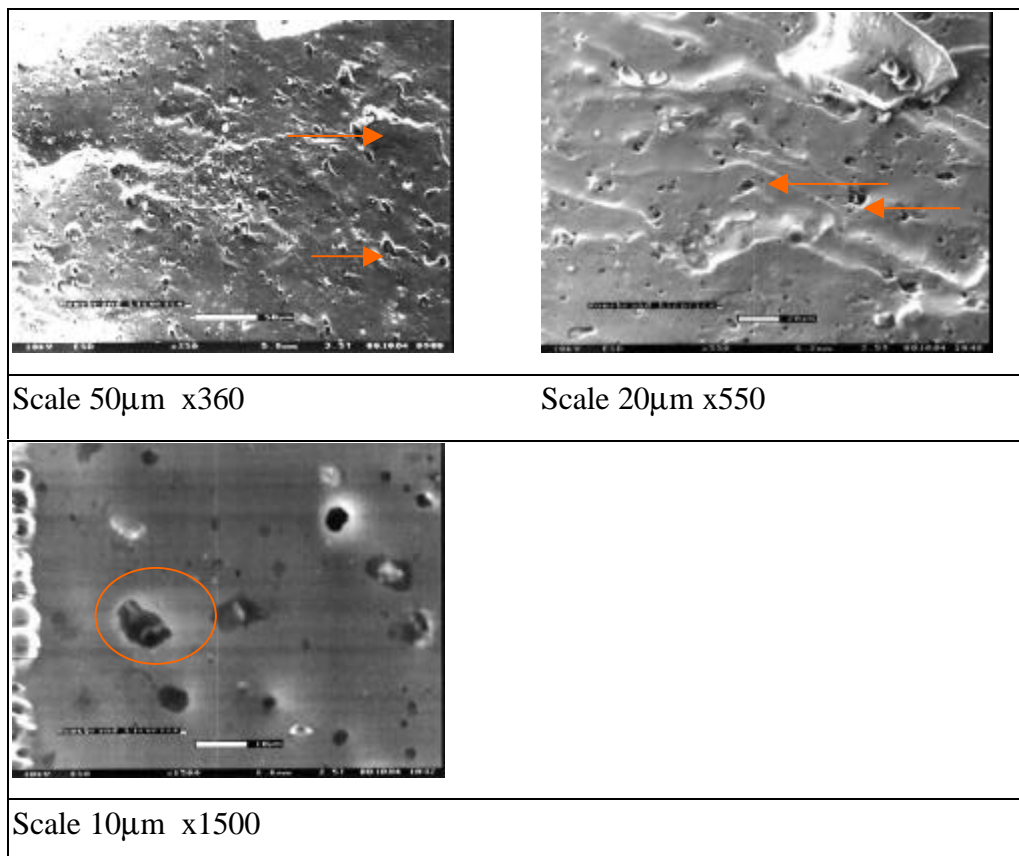
Figure 3: Licorice moisture content for Betta, Kenman and Pascall brands

### 5.3 *Microscopy*

#### 5.3.1 *Environmental Scanning Electron Microscopy*

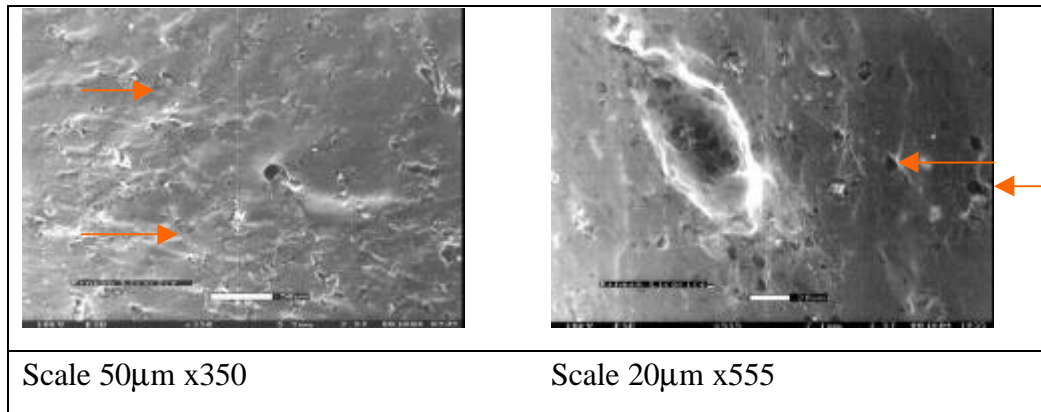
The three samples were viewed using ESEM at different magnifications between 350 and 1500. Figures 4,5&6 shows ESEM pictures at various magnifications for the three samples. These samples show the surface of liquorice that has been fractured in a latitudinal direction. The samples were fractured at low temperatures. This procedure ensures that the fracture minimises surface defects. For quick observation the Betta and Kenman show a surface different the Pascall brand.

