DEVELOPMENT OF PEANUT BUTTER SLICES

By

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Introduction

Peanuts are very nutritious (26% protein), high in energy, and an outstanding source of vitamin B. Following India and China, the United States of America is the third largest producer of peanuts in the world, but the largest exporter of edible peanuts. The U.S. grew 3.85 billion pounds of peanuts this year (1999). In Oklahoma, 202 million pounds of peanuts (5% of the total U.S. production) were harvested this year, making it the highest quantity output since 1994 (Oklahoma Farm Statistics, 1999).

A "peanut butter" type of product was needed at the end of World War I in 1918, when farmers were seeking a market for the expanding peanut crop that was more lucrative than pig feed (Woodroof,1966). Presently, peanut butter accounts for approximately half of the total food use of peanuts in the U.S. It is estimated that a typical school student will have eaten 1500 peanut butter sandwiches before graduating from high school. Also, peanut butter is adopted as a staple diet by many persons, who, for their own reasons, prefer vegetable foods only. If a new, more convenient form of peanut butter could be made for consumers, its consumption would likely increase. This new and convenient form could be in a slice form, much like cheese, ready to be put on bread. The combination of nutrition and convenience would attract larger consumer markets of every age. Peanut butter slices could become an important value-added product.

Objectives

The purpose of this project was to develop a cheese-like slice from peanut butter. An ideal formulation had a shear-thinning texture that could hold its shape, but become soft when eaten. It also had an acceptable shelf life, and a color and flavor identical to peanut butter. This slice could also be easily peeled from the wrapper, leaving little residue in the packaging material. In an effort to maintain the identity of peanut butter (which according to the FDA, requires it to be 90% peanuts), it was also desirable to limit the amount of additional ingredients in the formulation.

Once an acceptable formulation and process were developed, the main objectives of this project were to determine the effects of processing and storage on the textural stability of the product. Specifically, those objectives were as follows:

1. Determine the effect of different formulations on texture.
2. Determine the effect of final process temperature on texture.
3. Determine the effect of the cooling rate on texture.
4. Determine the effect of storage temperature on textural stability.
5. Determine the effect of storage time on textural stability.

CHAPTER II

LITERATURE REVIEW

Peanuts

The peanut plant is one of the most useful plants in the world. The pleasant aroma, irresistible nutty flavor, and smooth texture of peanuts are enjoyed every day by Americans and people around the world. Peanuts are also found to be very rich in energy. One pound of peanuts provides approximately the energy value of 2 lb. of beef, 1.5 lb. of cheddar cheese, 9 pints of milk, or 36 medium size eggs (Woodroof, 1966). There are several types of peanuts that are grown in the United States. Most common among these types are the Spanish, Virginia, and Runner varieties. Due to its uniformity in size (important to achieve evenly roasted peanuts to get the best tasting peanut butter) the Runner variety is the most widely used type for producing peanut butter. Peanuts are grown primarily in the states of Georgia, Alabama, and Florida in the U.S. Peanuts in the United States are grown mainly for food use in products such as candies, salted peanuts, 'roasted in the shell' peanuts, and peanut butter, with more than 60% of peanut production being used for making peanut butter.

Agricultural Development

Peanuts were found widely distributed in South America, along the Amazon River, mainly in Perú and Brazil. Portuguese slave ships carried the peanut plants from the shores of South America to Africa, from where they made their way to the plains of North America (Higgins et. al, 1941). George Washington Carver is said to have made 300 products from peanuts before World War II. During World War II peanuts were one of the strategic crops grown since a tremendous amount of peanut oil, food, and feed were needed for the war. As a result, a large number of community shelling plants were built. Around 1900, small devices began to appear in the market which enabled women to make peanut butter in their own homes, but the industrial manufacture of peanut butter did not begin until much later (Woodroof, 1966).

Peanut Butter

Peanut butter is undeniably the most important product made from peanuts in the United States. The history of peanut butter is not well known. This history dates back to 1890 when it was discovered that very palatable paste or butter could be obtained by grinding peanuts. It was soon known as peanut butter and it is believed to have been made from raw peanuts (Woodroof, 1966). In 1900 a physician in St. Louis, Missouri was reported to be the first to manufacture peanut butter commercially and recommended it for invalids because of its high nutritional value. At the end of World War I, in 1918, the need for a peanut product such as peanut butter became evident since farmers were looking for a market for the expanding peanut crop which was more lucrative than pig feed (Woodroof, 1966). The commercial production of peanut butter was very disorganized until the Peanut Butter Manufacturers Association was formed around 1940. Until that time, only 25% of edible peanuts were used in production of peanut butter. The manufacturers association started paying more attention to the varieties of peanuts, the operations applied in the manufacture of peanut butter such as roasting, and blanching, as well as the effect of the particle size and some other factors which helped in getting a better product. By 1950, about half of the production of peanuts was used in butter, and by 1964 the proportion had risen to more than 60% (Woodroof, 1966). Peanut butter today is very similar to the first formulations made 100 years ago. It contains about 90% ground, blanched, dry roasted peanuts, 1% salt (flavor enhancer), 7% dextrose (flavor enhancer), and 2% of hydrogenated vegetable oil, lecithin, or whey (stabilizers that prevent the separation of the oil) (Woodroof, 1966). 'Old-fashioned' or 'Natural' peanut butter does not contain stabilizers so the oil will separate. There are three textures of peanut butter: smooth (no perceptible grainy peanut particles), regular (perceptible peanut particles not more than 1/16 inch in diameter), and chunky (partially fine and partially grainy particles of sizes bigger than 1/16 inch. in diameter). There are three grades: Grade A (good color, good consistency practically free from defects), Standard (fairly good color, fairly good consistency, fairly free from defects), and Substandard (fails to meet the requirements of U.S. standards). The first uses were for sandwiches, combination dishes, candies, cookies, ice cream, and many other products consumed in the home, at school, and public places. People of all ages eat peanut butter due to its pleasant flavor, nutritional quality, and stability (it does not spoil easily by bacterial or fungal growth) (Woodroof, 1966).

Current Manufacture Of Peanut Butter

The manufacture of peanut butter is relatively simple, consisting of shelling, dry roasting, cooling, and blanching the peanuts, followed by inspecting, grinding, packaging and storage (Woodroof, 1966).

Shelling

Shelling consists of removing the shell or hull of peanuts with the least damage to the seed or kernels. Hand shelling yields the highest percentage of undamaged kernels and is used by small producers around the world. Machines are also available for shelling. A laser beam inspects the peanuts to remove any immature kernels. After the peanuts are shelled, the kernels are passed over oscillating shaker screens and separators, which remove foreign material, undersized kernels, unshelled peanuts, and split kernels. The kernels then go to a conveyor-belt picking table where defective kernels and any remaining foreign material can be removed by hand. Once the kernels are cleaned, they are graded, sized, and bagged for shipment to market (Woodroof, 1966).

Dry Roasting

Peanuts are roasted by one of two methods: batch or continuous. Batch roasters have many advantages that cannot be met by one big continuos roaster. For example, peanuts frequently come in lots of different moisture content, which need special attention during roasting. This can be done more satisfactorily in batches than by continuous roasting. Not only must each batch be roasted in the same manner, but also all of the peanuts in the batch must be uniformly roasted. The first effect of roasting is rapid drying of the peanuts, in which the moisture content is reduced from about 5% to 0.5%. This is followed by the development of oily translucent spots on the surface of cotyledons, called 'Steam blisters'. Steam blisters are caused by oozing of oil from the cytoplasm as free oil. Change in color is due to the cell walls becoming wet with oil. This stage is referred to as 'white roast'. The skin too becomes wet with oil and darker in color. The final stage in roasting is the development of a brown color, at which time the peanuts are 'done' or 'brown roasted'. The color and flavor of the peanut butter depends on the extent to which brown roasting is allowed to proceed. High roasting temperatures are undesirable because they break down the oils, scorch the surface of the peanuts, and char the broken pieces of loose skin. The ideal temperatures are 800°F in the oven, and 320°F for the final temperature of the peanuts. The ideal roasting time is 40 to 60 minutes (Woodroof, 1966).

Cooling

Heat should be removed from roasted peanuts as quickly as possible to stop the cooking process at a definite point which is expected to produce a uniform product with an even color, and should prevent the loss of too much oil. The hot peanuts pass from the roaster directly to a perforated metal cylinder or cooler box where a large volume of air is pulled through the mass of peanuts by suction fans. The coolers should be designed so that the air is distributed uniformly and the product cooled evenly (Woodroof, 1966).

Blanching

Most peanuts are blanched or whitened by removing the red skins and hearts. Blanching cleans the kernel of dust, molds, possible filth, or other foreign materials. The skins of peanuts contain tannin and the hearts contain a bitter flavor. Hence, the flavor of blanched peanuts is milder than the unblanched. When blanching the peanuts for peanut butter, the hearts are always removed. For other uses of peanuts the hearts are not removed. This kind of blanching is called 'dry blanching'. The peanuts are heated to 280 °F for 25 min to loosen the skin. After cooling, the peanuts are rubbed gently. The skins are rubbed off and blown into porous bags. The hearts are separated from the cotyledons by screening. During heating and blanching there is a loss in weight of about 12%, with 3% due to moisture loss, 4% hearts, and 5% loss in skins (Woodroof, 1966).

Inspecting

After blanching, the nuts are screened and inspected to remove scorched and rotten peanuts, rocks and other undesirable materials. Light peanuts are removed by blowers, discolored peanuts by electric eyes, and metal parts by magnets (Woodroof, 1966).

Grinding and Cooling

Grinding is the simplest but most delicate operation in the process. Peanut butter is made by two grinding operations to avoid damaging the flavor of the peanuts because of excessive temperature. The first operation reduces the peanuts to a medium grind and the second to a fine and smooth texture. In the second grinding operation, salt, sweetener, and stabilizer are added. To prevent overheating, mills are cooled with water jackets. Peanuts should be kept under constant pressure from the start to the end of the grinding process. This is required to ensure uniform grinding and protect the product from air bubbles. To ensure complete and uniform assimilation of all additives into the peanut butter, the mixture may be discharged into a mixing pump where the peanut butter is homogenized. After this, the jars are filled. The temperature for filling the jars should be 85°F to 110°F (Woodroof, 1966).