A closer inspection of Betta brand, Figure 4, it is notice that there is a definite particle distribution over the surface. At a 360 magnification the particles are up to 20 $\mu$ m in size. At x1500 the particles are quite irregular with a non-spherical appearance about 10 $\mu$ m long and 5 $\mu$ m wide. During the continuous extrusion process any scrap liquorice, is recycled back into the hopper as rework. These particles are not melting and gelling in with the new product therefore they stay as particles in the gel matrix.



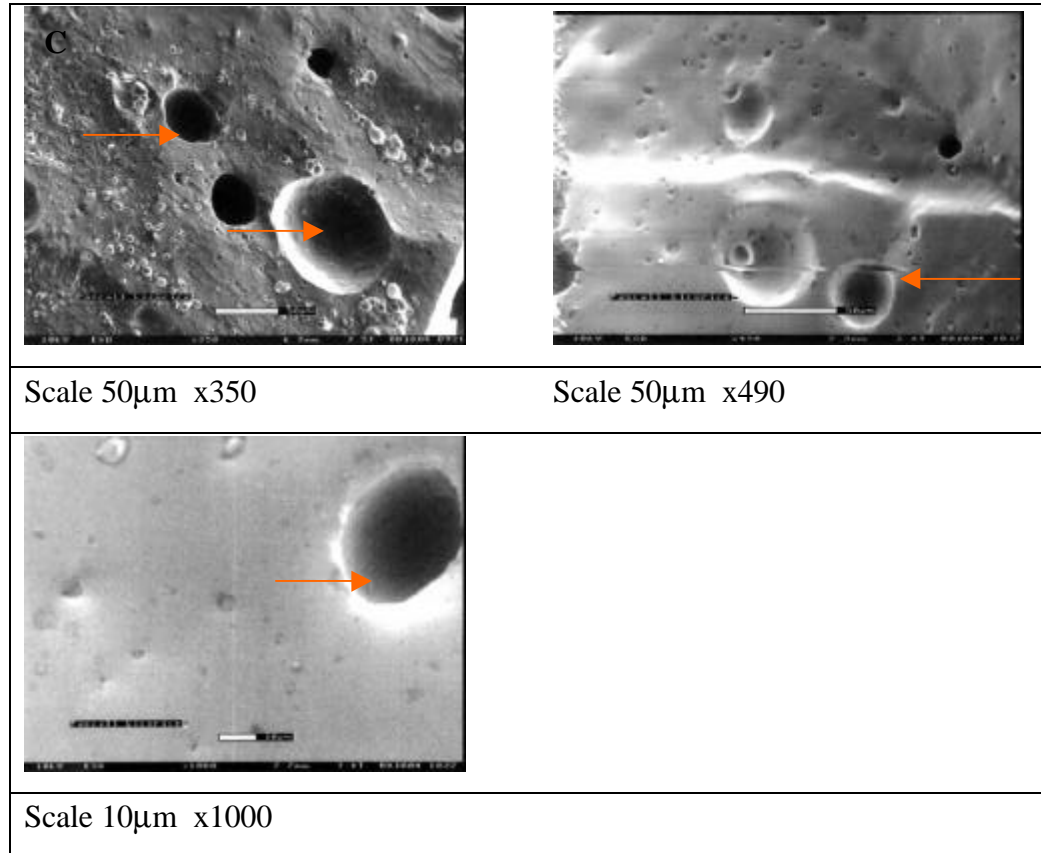
**Figure 4: Environment Scanning Electron Microscopy of Betta liquorice samples. (Preparation method one: Samples frozen using liquid nitrogen, fractured across the grain)**

A closer inspection of Kenman brand (Figure 5) particle distribution over the surface however the particles are not as dense as the Betta brand. At a 350 magnification the particles are smaller less than  $5\mu\text{m}$  in size. At x555 the particles are again quite irregular and non-spherical appearance about  $5\mu\text{m}$  long and about  $3\mu\text{m}$  wide. Again these particles would have be a result rework in the extrusion process.