Packaging

The heat generated by grinding and mixing should be removed immediately to ensure proper crystallization of the fats. Heat exchangers are used to cool the peanut butter from 170°F to 120°F or less before packaging. Vacuum packaging is recommended since exposure to air produces rancidity (degradation of the fats). The main factor in preventing oxidation is proper packaging. A possible solution is to exclude air from the container as much as possible. This also results in reduced firmness, more uniform texture, and less tendency for oil separation. It has been found that even without vacuum packaging, a completely filled and sealed jar contained an insufficient amount of oxygen to cause rancidity to the layer in direct contact with the head space. After being filled, the jars are closed, labeled, and placed in cartons by automatic machines (Woodroof, 1966). Storage temperatures for the finished product should be about 50 °F.

Peanut Butter Slices

Previous products developed

Developing new products from peanut butter has been a goal of the peanut and food industry for a long time. 'Peanut butter spread' is a new category of peanut butter which contains only 60% peanut butter, increasing the addition of salt, sugar, and other undisclosed ingredients. This spread is similar to normal peanut butter but is reduced in fat. Although, by stipulation of the Food and Drug Administration (FDA), peanut butter must contain at least 90% peanuts, the FDA has allowed the use of the name 'peanut butter spread' (How peanut butter is made, 1999).

A number of attempts have been made at developing a peanut butter slice, and several formulations and methods have been patented during the past 50 years. Ayres et al (1973) proposed a method of making peanut butter in slice form. According to this patent, the composition of the peanut butter slice was based on a mixture of peanut butter, and mono-and-diglycerides as stabilizer. Different toppings such as chocolate, nuts, candy, and fruits could be added. These slices were wrapped individually, and were stored at refrigerator and freezer temperatures. Weisgurt (1941) proposed a solidified peanut butter which had the same organoleptic characteristics as the normal peanut butter. It's composition was a mixture of peanut butter and beeswax, which made the butter harder. Another invention, (Castillo, 1994), relates to a non-spread peanut butter slice, where peanut butter was made into a dough mixed with egg white, flour, and emulsifier. This dough was extruded into sheets, which were separated from each other with wax paper to avoid stickiness. Ferguson (1962) proposed a new shape-retaining peanut spread product, which consisted of a mixture of an oil composition (based on hydrogenated cotton seed oil, hydrogenated soybean oil, glycerol monostearate, glycerol monopalmitate, and stearine), non-leachable peanut butter, honey, salt, and skimmed milk. This mixture could take any shape. The product would hold its shape even at warm temperatures and was able to be spread although it was cold. Harrison (1971), describes a layer of peanut butter between two layers of solidified jelly.

The product proposed in this thesis is a peanut butter slice that can hold its shape but become soft when eaten, having an acceptable shelf life, and a color and flavor identical to peanut butter. It should also be easily peeled from the wrapper, leaving little residue in the packaging material. It was also desirable to keep the identity of peanut butter (which requires it to be 90% peanuts), and therefore it was necessary to limit the amount of additional ingredients in the formulation. This new slice is substantially different from the inventions previously described since the high content of peanut butter produces a product of a very different texture and consistency than previous inventions, both during processing, and in its final state. During processing, the product was in a very molten state, making possible the use of the same standard equipment as is used for producing individually wrapped cheese slices. In addition, the process described here creates a final product with improved shelf stability. Problems with the previous products include low peanut content (so that the identity of peanut butter is not maintained), lack of a large-scale processing method, and poor shelf stability.

Since the components of this new product are gums (Agar, and Gellan), starch (Tapi), and wax (Paraffin) a brief introduction will be given for each of them.

Ingredients and Additives

Gums

Gums are substances that associate with water molecules in such a way that the behavior of the water is modified, allowing us to perform functions not normally possible. Hydrogels is the most descriptive term for these materials. Just a small amount of the hydrogel (normally less than 10% of the weight of the water) is needed for this change to occur. Gums are polymers with acidic, neutral, or basic groups scattered among the linear, branched, or cross-linked chain molecules. Solubility in water is a characteristic of many gums and their capacity to yield highly viscous solutions is related to the presence of hydroxyl groups, which form hydrogen bonds with water molecules. Gums are used in the food industry, medicine, graphic arts, boxboard manufacture and many other type of products (Davidson, 1980). Some of the gums used in this research were: CMC, Carrageenan, Agar Gum, Guar Gum, Gum Arabic, Gum Tragacanth, Locust Bean Gum, Xanthan Gum and many others. The selection of these gums for the final formulations will be explained in Chapter III. Following is a brief description of the gums used which yielded the best results.

Agar Gum

Agar is a complex water-soluble polysaccharide, hydrophilic colloid extracted from a marine algae of the class *Rhodophyceae*. It is approved for food use being in the GRAS (Generally Recognized As Safe) list under the Food and Drug Act. Agar occurs as a mixture of at least two polysaccharides: agarose, which is the D-*galactopyranosyl* (gelling agent) and 3,6-anhidro--L-*galactopyranosyl* units coupled 1:3. It forms firm gels at very low concentrations as low as 1%. The gel strength varies in direct relationship to the concentration, which is commonly 1-2%. It is available in various forms. The most common form is a powder which is white to pale yellow, has a mucilaginous taste, and is either odorless or has a slight characteristic odor. Few microorganisms metabolize agar or elaborate enzymes that degrade it. This is a possible reason why agar is very stable over other naturally occurring colloid gels. Agar is among the most potent gel-forming agents known. Gelatin is perceptible at concentrations as low as 0.04%. It is valuable for its diffusion prevention, texture enhancement effects, elasticity, and relative transparency. Agar is used in the food industry predominantly for its stabilizing and gelling characteristics. It has the unique ability of holding large amounts of moisture. Since it is nonnutritive, it is useful in low-calorie foods (Frutarom. User's manual, 1999).

Gellan Gum

Gellan gum is a new hydrocolloid. It has high molecular weight, and is an extracellular heteropolysaccharide. It is produced by fermentation of a pure culture of *Sphingomonas elodea* by NutraSweet Kelco, and is being developed for the food industry. Gellan gum is a gelling agent capable of forming gel at a concentration as low as 0.05%. Its use in the food industry is ideal for a variety of texturizing, stabilizing, and film forming applications. Food texture can be easily modified by this agent (The Nutra Sweet Company User's Manual, 1996).

Tragacanth Gum

Tragacanth gum is a natural vegetable gum extracted from various species of shrubs belonging to the genus *Astragalus*. It is a slightly acidic salt; a complex mixture of polysaccharides containing calcium, magnesium, and potassium. Tragacanth is very stable to changes of pH, and has many uses such as bakery, confectionery, pharmaceutical, and cosmetics (Davidson, 1980).

Starches

Starch is widely distributed as the reserve carbohydrate in the leaves, stems, roots, and fruits of most land plants. It is composed of carbon, hydrogen and oxygen in the ratio of 6:10:5 ($C_6H_{10}O_5$), which is considered a carbohydrate organic compound. Most starches are polymers of glucose (dextrose) and consist of a mixture of two polysaccharide types: amylose, an essentially linear polymer (which units are in the alpha-D-glucopyranose form) and amylopectin, a highly branched polymer (consisting of short linear amylose chains connected to each other by alpha-1,6-linkages). The different properties of starch are determined by the amounts of these two fractions (Galliard, 1987).

Tapioca starch

Tapioca is imported from Thailand and Brazil. It is a high molecular weight carbohydrate produced by processing the tuberous roots of the cassava plant. Its applications are in the manufacture of various products such as textiles, paper, food, pharmaceuticals, and building materials. Its use is based on its thickening, gelling, adhesive, and film-forming properties, as well as its low cost, controlled quality, and ready availability (Zubro User's Guide for tapioca starch, 1999).

Corn Starch

Corn starch is one of nature's major renewable resources. It is white in appearance, acid by nature (pH= 4.5-5.5), its protein content is 0.6%, and its granules are medium and round in shape (Beynum, 1985). Corn starch is widely used in textiles, food (mostly as a cereal), and pharmaceuticals. It is a flocculent, and thickening agent. Ready - to- eat foods are often produced using corn starch because it enables them to keep their proper textural characteristics while being exposed to temperature changes during freezing, thawing, and heating. Corn starch was used as an additive in the beginning of the formulation development of the peanut butter slice.

Waxes

Wax has been around as long as man has roamed the earth. The Egyptians in 4200 B.C. found various uses for beeswax. For example, they used it in the preservation of mummies. The English term wax is derived from the Anglo-Saxon *weax*. The wax components consist mainly of alkyl esters produced by the esterification of high molecular weight alcohol and acids of the ethanol series. The esters are usually in the company of free alcohol or free acid and by end residues of hydrocarbons of very high molecular weight. There are natural and synthetic waxes. Examples of natural waxes include: paraffin wax, microcrystalline wax, mineral waxes, vegetable waxes, and animal waxes. Alcohols and fatty acids, fatty acid esters and glycerides, hydrogenated oils, ketones, amines, amides, chloronaphthalenes, synthetic mineral waxes, and synthetic animal waxes are among the synthetic waxes (Warth, 1956. and Bennett, 1963).

Paraffin wax

The United States Pharmacopoeia defines paraffin wax[1] as a purified mixture of solid hydrocarbons obtained from petroleum. It is a colorless or white, more or less translucent mass and shows a crystalline structure without odor and taste. Paraffin wax is found in crude petroleum and is extracted from the high boiling fraction during the refining process. Paraffins are one of the components of petroleum among olefins,

[1] Synthetic refined paraffin wax is allowed for food use in the United States, (21 CFR, Code of Federal Regulations, 184-1973) (Krochta, 1994) but it's levels should not exceed 0.065%.

naphthenes and aromatics. These differ from one another in chemical structure. Paraffins are saturated open-chain carbohydrates, where the carbon atoms are linked with simple bonds and the remaining valences of the carbon are satisfied with hydrogen atoms. Methane is the simplest paraffin hydrocarbon (CH_4). It is sold in various grades, which differ from one another mainly in the melting point. The melting point of a wax is not a main determinant of the wax quality because it varies depending on the melting point of its constituents. The characteristics that determine the quality of the paraffin wax are oil content, stability to light, and tensile strength. The most commonly used grade of paraffin wax is the refined grade. This type of wax is hard, contains a very small percentage of oil, is tasteless, odorless, and is stable to light. These characteristics are very important in the manufacture of the peanut butter slices since it will be undesirable to change the organoleptic characteristics of the peanut butter (Bennett, 1963).