**Figure 5: Environment Scanning Electron Microscopy of Kenman liquorice samples. (Preparation method one: Samples frozen using liquid nitrogen, fractured across the grain)**

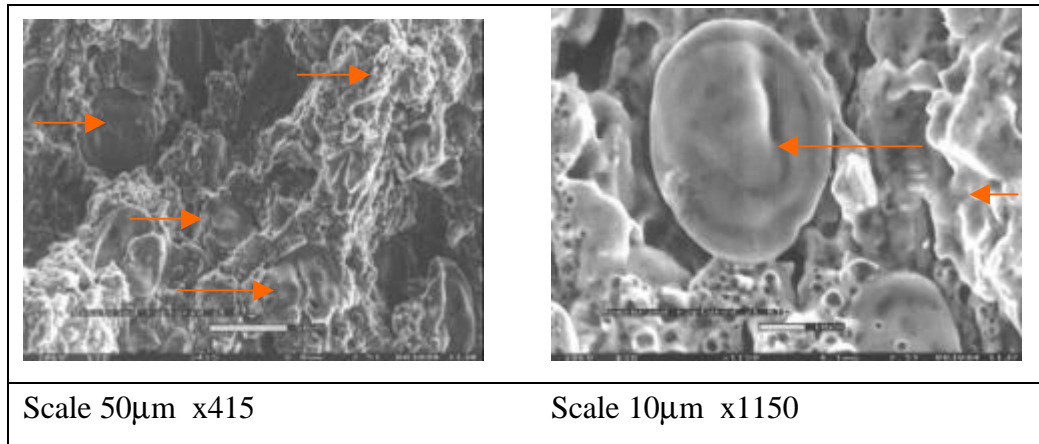
The Pascall brand (Figure 6) shows a different surface appearance then the other two liquorice brands. The surface is smoother with fewer particles. This could be due to the processing method. The Pascall is a batch process. During the process the liquorice goes through numerous heating and mixing vessels plus the liquorice is stored a few days in tray. This could give the rework time to melt and mould into the gel structure. The Pascall brand has pockets that are up to  $100\mu\text{m}$  in size and had a concave like appearance. These cannot be seen in either of the other brands. The pockets are thought to be lipid or micelles from the vegetable fats and oils in the ingredients. The pockets could also be air pockets formed in the mixing process. Again these lipid structures could form when the liquorice is allowed to sit in the trays and solidify.



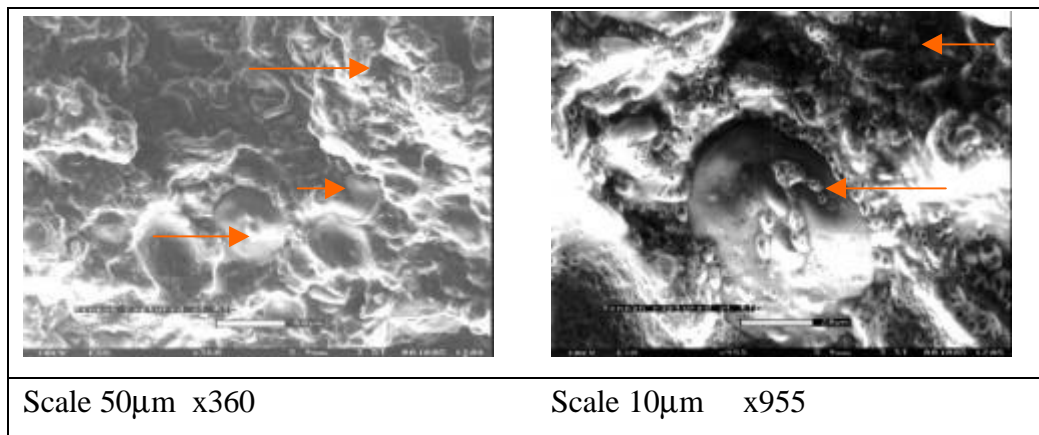
**Figure 6: Environment Scanning Electron Microscopy of Pascall liquorice samples. (Preparation method one: Samples frozen using liquid nitrogen, fractured across the grain)**

The surface of all the liquorice samples is smooth which was quite unexpected. This unexpected result was thought to be a cause of the preparation of liquorice samples. It was thought that the freezing process could deteriorate the gel matrix of the liquorice.

A second set of ESEM was performed using a different sample preparation technique. This time the samples were fractured at room temperature (25°C). Figures 7, 8 & 9 show ESEM pictures for the three liquorice samples using the second preparation technique. For the Betta (Figure 7) and Kenman (Figure 8) brands platelet structures can be seen. These platelet structures are approximately 50µm in diameter and slightly spherical. The platelet has a smooth surface finish which is slightly concave in shape. According to (McDonough, 1996) in the ESEM gelatinised starch granules are not only concave in shape but also curled and slightly bubbled in appearance. The other starch granules were smooth with a concave centre. There it was assumed that these platelet structures are partly gelatinised starch granules. Around these granules is a gel matrix, which shows reasonable depth into the liquorice. This matrix is the gelatinised starch it has swollen then ruptured

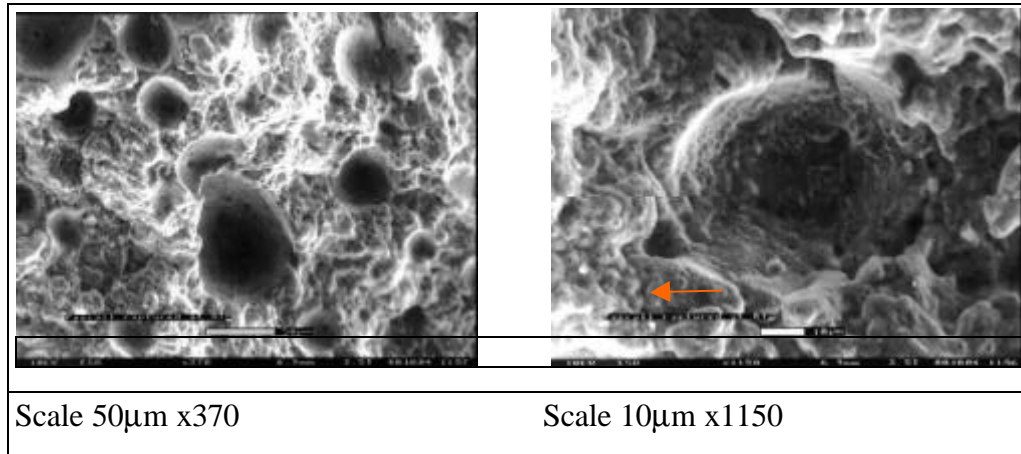


**Figure 7: ESEM of Betta liquorice sample. (Preparation method two: Sample fractured at room temperature and across the grain.)**



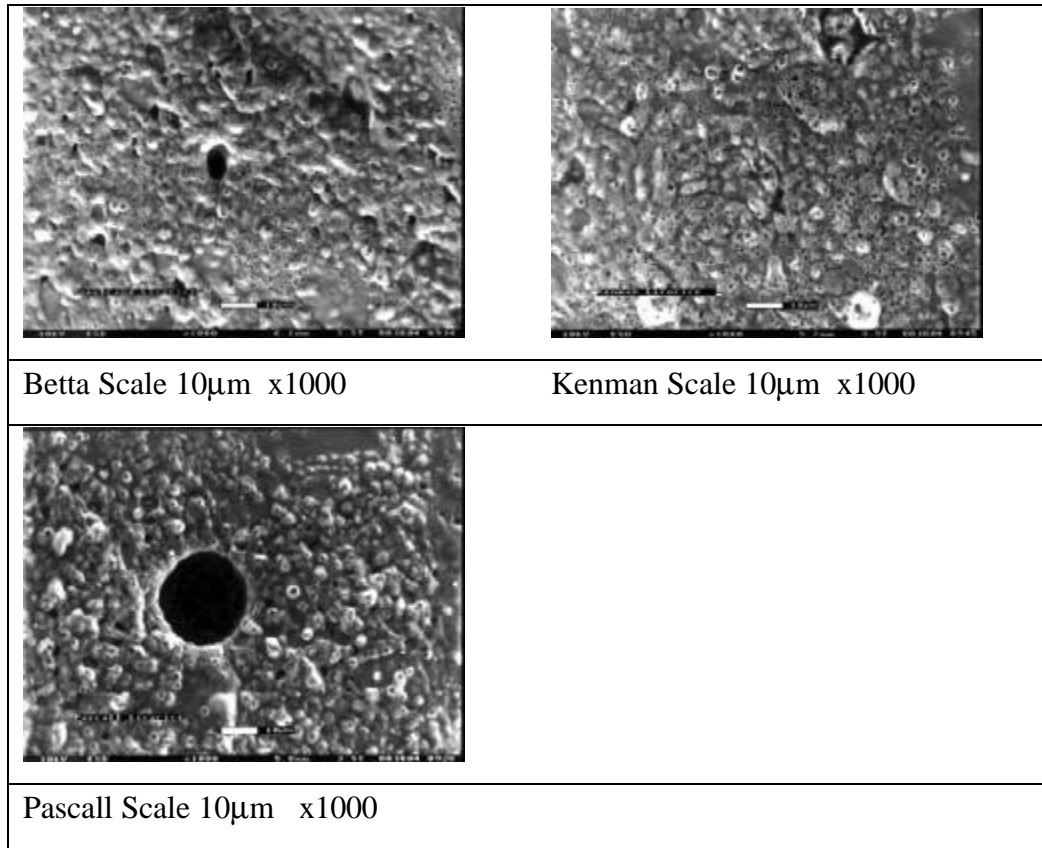
**Figure 8: ESEM of Kenman liquorice sample. (Preparation method two: Sample fractured at room temperature and across the grain.)**

Again in the ESEM picture of the Pascall sample, the concave pockets can be seen. However, the platelet structures could not be seen in the Kenman and Betta brands. Note for the Pascall brand at the x1150, the surface is starting to bubble and un-real picture are forming.