Beeswax

Beeswax is secreted by the honey bee for building its combs. Chemically, beeswax is composed of myricyl palmitate, cerotic, and long-chain carboxylic acids. It is amorphoid by nature, and its color varies from a deep brown to a light taffy shade. Beeswax has a distinctive honey odor and an aromatic taste. It is used in candles, confectionery, cosmetics, medicines, etc. (Bennett, 1963)

CHAPTER III

PEANUT BUTTER SLICE DEVELOPMENT

Peanut Butter Slices Description

The development of a new product is always a challenge. Imagination, good will, and perseverance are important factors in achieving this goal. As stated before, the ideal peanut butter slice would have certain characteristics that make it both unique and convenient. The slice would be easily peeled from the wrapper and would be flexible enough to keep its shape without breaking. The target peanut butter slice would keep the flavor, aroma, and color of the original peanut butter. Ideally it would be made mostly of peanut butter, thus keeping the identity of peanut butter and would have a shear-thinning texture which holds its shape when stored at room temperature (22°C) or at refrigeration temperatures (4°C).

Formulation Development

A number of different ingredients have been tried such as gums, starches, wax, water, oil, and peanut butter. The behavior of these ingredients with the peanut butter, and the interaction among them, resulted in development of various formulations and procedures. Table I shows the range of percentages of each ingredient tried during formulation development. Different mixing procedures are described in subsequent sections of this Chapter.

Table I. Percentage by Weight of Ingredients added in Stage One of the Peanut Butter Slice Formulation

Ingredient	% Added
Peanut butter	40.54-84.75
Gum	0.42 - 5.41
Starch	1.41 - 4.05
Wax	1.41 - 4.05
Oil	5.41-5.65
Water	6.35 - 40.54

For these formulations, (listed in Table I) several different ways of mixing, heating, and adding the ingredients were tried. These different methods are described below.

Method 1

Hot vegetable oil was mixed with heated wax, starch, and gum. The ingredients were thoroughly mixed. Peanut butter was added and the mixture was stirred and poured into the molds to cool. Once the mixture was cool, the slice was wrapped and kept at room temperature. This method was discarded because the starch and gum did not dissolve in the mixture, and formed lumps.

Method 2

The vegetable oil was heated to dissolve the gum, and the wax was added to the heated mixture until the wax was melted. Starch and peanut butter were added and mixed. The paste was spread on molds to cool. The problem with this method was that the gum did not dissolve in the hot oil, but burned and formed lumps. This method was also discarded.

Method 3

A mixture of vegetable oil and gum was added to the heated wax. While stirring and heating the mixture, starch and peanut butter were added. The ingredients were thoroughly mixed, and the mixture was poured into the molds to cool. Again, in this method the gum did not dissolve in the cold oil, and the starch formed lumps when added.

Method 4

The wax was heated and mixed with vegetable oil, the gum and starch were added, and all the ingredients were mixed while being heated. Then the peanut butter was added. The mixture was poured into the molds to cool. This method was also discarded because the gum did not dissolve in the hot mixture and burned causing the color to change to dark brown. The starch also formed lumps.

During the use of these procedures approximately 150 different formulations were developed. The gums used were agar-agar, guar-gum, a mixture of Xanthan and guar-gum (Vis*Quick 21), a mixture of two types of Carrageenan (bengel WG-2000 and Carrageenan bengel CI-200), a mixture of cellulose gel and sodium carboxylcellulose (AVICEL).

Since the major problem encountered with these procedures was the dissolution of the gums and starch, water was added to the formulation to dissolve both ingredients. The quantity of water used is shown in Table II. Oil was excluded from the formulation because the slices become very oily after approximately 20 days of storage. The process was also changed significantly. To dissolve the gum in water, a blender was used to improve the dispersion of the gum. Three new different methods were tried, as described in methods 5 to 7.

Method 5

Water and gum were blended forming a gel. The starch was dissolved in water and added to the gel. All the mixture was blended for three minutes, and added to the peanut butter, which was mixed with the hot wax. All the ingredients were mixed and poured into the molds to cool.

Method 6

Water, starch, and gum were blended. The gel formed was added to the hot mixture of peanut butter and wax. The ingredients were mixed by hand and poured into the molds to cool.

Method 7

Water and gum were blended (if necessary, hot water was used to better dissolve the gum). The gel formed was added to a hot mixture of peanut butter and wax. While mixing the ingredients, the starch which had been previously dissolved in water, was added. All the ingredients were mixed thoroughly and poured into molds to cool. The slice was then kept at room temperature.

After making some samples with the three different procedures mentioned above, it was observed that there was no difference in the characteristics of the final product when using method six or seven. Since it was simpler, method six was chosen to be used for further peanut butter slice production.

In this second part, 692 new formulations were developed using method 6 and the following gums: CMC and Cellulose gel (AVICEL), Arabic, Tragacanth, Tragacanth (M-3), Locust bean, CMC (Carboximethil cellulose), HPC (Hydroxipropyl methylcellulose), Guar gum, Xanthan, Xanthan and Locust bean, Locust bean (A-100), CMC and HPC, Carrageenan, VQ21, Carrageenan (bengel WG-2000) and Carrageenan (bengel CI-200). Two temperatures of water (hot and cold) were used when blending the gum. Table II shows the range of percentages of each ingredient used in this second stage of development.

Table II. Percentage by Weight of Ingredients Added in the Slice Formulation, Stage Two

Ingredient	% Added
Peanut butter	79.96-65.59
Gum	0.75-2.16
Starch	5.33-6.56
Water	11.33-19.13
Wax	2.64-6.56

Method six was good when hot water (50°C) was used to dissolve the gum but a change in color was often observed. HPC was tried in an attempt to give more elasticity to the slice, but this addition greatly changed the color of the slices. A big change in color was also obtained when working with VQ21, Carrageenan (bengel CI-200), CI and

Carrageenan (bengel WG-2000), and Avicel. The best samples were obtained using Avicel and Guar gum, with method number six using hot and cold water (50°C, and 18°C). Good results were obtained when using Locust bean, Arabic, Tragacanth, Xanthan, Xanthan and Locust bean (1:1), Xanthan and Locust bean (0.6:0.4), Tragacanth M-3, Locust bean A-100, CMC L-60.

In an intent to reduce the number of added ingredients, starch was taken out of the formulation. Various new formulations were tried without starch. The best formulations obtained were the ones in which the following gums were used; Locust bean, Arabic, Xanthan, Xanthan and Locust bean (0.6:0.4), Locust bean A-100, CMC L60, and Tragacanth M-3. The slices made with the last three gums were the best because they were very elastic and clean peeling. However, they were very easy to break because of elongation. As a result, the gums used in the slices without starch were the following: Xanthan, Locust bean, a mixture of Xanthan and Locust bean, and Avicel. With this change in formulation, the number of ingredients was reduced to four; namely peanut butter, gum, water, and wax. Using method six for preparation, 160 different formulations were developed, varying the amount of ingredients as shown in Table III.

Table III. Percentage by Weight of Ingredients added in the Slice Formulations without Starch.

Ingredient	% Added
Peanut butter	73.98-85.71
Gum	1.14-1.60
Wax	2.86-9.86
Water	10.29-14.55

Seven formulations were selected using the four gums mentioned above. These formulations are described in Table IV.

Table IV. Peanut Butter Slice Formulations without Starch

	Formulation (g)						
Sample	1	2	3	4	5	6	7
Peanut butter	30	30	30	30	30	30	30
Gum	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Water	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Wax	1	1.5	2	2.5	3	3.5	4

Best Formulations and Process Selection

The shelf-life of the slices was approximately fifty days, being stored at 22°C. Mold grew on them after this time and the appearance was oily. To reduce the amount of moisture in the slice a formulation without water needed to be tried. Reducing the moisture would reduce the water activity of the slice, causing the shelf- life of the slice to increase. The new formulation consisted of peanut butter, gum, and wax. The amount of these ingredients were the ones mentioned in Table IV and the gums used were Xanthan, Avicel, Locust bean, and a mixture of Xanthan and Locust bean. Since the gum could not be dissolved in water, new methods were also developed for these formulations. Those new methods are described below.

<u>Method 8</u>

The wax was heated and mixed with the peanut butter. The powdered gum was added to the hot mixture. All the ingredients were mixed thoroughly at a high speed (3) using a Hamilton Beach three speed electric hand mixer (type MO8, model 2300) and heated (61°C) for 10seconds. This mixture was poured into the molds and cooled at room temperature. This method worked very well since, for the first time a homogeneous mixture was obtained without lumps being formed by the gum. Also, the slice did not suffer any change in color or present an oily appearance.

Method 9

Another method tried was using a Waring Commercial two speed (high and low) laboratory blender (Model 31BL40), rather than using a mixer. The peanut butter was blended while the hot melted wax was added. Finally the gum was added also while blending at a high spedd. The resulting mixture was very thick and needed to be spread on the molds instead of being poured. The gum did not dissolve completely, forming lumps, and the mixture could not be heated being in the blender. Method 8 was adopted as the preferred method.

At this point, some slices were elastic, others were sticky and did not peel easily, and still others were hard and broke when peeled, so the formulation needed to be modified. After developing 100 different formulations, the best slices (slices that did not break when where peeled) resulted from having levels of wax ranging from 3.16% - 6% and levels of gum ranging from 1.9%- 3.33% . The best slices obtained were the ones in which Locust bean and Xanthan gums were used. In the samples which utilized Avicel gum, the slice was too soft to be peeled or too hard to be peeled without breaking it. Also, the slices made with Xanthan mixed with Locust bean were soft, and oily. All these gums produced an off-flavor (not characteristict flavor) in the slice. In the aim of developing a better slice, new gums and a starch were tried. The gums were: Gellan gum, Tragacanth, Carboximethylcellulose 9000 (CMC), and Agar-Agar gums. The starch tried was Tapi (from Tapioca starch).

Many new formulations using method 8 were developed combining different levels of wax (3.16-6%) with these gums. It was found that the texture of the slice changes depending on the temperature of process so a new better way of controlling the temperature at the time of heating the mixture was needed. Applying nine different temperatures of heating the ingredients with nine different times ranging from three seconds to thirty seconds, 210 new formulations were developed. Since a wide range of different textures (very soft to very hard) developed, it was difficult to determine what texture was going to be acceptable by the average consumer, and whether or not the gums were going to give "off-flavors" to the slice. An informal test panel was conducted to decide what texture was preferred and which gums did not give any kind of off-flavor. Although the softer texture was the favorite one of the panel, it was not the ideal one for peeling the slice, since it did not peel cleanly from the wrapper. The texture chosen for further studies was using 2.48% gum and 4.64% wax. With this formulation, the slice developed was not too soft or too hard and was easily peeled. The best tasting slices chosen by the panel were the ones in which Agar-Agar, Gellan gum, and Tapi were used. These ingredients did not leave any kind of off-flavor in the slice.