**Figure 9: ESEM of Pascall liquorice sample. (Preparation method two: Sample fractured at room temperature and across the grain.)**

This bubbling problem was encountered when the magnification was too great. If the samples were viewed at median magnification for long period or high magnification for short lengths of time the electron beam destroyed the sample. Localised heating from the beam caused the sample to bubble and burn. It was difficult to gain a reasonably high quality picture of the surface structure at these high magnifications. Figure 10 shows the liquorice samples bubbling. However, the Pascall sample seen to bubble more easily than the other two samples. This could be influenced by the presence of the lipid structure in the liquorice.



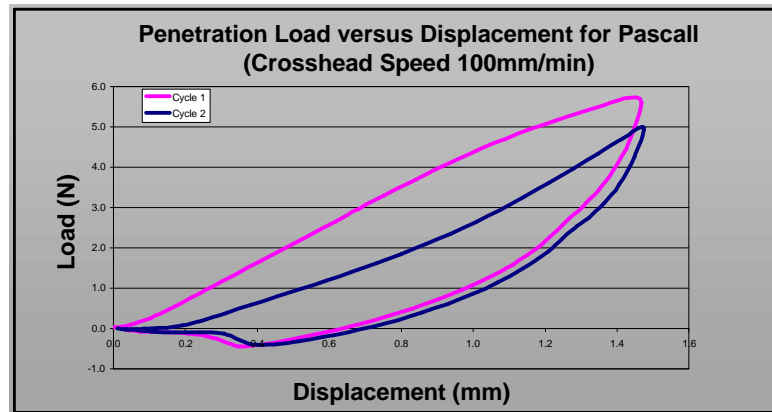
**Figure 10: ESEM of commercial liquorice samples. Local heating of the sample during high magnifications can cause artifacts, (burning or bubbling or sample)**

## 5.4 *Mechanical Testing*

### 5.4.1 *Instron Penetration Tests*

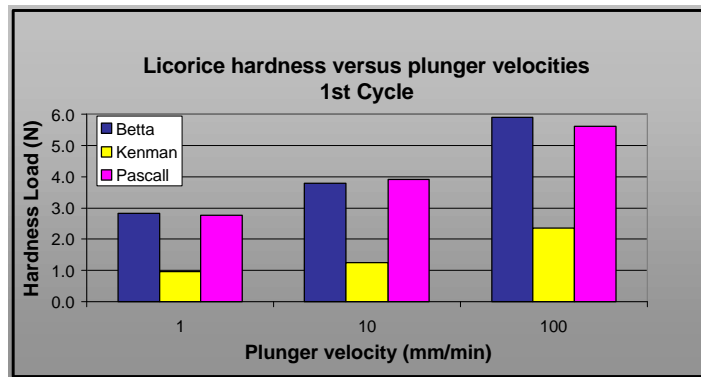
For each penetration test a plot similar to Figure 11. This plot shows the penetration load as the probe is plunged into the sample. From Figure 11 the pink represents the first cycle while the blue line represent the second cycles. Note the second cycle does not follow the exact path of the first cycle. Also the load at the maximum penetration is reduced in the second cycle. This trend occurred for each sample at each different plunger speed. This trend suggests that liquorice has slow relaxation strength.

A full set of penetration load versus displacement plots for each sample at different plunger speeds can be found in the appendix.



**Figure 11: Penetration Load versus Displacement for Pascall Liquorice at a plunger speed of 100mm/min.**

For the penetration load versus displacement plots in the Appendix the hardness parameter was recorded for each sample and plunger speed and plotted in Figure 12. From this it is possible to see the difference in hardness between the Kenman and Betta as well as difference between Kenman and Pascall brands however there is no difference between Pascall and Betta therefore no evidence to suggest that this difference is a direct influence of the continuous or batch processing.



**Figure 12: Liquorice hardness for 1st cycle penetration.**

#### 5.4.2 *Tensile Tests*

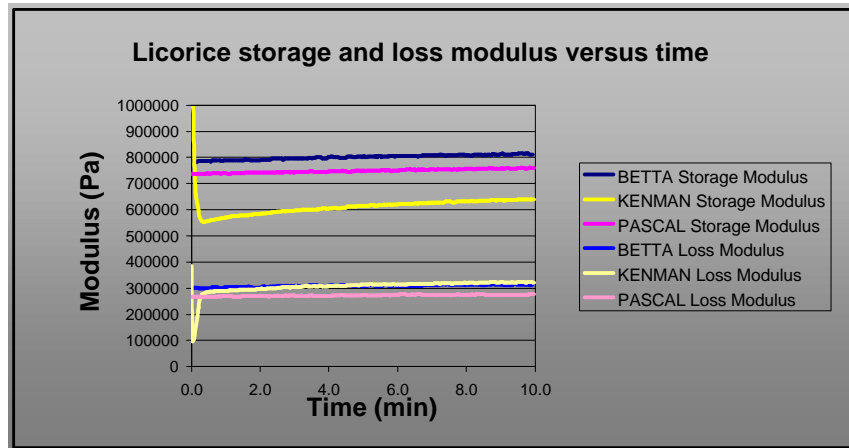
Tensile testing is not widely used with foods systems. The major problem encountered while performing the tensile experiments is to prevent the sample from failing at the clamps. To prevent failure at clamps various methods have been used. Cutting the sample into dumbbell-shaped test pieces “dog bone shapes” could solve this problem. The sample is then more likely to break in the narrow centre portion of the test piece. When “dog bone shapes” were used the Kenman and Betta brands still didn’t break in the reduced cross-sectional area region. 2 out of 5 of the Pascall specimens failed in the correct position. Therefore was unable to gather any true results for maximum load and elongation of the liquorice.

Another unique solution developed by Pool (1969) avoided the clamp failure problem. This technique used an adhesive (Eastman 910, methyl-2-cyanoacrylate) to cement the end of the food sample to two metal plates. In this experiment the cement formed a bond stronger than the test samples tensile strength. This of method could be used in the future to get true results from this type of experiment.

### 5.4.3 *Dynamic Mechanical Analysis (DMA)*

Measurements for viscoelastic properties of polymeric systems are performed within a region referred to as the linear viscoelastic region. In this region, as the stress applied to the sample is increased, the relationship between the stress and strain is constant, despite the variance of strain with time.

For the Licorice storage and loss modulus versus time plot all three samples are in a linear region at these conditions.



**Figure 13: licorice storage and loss modulus over time.**

## 6.0 Recommendations for Further Study

### 6.1.1 *Environmental Scanning Electron Microscopy*

For this project ESEM was limited at viewing the final product of commercial liquorice. ESEM pictures of the raw ingredients would give a greater understanding of these ESEM pictures taken in this study. The ESEM has a heating element so it would be possible view the liquorice from the stage when the all ingredients are mixed through the gelatinisation process. This when give a better idea of the type of structure being viewed in the final product. After gelatinisation, it would also be worthwhile to model the batch and continuous processes then view the final products.

### 6.1.2 *Dynamic Mechanical Thermal Analysis*

A very limited DMTA for the liquorice was completed in this study.

In order to learn more about the rheology of liquorice a temperature sweep test. The dynamic mechanical properties can be then obtained as a function of temperature. The experiment would be performed at a constant frequency (1 Hz), between a temperature range of  $-40^{\circ}\text{C}$  and  $125^{\circ}\text{C}$ , with a low heating rate of approximately  $5^{\circ}\text{C}/\text{min}$ . A low applied static strain and dynamic strain would be preferred.

A second study would concentrate on the non-linear dynamic mechanical behaviour. The dynamic stress ( $\sigma_{\text{dy}}$ ) versus dynamic strain ( $\epsilon_{\text{dy}}$ ) curves could be measured for the samples under different static strains ( $\epsilon_{\text{st}}$ ). This experiment would be performed at room temperature and a 1 Hz frequency. (Rodriguez-Rerez and Saja, 1999)

### 6.1.3 *Differential Scanning Calorimetry (DSC)*

This experiment would be used to study characteristic of the liquorice that gelation matrix: The melting point ( $T_{\text{m}}$ ), glass transition temperature ( $T_{\text{g}}$ ), and the crystallinity ( $X_{\text{c}}$ ).

(Rodriguez-Rerez and Saja, 1999)

## 7.0 Conclusion

The colour, flavours and preservatives are only difference between the ingredients of the three liquorice products. The colour, flavours and preservatives make up only a small percentage of the total bulk of the liquorice therefore it is assumed that there are no major differences in the ingredients. Therefore it was assumed that it is possible to compare these liquorice products.