Final Formulation and Process Selection

Controlling the process temperature at the time of mixing the ingredients was very important, since the texture of the slice changed greatly with temperature changes. A water bath and a hand mixer were used. The bath was a circulating bath model 911 manufactured by Fisher scientific, using an immersion circulator model 71 1112 with an analog controller. With this water bath, three different water temperatures for mixing the ingredients were applied: 78°C, 70°C, and 60°C. The temperatures achieved in the mixture were approximately 61°C, 56°C, and 47°C, respectively. The final process consisted of melting the wax (at the temperatures mentioned above), adding the peanut butter (Jif creamy peanut butter)[2] to the hot wax (Gulf wax, household Paraffin wax) while mixing, and finally the powdered gum (Agar-Agar, from Frutarom, and Gellan gum, from The Nutra Sweet company) or starch (Tapi, by Zubro, Inc.) was added to the hot mixture. After mixing the ingredients thoroughly for two minutes, the hot mixture was poured into the molds and cooled.

The final formulation consisted of 94.9-90.9 % peanut butter, 1.8-3% gum or starch, and 3.1-6% wax.

[2] The slice was made with already made Jif creamy peanut butter. The making of the peanut butter was not part of the research.

CHAPTER IV

EXPERIMENTAL DESIGN AND TEXTURE STUDIES

Experimental Design

Experimental design is a strategic weapon for developing new robust products, reducing time to market, improving quality and reliability, and reducing life-cycle cost. Proper design of an experiment turns new inventions into useful products. One of the objectives of experimental design is modeling. Regression Analysis techniques must be used to generate the applicable predictive model (Blake,1994). The design of experiments permit us to study the effects of the numerous variables that are involved in a given process. The inputs (variables) in any given process must be varied in order to observe the effect of each on the output (Regis, 1993).

Once the final product three formulations were chosen, the primary objective was to evaluate the textural stability of the slices under various storage and process conditions.

In this case, a full factorial design was chosen, because there were more than two primary independent variables which were: process temperature, cooling rate, storage temperature, storage time, and formulation. The full factorial design involved running all combinations of conditions of the independent variables and observing the effects of all primary variables and their interaction in all combinations. This factorial was a 3x2x3x5x3 factorial. Hence, it required all 270 combinations of 1 variable (cooling rate

'CR') with two conditions, 3 variables with three conditions each (process temperature 'PT', storage temperature 'ST', and formulation 'F'), and 1 variable with five conditions (storage time 'St'). From Figure 1, it can be seen that three different formulations were each processed at three different temperatures, cooled at two different rates, (the cooling of the slice was achieved by exposing the slice at two different temperatures –21°C and 20°C. The slices were cool for 2 minutes inside a freezer which was set to –21°C, and for ten minutes over the shelf at room temperature 22°C. Each slice was then wrapped individually and stored after setting for one hour), stored at three different temperatures, and then tested at five different time intervals

The texture analysis was performed at time intervals of one hour, one day, one week, one month, and two months after the making of the slices. The slices at the same time were kept at storage temperatures of 4°C (refrigeration), 22°C (room temperature), and 35°C (warm) for each of the times mentioned above.

. The number of true replications (replications done at different days), were 4 for each of the 270 combinations. The replications were prepared independently of one another at the same treatment combination. This means that a total of (4 times 270) 1080 samples (peanut butter slices) were made. Texture analysis was performed on each one of these samples. Taking a total of six sub-samples from each slice. The round shaped sub-samples were taken randomly (all of them having the same size), mainly from the center of the slice, avoiding the edges (sometimes the edges were thinner than the rest of the slice), or some other thinner part. The resulting TPA parameters attained included 'hardness', 'adhesiveness', 'cohesiveness', 'gumminess', 'chewiness', and 'resilience'.

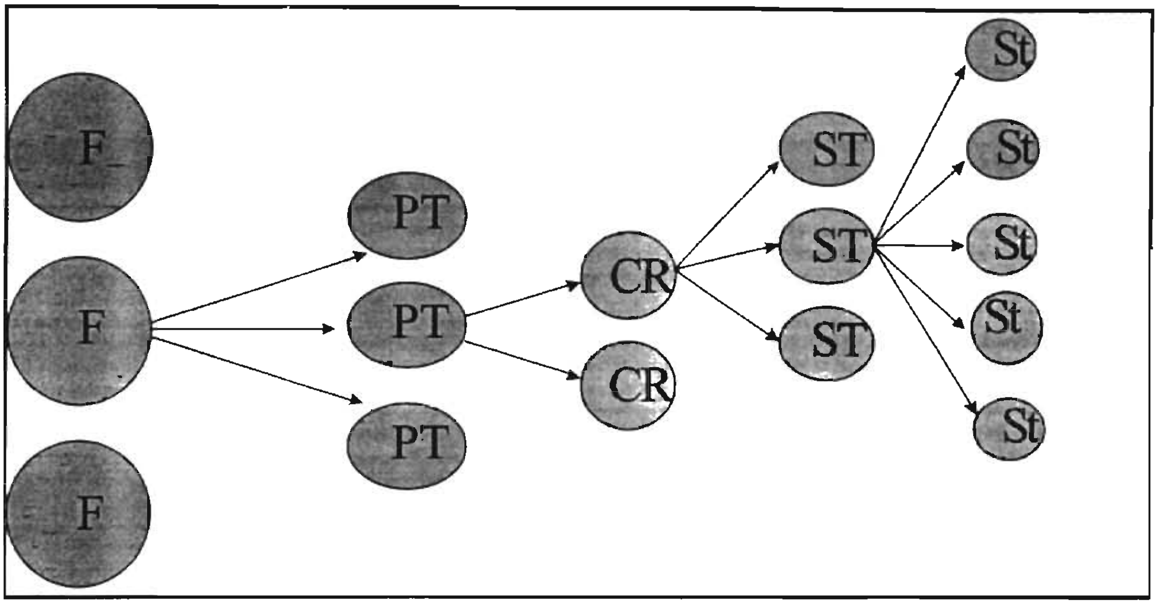

Figure 1. Full Factorial Experimental Design F= formulation, PT= process temperature, CR= cooling rate, ST= storage temperature, St= storage time.

Texture Studies

Texture analysis was conducted using a Texture Analyser (TA-XT2I from Stable Micro Systems) and the Texture Profile Analysis Method. The slices were taken out of their storage locations (room, refrigerator, or oven) one by one to be tested (taking care that no difference in time existed from when they were taken out from the storage place until their texture was measured this was done to avoid changes in temperature). Six measurements (observations of each sub-sample) on each slice sample (of a total of 1080) were made.

Definition of Terms

In this sub-section, a brief definition of the textural parameters is presented

(Texture Analyser user's manual, 1996)

Hardness (g_f).

It is the force (given in g-f) necessary to attain a given deformation

Adhesiveness (g_f sec).

It is the quantity which represents the work necessary to overcome the attractive forces between the surfaces of the sample and the surface of the probe with which the sample comes into contact

Cohesiveness (no units).

It is the quantity which represents the strength of the internal bonds making up the body of the sample.

Gumminess (g_f)

It is the quantity which represents simulate the energy required to disintegrate a semi-solid sample to a steady state of swallowing. (Hardness*Cohesiveness)

Chewiness (g_f).

It is the quantity which represents the energy required to masticate a solid sample to a steady state of swallowing. (Hardness*Cohesivenness*Springiness)

Resilience(no units).

It is a measurement of how the sample recovers from deformation.

Texture Profile Analysis

Texture Profile Analysis (TPA) of the slice was obtained by subjecting a slice sample to an increasing force (two compression cycles) and measuring the deformation that results. This test is also called the "Two Bite Test" A 2.5- mm diameter, acrylic cylinder probe was used for the texture analysis (cylinder probes measure compressive and shear forces). The settings to run the test were as follows: Pre-test speed 5.0-mm/s, test speed 2.0-mm/s, post test speed 5.0-mm/s, distance 3 mm (it is the distance we want the probe to travel), threshold 0.15 newtons. (Texture Analyser user's manual, 1996)

Figure 2 shows a typical TPA result curve and the generation of the resulting parameters.

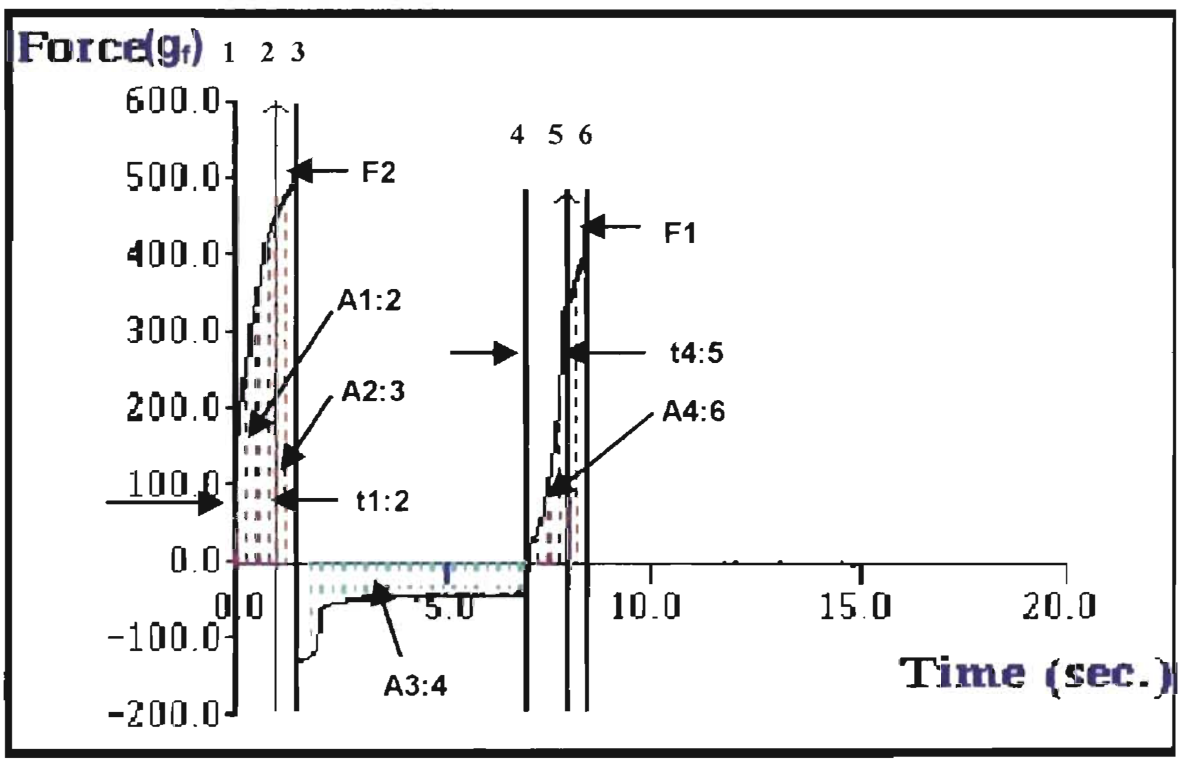

Figure 2. Typical TPA Curve

Referring to Figure 2, the formulas and values used by the Texture Analyzer software in the calculation of the textural parameters are as follows:

• Hardness	F2
• Adhesiveness	A3:4
• Cohesiveness	A4:6 / A1:3
• Gumminess	F1 * Cohesiveness
• Resilience	A2:3 / A1:2
• Springiness	t4:5 / t1:2
• Chewiness	Gumminess * Springiness

Statistical Analysis

The main objective of the texture studies was to be able to predict the texture of the slice by studying the effects of the independent variables on the dependent ones. To achieve this objective, statistical analysis was performed. Since the design had more than two treatment groups such as process temperature, cooling rate, etc., and it was unbalanced (unequal number of observations per cell) a "Multivariate General Linear Model" GLM Analysis was performed instead of performing a "Multivariate Analysis of Variance" ANOVA. The only difference between GLM and ANOVA is the mathematical methods used for each, and some other additional information that is computed when GLM is used. Also, ANOVA is only used for balanced designs. The methods tested whether there are any differences between the groups with a single probability associated with the test. The hypothesis tested was that all groups had the same arithmetic mean (Cody, 1997). After performing the GLM analysis, we were able to determine which terms (independent variables) of the process significantly influence the texture of the slice. The interactions taking place among these terms and their significance in the texture was determined. A detailed analysis of the output was performed to understand the nature of the main effects and the nature of the interactions a main effects plot and an interaction plot of the analysis of means 'Least Square Means' were used. Then a Hsu's MCB (Multiple Comparison test with the Best) was performed for further understanding of the results already gotten. This test helps us see where the real differences among the treatment combinations are. The MCB test checks to obtain a confidence interval for the difference between each level mean and the best of the other level means. The largest mean is considered the best. Means with the same letter are not significantly different. For more statistical data about this test refer to Appendix D.

Finally, a "Multiple-Regression Analysis" was done. This form of analysis is a method for relating two or more independent variables to a dependent variable (Cody,1997).

CHAPTER V

RESULTS AND DISCUSSION

This chapter presents the statistical analysis performed on the process variables. that were involved in the manufacture of the peanut butter slice, and their effect on the texture variables (hardness, adhesiveness, cohesiveness, gumminess, chewiness, and resilience). Process variables tested included: Temperature (PT), Cooling Rate (CR), Storage Temperature (ST), Storage Time (St), and Formulation (Form).

The texture of the slice was greatly dependent not only on it's formulation, but also on the process parameters. This was significant when considering the main effects of the process variables on the texture variables and also when considering the two-way interaction among these variables. Although three, four, and five-way interactions existed and were also significant; this study focused only on the two-way interactions.

Statistical Analysis

The subsequent sections of this chapter will discuss in detail the main effects of the process variables on the dependent variables and the two-way interactions of the independent variables on each of the dependent variables. For each dependent variable, the results, including GLM, Main Effects Plot, Regression Analysis mathematical model, Interaction Plot, and Hsu's MCB Multiple Comparison test, are presented.

Hardness

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction on hardness. Table V is an Analysis of Variance (ANOVA) table for hardness, using the adjusted sum of squares (SS) values for the statistical tests.

Table V. Analysis of Variance for Hardness using Adjusted SS

Source	DF	Adj. SS	Seq. SS	Adj. MS	F	P
PT	2	3316200	2055500	1027700	31.41	<0.001
CR	1	1018600	332770	332770	10.17	0.001
ST	2	260830000	187180000	93592000	2860.75	<0.001
St	4	9343800	6604600	1651200	50.47	<0.001
Form	2	729950	530770	265390	8.11	<0.001
PT*CR	2	77177	42893	21446	0.66	0.519
PT*ST	4	178880	219010	54753	1.67	0.153
PT*St	8	1216700	672440	84055	2.57	0.009
PT*Form	4	832280	729050	182260	5.57	<0.001
CR*ST	2	336010	182110	91057	2.78	0.062
CR*St	4	448080	248880	62220	1.9	0.107
CR*Form	2	539330	430620	215310	6.58	0.001
ST*St	8	57290000	41100000	5137500	157.03	<0.001
ST*Form	4	509780	364760	91191	2.79	0.025
St*Form	8	849650	541250	67656	2.07	0.035
PT*CR*ST	4	1288500	931170	232790	7.12	<0.001
PT*CR*St	8	673940	319180	39898	1.22	0.283
PT*CR*Form	4	781800	498570	124640	3.81	0.004
PT*ST*St	16	1760200	1403300	87705	2.68	<0.001
PT*ST*Form	8	1349500	1131800	141480	4.32	<0.001
PT*St*Form	16	1993800	1719000	107440	3.28	<0.001
CR*ST*St	8	749730	858110	107260	3.28	0.001
CR*ST*Form	4	652690	498760	124690	3.81	0.004
CR*St*Form	8	415310	180370	22546	0.69	0.702
ST*St*Form	16	1017500	915030	57189	1.75	0.032
PT*CR*ST*St	16	754690	553020	34564	1.06	0.392
PT*CR*ST*Form	8	1032700	824910	103110	3.15	0.001
PT*CR*St*Form	16	614230	422230	26389	0.81	0.680
PT*ST*St*Form	32	1893200	1672800	52276	1.6	0.018
CR*ST*St*Form	16	661200	577430	36089	1.1	0.345
PT*CR*ST*St*Form	32	1530900	1530900	47841	1.46	0.045
Error	5976	195509020	195509020	32716		
Total	6245	550196266				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice in Table V is that the effect of the main factors ('PT', 'CR', 'ST,' 'St', and 'Form') on the texture of the slice is very significant ($P<0.05$). The impact of these variables on hardness is shown in Figure 3. After performing the MCB comparison test we are also able to observe (Figure 3) which of each of the independent variables' means are statistically significant among each other for hardness. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

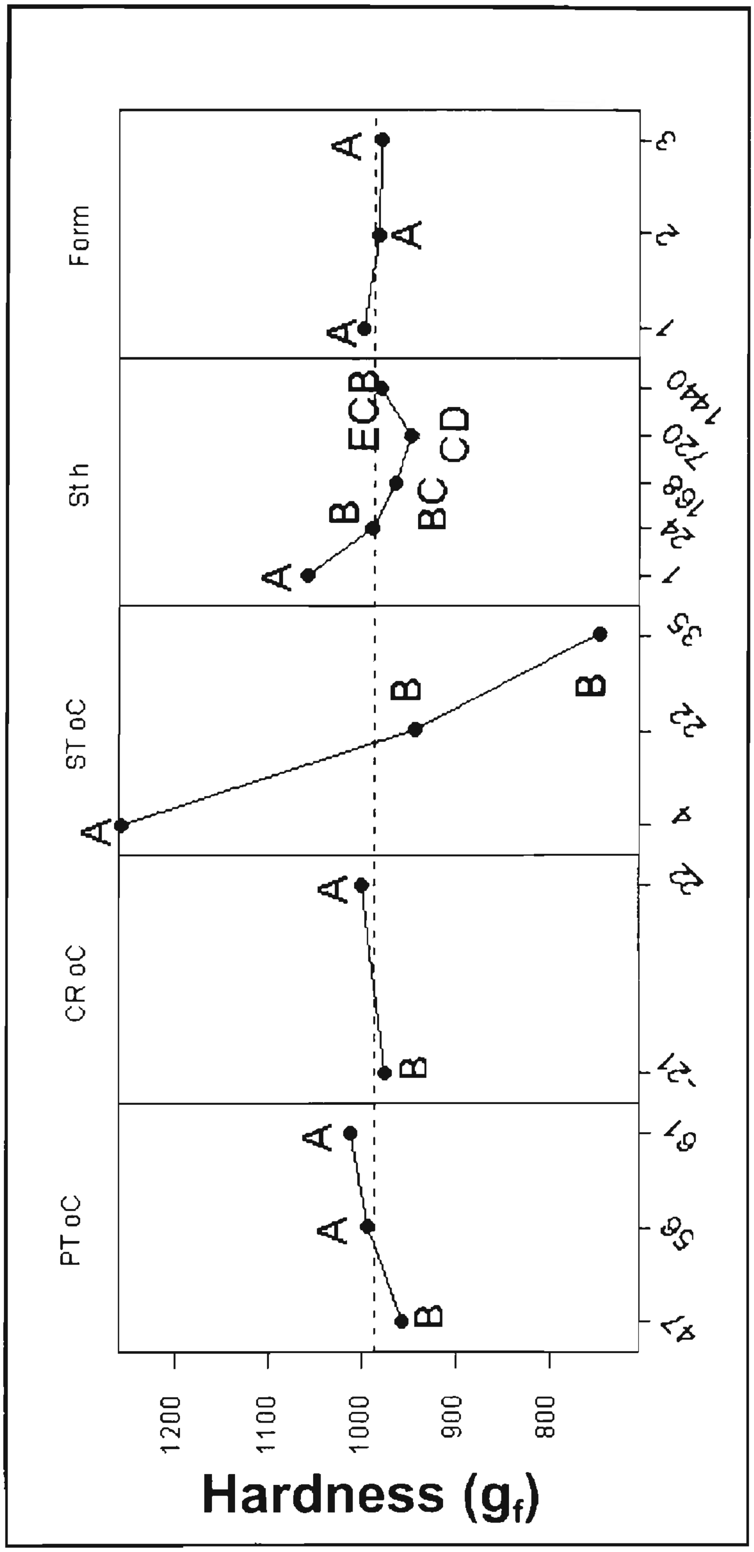

Figure 3. Main Effects Plot – Data Means for Hardness[3]

[3] The horizontal dashed line represents the great mean which is the mean of means.

From Figure 3, it can be observed that Storage Temperature (ST) is the main factor that affects the hardness of the slice, since the range of variation in hardness values is the widest (1200 g_f. <hardness<800 g_f.). Hardness is greatly affected by the storage temperature and the lower the temperature of storage, the harder the slice is. It is also observed that formulation and cooling rate have minimal effect on hardness as the range of variation in the values of hardness for those variables is not very wide (980 g_f<=hardness<=1000g_f). From the MCB test (see Appendix D1) we can see that the best treatment combination for hardness is.

PT=61°C, CR=22°C, ST=4°C, St=1,24,1440 hrs, Form=1.

The linear equation obtained from the 'Multiple Regression Analysis' is a mathematical model of the relationship between the independent variables and the dependant variable, hardness.

The regression equation is:

$$Hardness\ (g_f) = 1148 + 3.52\ PT + 0.36\ CR - 16.25\ ST - 0.03\ St - 6.46\ Form$$

Further details on the Regression Analysis performed on the response variable , hardness are presented in Appendix C1.

The second thing to notice in Table V is that there are strong two-way (P<0.001), three-way (P<0.001), and four-way (P=0.001) interaction terms. The five-way interaction term (P=0.045) is not that strong. The "strongest" interaction terms for hardness are presented in Table VI.

presented in Table VI.

Table VI. Most Significant Interactions Terms for Hardness

Interaction	Independent Variables						
two-way	PT* St	PT*Form	CR*Form	ST*St	---	---	---
three-way	PT*CR*ST	PT*CR*Form	PT*ST*St	PT*ST*Form	PT*St* Form	CR*ST*St	CR*ST*Form
four-way	PT*CR*ST *Form	PT*ST*St*Form	---	---	---	---	---
five-way	---	---	---	---	---	---	---

Since a large number of independent and dependent variables were involved in this experimental design, it would be inconvenient to show an individual figure for each of the interactions, since 120 interaction plots would be required to be plotted and analyzed. However, since the concept in analyzing these interaction plots is the same, one individual two-way interaction plot is plotted and analyzed as an example for each of the dependent variables. Following this figure, the remaining two-way interaction plots are plotted in a single figure called the 'Full Interaction Plot' for each of the dependent variables.

The best way to understand the effects of these interactions on hardness is through an 'interaction plot'. An interaction plot provides a graphical representation of the significant interactions between the independent variables. Perpendicular lines or intersecting lines indicate that a significant interaction exists between the terms. Parallel lines indicate that interaction does not exist between the terms. As an example, the ST*St interaction term is analyzed in the interaction plot shown in Figure 4, since ST*St is one of the interactions that is strongly statistically significant for hardness ($P<0.001$).

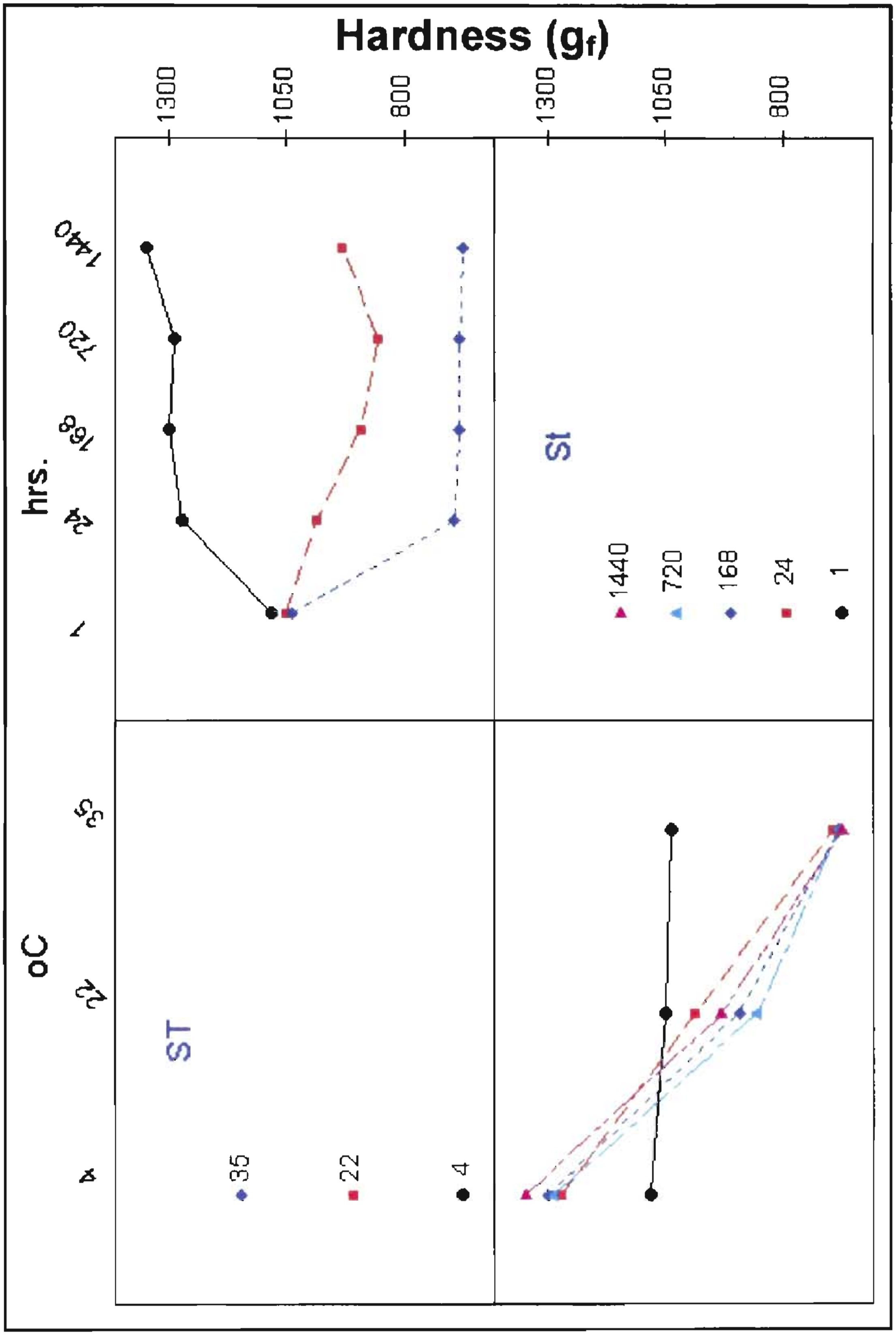

Figure 4 Interaction Plot (ST*St) – Data Means for Hardness

In Figure 4, it is observed that hardness is strongly affected by the interaction between ST and St. The texture of the slice changes abruptly (decrease in hardness) after 24 hours of storage at 35°C. There is no significant change in hardness for the next period of two months. The opposite happens when storing the slice at 4°C. In this case hardness tends to increase as the Storage Temperature decreases. The least change in the slice texture is noted when it is stored at 22°C (room temperature). The Main Effects Plot and the Interaction Plot lead to the same conclusion: the slice is harder when it is stored at low temperatures. The difference is that from the interaction plot the rate of change (increase or decrease) of hardness can also be determined.

The third thing to notice in Table V is that the terms that do not interact are PT*CR (P=0.519), PT*ST (P=0.153), CR*ST (P=0.062), and CR*St (P=0.107) (See also Figure 5). Another noteworthy observation is that although the process variables by themselves have a great effect on hardness, their interaction may not be significant. This can be observed in Table V where it can be seen that 'PT' affects hardness significantly, as well as 'ST'. However, when they (PT*ST) interact the effect on hardness is not significant anymore (P=0.153). A two-way interaction plot for all the independent variables is shown in Figure 5.

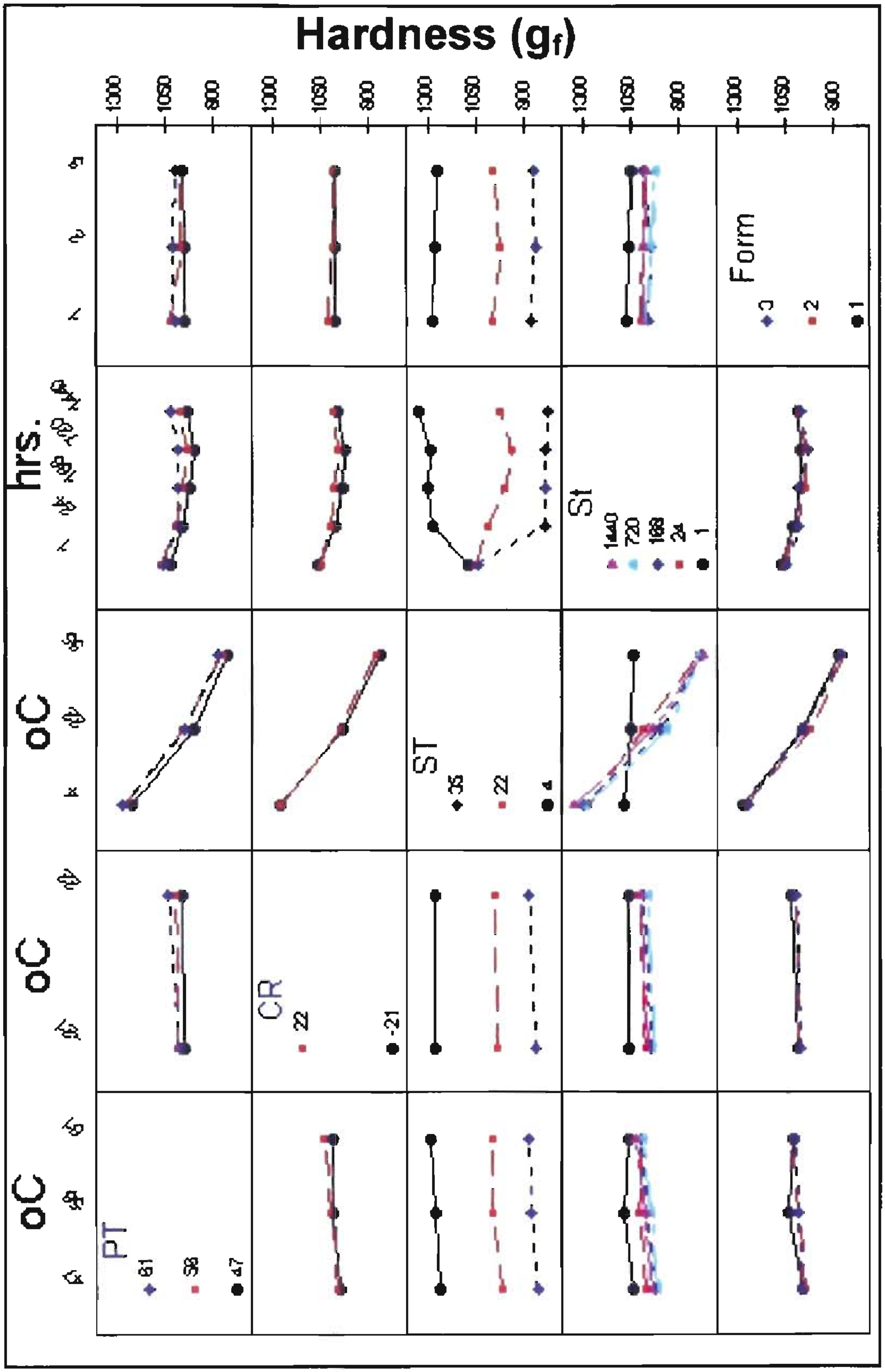

Figure 5 Full Interaction plot – Data Means for Hardness

In Figure 5, the statistically significant and not significant interaction terms can be identified. As an example, if an interaction term is analyzed such as ST*CR (P=0.062), a quick look at the parallel lines in the interaction plot indicate that the variables St and CR do not interact and the interaction is not statistically significant. In performing a detailed analysis of this interaction plot, it is observed that the slice is equally hard when it is cooled at –21°C or at 22°C (i.e. the value of hardness at –21°C or 22°C is almost the same) and kept at a Storage Temperature of 4°C. Similarly, when the slice is stored at 22°C and 35°C, the cooling rate does not affect hardness. The analysis of all the other two-way interaction plots in Figure 5 can be performed in a similar way. It is concluded that the process variable that has the strongest effect on hardness is Storage Temperature (widest rage of variation of the values of hardness), and the interaction terms that have the strongest effect are ST*St (P=0.000), PT*Form (P=0.000), CR*Form (P=0.001), and PT*St (P=0.009).