There is no significant difference in moisture content between the three liquorice samples. It was inconclusive whether the final moisture content is a result of different processing methods.

Overall the ESEM of the three liquorice samples were quite successful. The pictures showed differences between the two different processing method of continuous and batch. For the continuous mode platelets and small particle fragments were distributed throughout the matrix structure. These structures were not found in the batch Pascall brand, however the different lipid or fat pockets were found in this brand. Therefore it is possible that the difference in microstructure was a direct result in the processing method.

The mechanical testing did not show any possible difference between the processing methods. In the future, an improved testing method will need to be used to gain good results of elongation and tensile strength of the liquorice. The penetration testing showed a good trend that hardness increased as the plunger speed increase however this test did not show that the hardness of the liquorice could be related to the different processing method.

Further study need to be undertaken to justify if there is any relationship between the viscosity of the liquorice and the processing method.

## 8.0 References and Readings

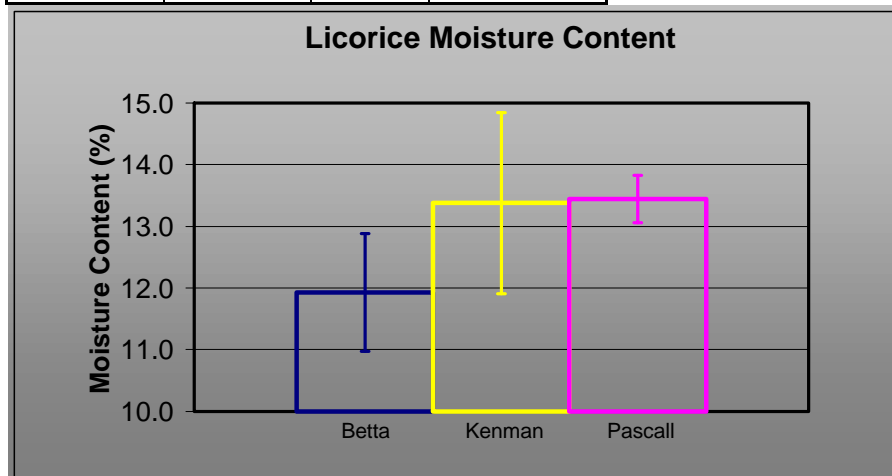
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# Appendix

**Experimental Results***Moisture Content Analysis*

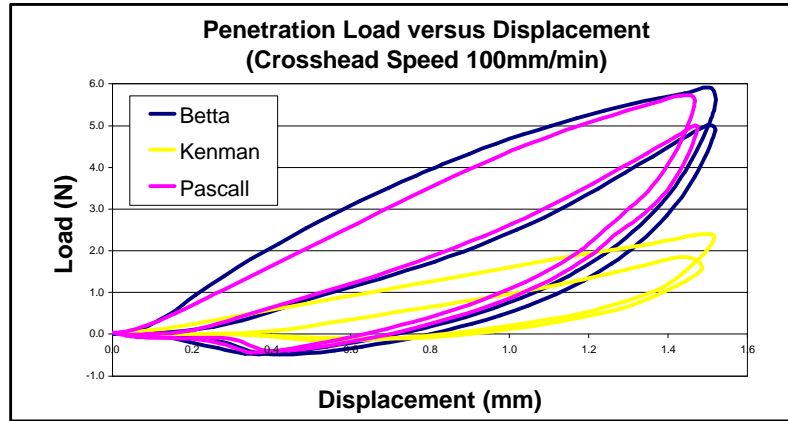
Table 1: Karl Fischer Coulometer Moisture Content Analysis

Specimen	Sample		
	Pascall	Betta	Kenman
1	13.14	11.23	13.43
2	13.52	11.68	14.85
3	13.79	11.25	11.86
4	12.95	13.56	11.94
5	13.81	11.93	14.82
Average	13.44	11.93	13.38
Standard Deviation	0.39	0.96	1.47

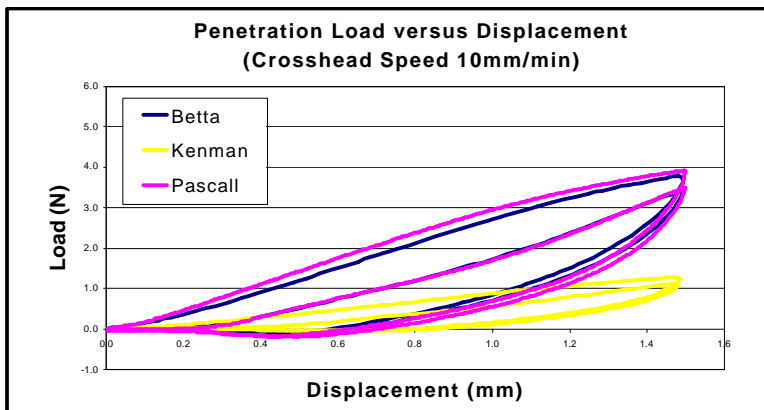
**Figure 1: Licorice moisture content for Betta, Kenman and Pascall brands**

*Mechanical Testing*

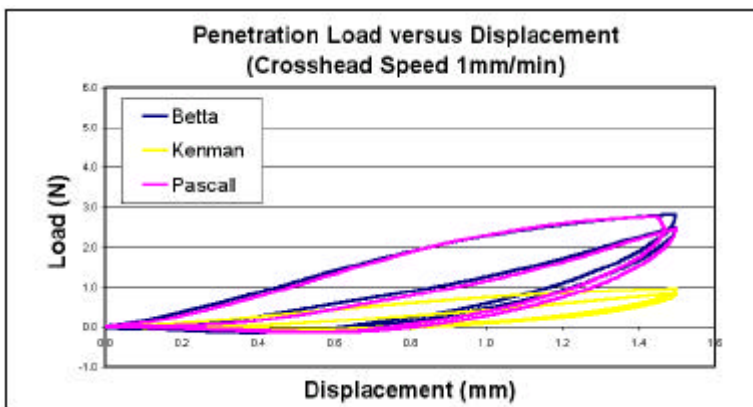
*Penetration Testing*



**Figure 2: Penetration load versus displacement for plunger speed 100 mm/min**



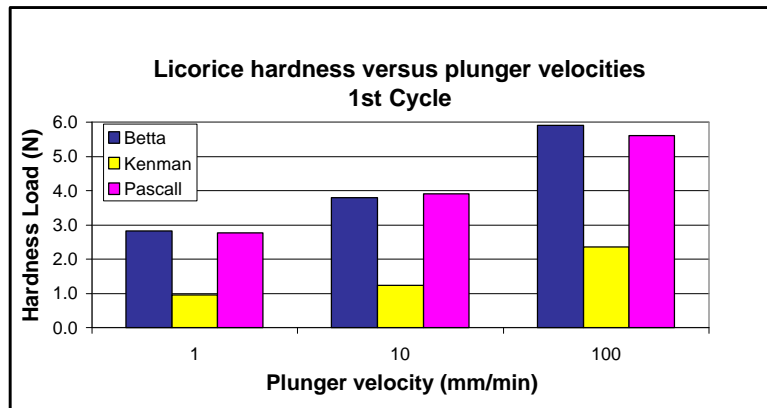
**Figure 3: Penetration load versus displacement for plunger speed 10 mm/min**



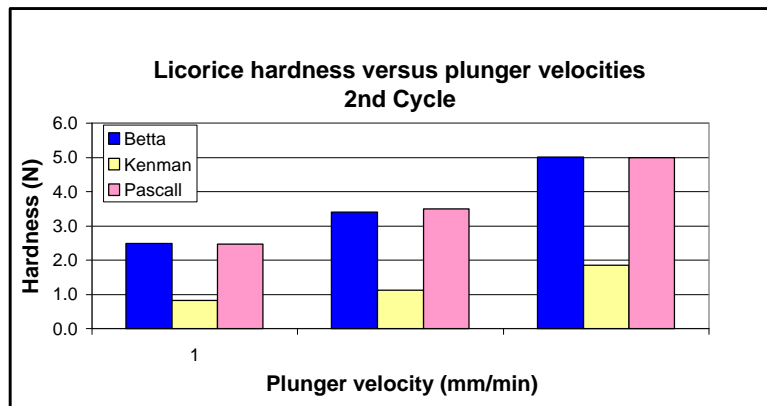
**Figure 4: Penetration load versus displacement for plunger speed 1 mm/min**

**Table 2: Licorice Hardness versus plunger speed per cycle**

Sample	Plunger Speed (mm/min)		
	1	10	100
<b>Cycle 1</b>	Hardness Penetration Load (N)		
Betta	2.822	3.786	5.901
Kenman	0.961	1.250	2.355
Pascall	2.769	3.917	5.605
<b>Cycle 2</b>	Hardness Penetration Load (N)		
Betta	2.488	3.403	5.008
Kenman	0.836	1.127	1.852
Pascall	2.471	3.492	4.992



**Figure 5: Licorice Hardness versus plunger speed for cycle one.**



**Figure 6: Licorice Hardness versus plunger speed for cycle two.**