<u>Adhesiveness</u>

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction on adhesiveness. Table VII is an ANOVA table for adhesiveness, using the adjusted sum of squares values for the statistical tests.

Table VII. Analysis of Variance for Adhesiveness, using Adjusted SS for Tests

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT	2	3529721	3297812	1648906	45.72	<0.001
CR	1	4454581	3013123	3013123	83.54	<0.001
ST	2	21179636	11699813	5849907	162.2	<0.001
St	4	1479133	784406	196102	5.44	<0.001
Form	2	1616243	780047	390024	10.81	<0.001
PT*CR	2	205167	122628	61314	1.7	0.183
PT*ST	4	3996915	4246229	1061557	29.43	<0.001

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT*St	8	1985909	995670	124459	3.45	0.001
PT*Form	4	370610	461487	115372	3.2	0.012
CR*ST	2	4456261	2837215	1418607	39.33	<0.001
CR*St	4	1500312	853629	213407	5.92	<0.001
CR*Form	2	907904	673480	336740	9.34	<0.001
ST*St	8	8184458	5716747	714593	19.81	<0.001
ST*Form	4	742869	507567	126892	3.52	0.007
St*Form	8	2104140	1839451	229931	6.38	<0.001
PT*CR*ST	4	293512	300532	75133	2.08	0.080
PT*CR*St	8	636191	584519	73065	2.03	0.040
PT*CR*Form	4	579068	447368	111842	3.1	0.015
PT*ST*St	16	1310099	1071711	66982	1.86	0.020
PT*ST*Form	8	1685139	1433579	179197	4.97	<0.001
PT*St*Form	16	1076913	1071574	66973	1.86	0.020
CR*ST*St	8	884663	558687	69836	1.94	0.050
CR*ST*Form	4	279814	292948	73237	2.03	0.087
CR*St*Form	8	422678	409863	51233	1.42	0.182
ST*St*Form	16	2165737	1717294	107331	2.98	<0.001
PT*CR*ST*St	16	1158491	872569	54536	1.51	0.086
PT*CR*ST*Form	8	1418251	1263668	157958	4.38	<0.001
PT*CR*St*Form	16	643374	534756	33422	0.93	0.537
PT*ST*St*Form	32	1896254	1581192	49412	1.37	0.080
CR*ST*St*Form	16	891348	1079582	67474	1.87	0.019
PT*CR*ST*St*Form	32	2549197	2549197	79662	2.21	<0.001
Error	5976	215535733	215535733	36067		
Total	6245	290140319				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice in Table VII is that the effect of the main factors ('PT', 'CR', 'ST', 'St', and 'Form') on the texture of the slice is highly significant (P<0.001). The impact of these variables on adhesiveness is seen in Figure 6. After performing the MCB comparison test we are also able to observe (Figure 6) which of each of the independent variables' means are statistically significant among each other for adhesiveness. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

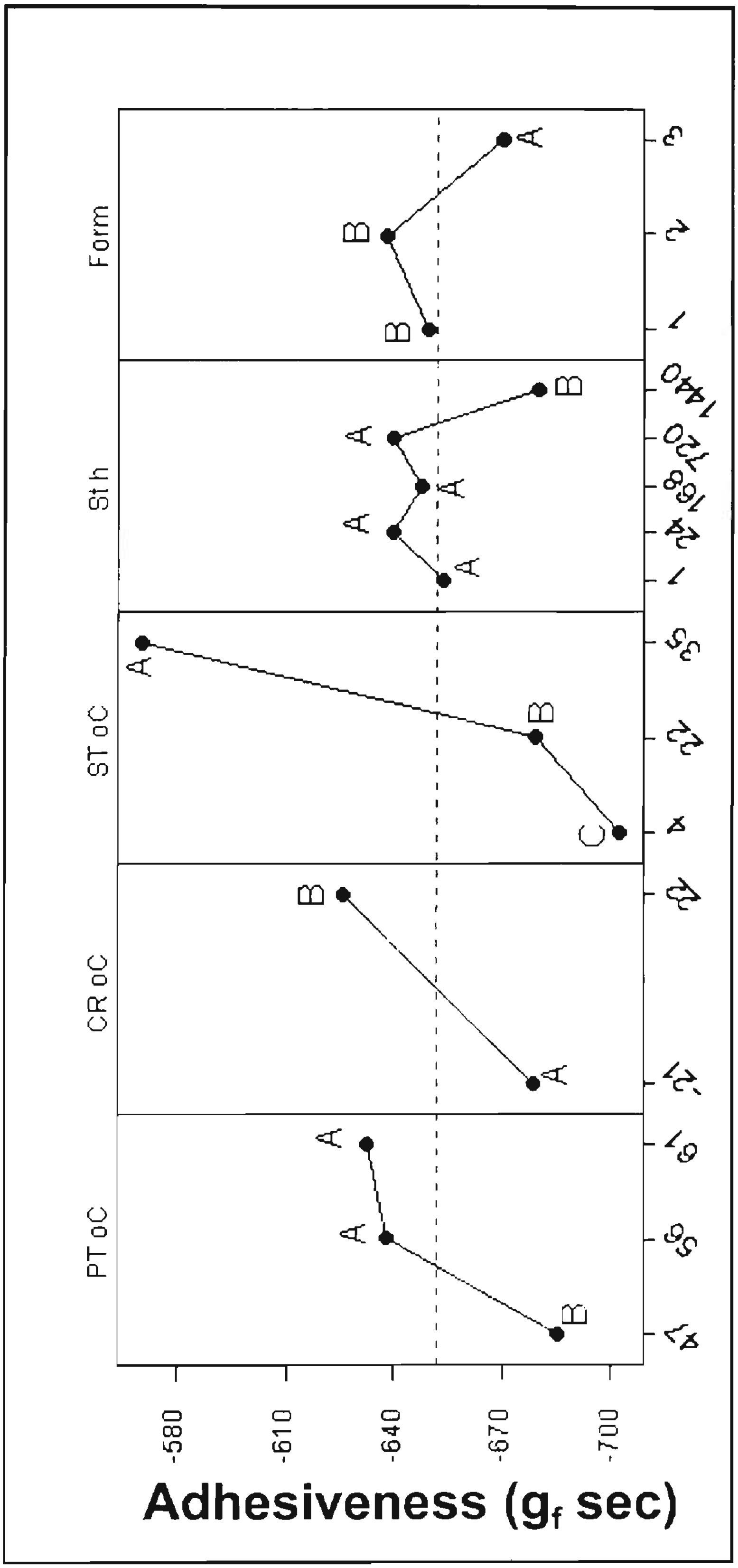

Figure 6. Main Effects Plot – Data Means for Adhesiveness

From Figure 6, it can be seen that the slice became more adhesive as the temperature of storage increased. Also, ST is the variable that affects the texture of the slice (as well as with hardness) the most, since the range of variation on adhesiveness values is the widest (-580 g_f sec<adhesiveness<-700 g_f sec). As far as formulation is concerned, the slice is the least adhesive with formulation three. However, it is a very important characteristic, since it determines whether the slice can be peeled easily from the wrapper. The rest of the process variables also affect adhesiveness but not as strongly (less range of variation) as 'ST'. From the MCB test (see Appendix D) we can see that the best treatment combination for adhesiveness is.

PT=61°C, CR=22°C, ST=35°C, St=24,720 hrs, Form=2.

The linear equation obtained from the 'Multiple Regression Analysis' is a mathematical model of the relationship between the independent and the dependent variable, adhesiveness.

The regression equation is:

$$Adhesiveness(g_f sec) = -927 + 4.07\,PT + 1.30\,CR + 4.12\,ST - 0.02St - 10.60\,Form$$

Further details on the Regression Analysis performed on the response variable , adhesiveness are presented in Appendix C2.

The second thing to notice in Table VII is that there are strong two-way ($P<0.001$), three-way ($P<0.001$), four-way ($P<0.001$), and five-way interaction terms ($P<0.001$). The most significant interactions are presented in Table VIII.

Table VIII. Most Significant Interactions Terms for Adhesiveness

Interaction	Independent Variables						
two-way	PT* ST	PT*St	CR*ST	CR*St	CR*Form	ST*St	St*Form
three-way	PT*CR*Form	PT*ST*Form	ST*St*Form	---	---	---	---
four-way	PT*CR*ST*Form	CR*ST*St*Form	---	---	---	---	---
five-way	PT*CR*ST*St*Form	---	---	---	---	---	---

The best way to understand the effects of these interactions on adhesiveness is thorough an interaction plot. As an example, the PT*St interaction term is analyzed in the interaction plot in Figure 7, since PT*St is one of the interactions that is strongly statistically significant for adhesiveness (P=0.001).

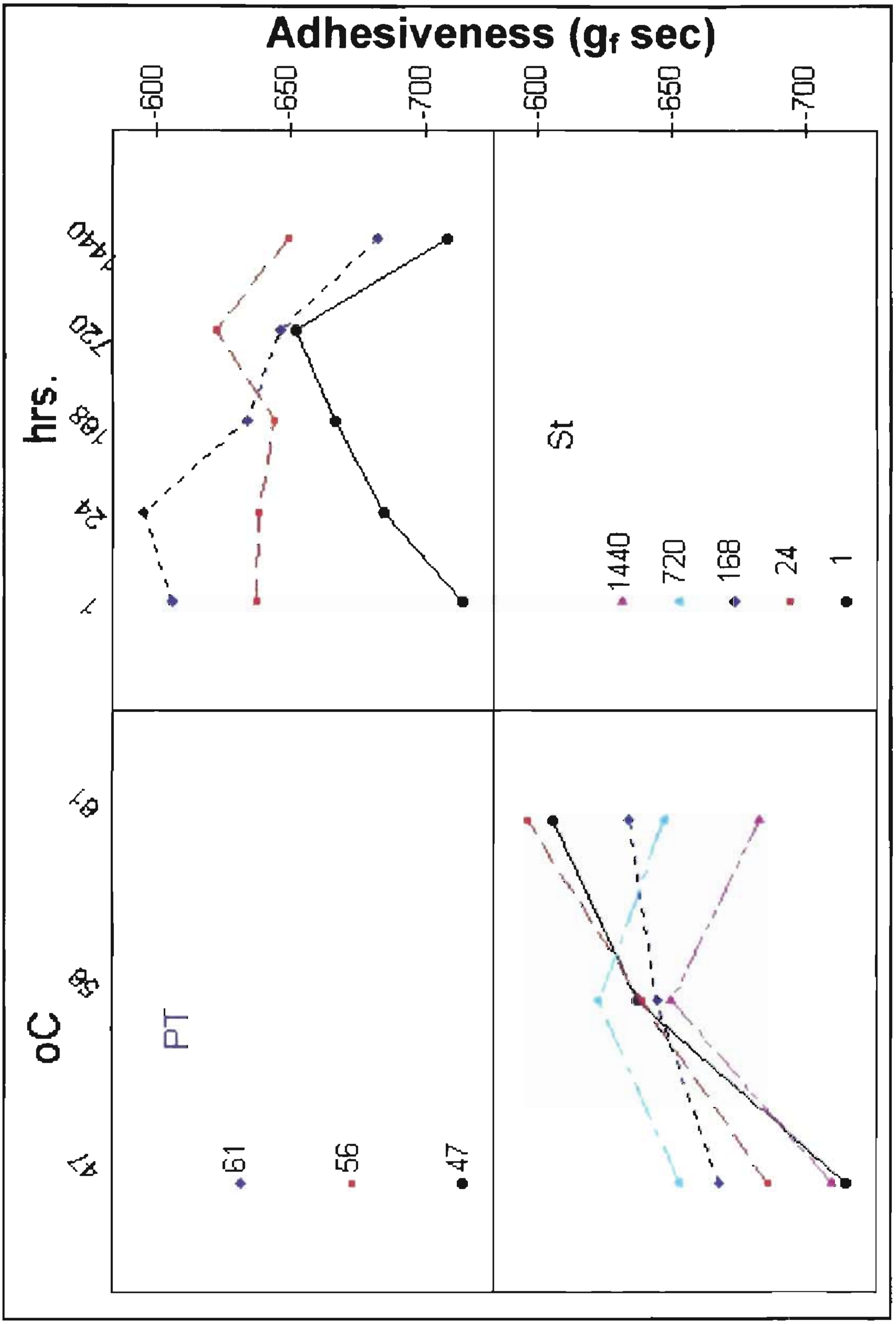

Figure 7. Interaction Plot (PT*St) – Data Means for Adhesiveness

In Figure 7, it is observed that adhesiveness is strongly affected by the interaction between 'PT' and 'St'. In this interaction, it is observed that the values of adhesiveness when measured after one hour of storage are very different, when the slice is processed at 61°C and 47°C. However, after two months of storage of the same slices (slices processed at 61°C and 47°C) no significant difference in adhesiveness values is noted .The greatest difference in adhesiveness is observed after one hour and 24 hours of storage. When the slice is processed at a temperature of 56°C this change in adhesiveness is not distinct. Both plots, the Main Effects Plot and the Interaction Plot lead to the same initial conclusion that the slice is more adhesive as 'PT' increases. However, from the interaction plot it is observed that as the time elapses the slice becomes less adhesive. This decrease in adhesiveness takes place after 24 hours when the slice is processed at 61°C, and after 720 hours (1 month) when the slice is processed at 56°C and 61°C.

The third thing to notice in Table VII is that the interaction between the terms 'PT' and 'CR' is the only one that is not significant for adhesiveness (P=0.183) (See also Figure 8). Once again, another interesting observation is that although the process variables by themselves have a strong effect on adhesiveness, their interaction is not significant. This can be observed in Table VIII where it can be seen that 'PT' as well as 'CR' affect adhesiveness, but when they interact (PT*CR) the effect on adhesiveness is not significant anymore. A two-way interaction plot for all the independent variables is shown in Figure 8.

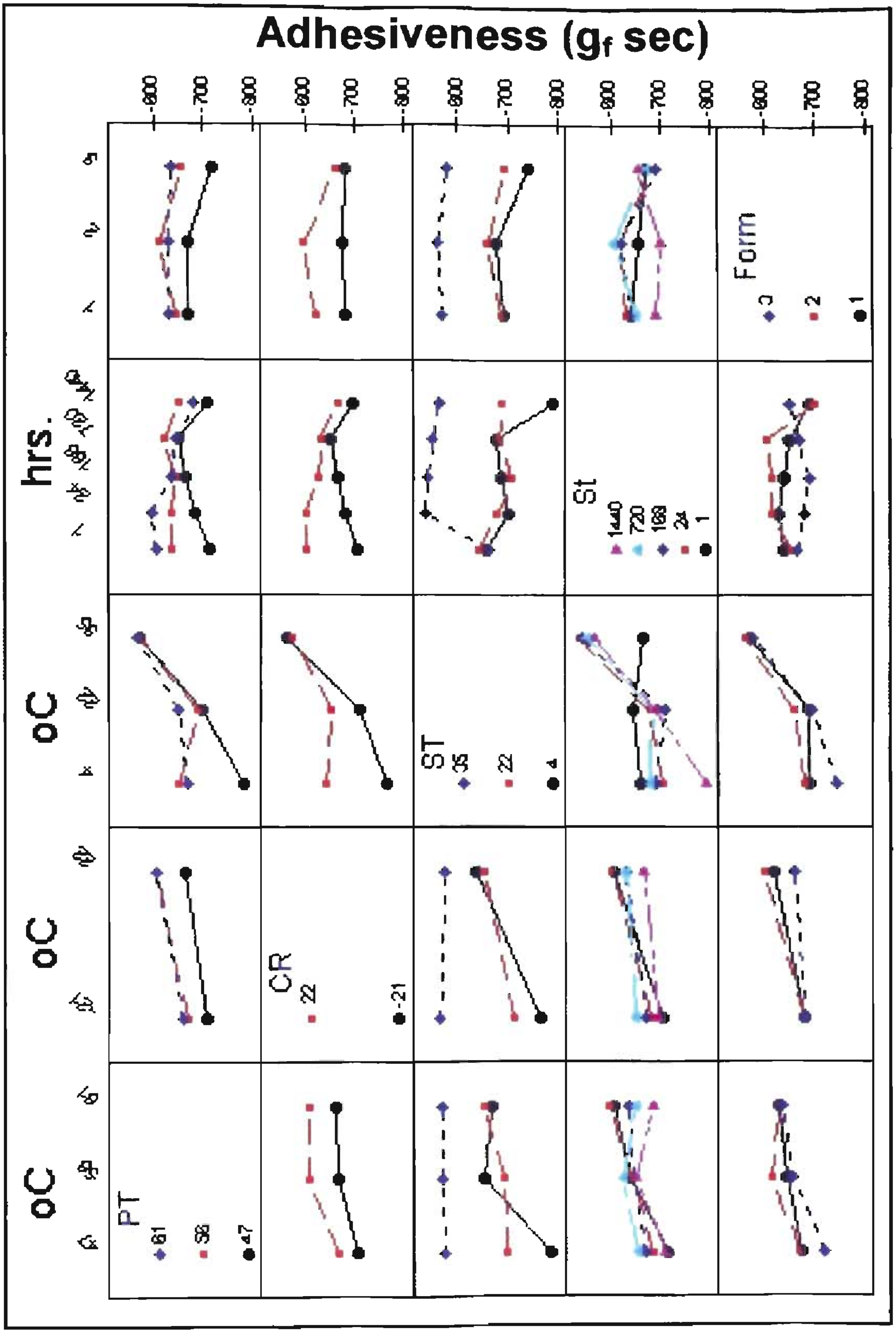

Figure 8. Full Interaction Plot – Data Means for Adhesiveness

From Figure 8, it is clearly observed that no significant interaction exists for PT*CR (parallel lines). It is concluded that the process variable that has the strongest effect on adhesiveness is Storage Temperature (widest range of variation of the values of adhesiveness) and the interaction that has the least effect is PT*Form ($P=0.012$), while the other interactions are almost equally significant for adhesiveness ($P<0.05$). Also, it can be concluded that the Cooling Rate 'CR' has a stronger effect on adhesiveness than on hardness. Texturally, the changes in adhesiveness were inversely proportional to hardness, which means that by controlling hardness, adhesiveness can also be controlled.

Cohesiveness

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction on cohesiveness. Table IX is an ANOVA table for Cohesiveness, using the adjusted sum of squares values for the statistical tests.

Table IX. Analysis of Variance for Cohesiveness, using Adjusted SS

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT	2	1028	528	264	3.27	0.038
CR	1	462.3	332.9	332.9	4.13	0.042
ST	2	931.2	782.5	391.3	4.85	0.008
St	4	1944.1	1419.2	354.8	4.4	0.002
Form	2	884	832.2	416.1	5.16	0.006
PT*CR	2	1040.8	531.6	265.8	3.29	0.037
PT*ST	4	2096.9	1533.6	383.4	4.75	0.001
PT*St	8	4033.3	2172.5	271.6	3.36	0.001
PT*Form	4	1839.6	1557.5	389.4	4.82	0.001
CR*ST	2	1038.9	850.3	425.2	5.27	0.005
CR*St	4	1966.1	1407.5	351.9	4.36	0.002
CR*Form	2	967.4	858.1	429.1	5.32	0.005
ST*St	8	3965.9	3505.1	438.1	5.43	<0.001
ST*Form	4	1936.8	1882.4	470.6	5.83	<0.001
St*Form	8	3622.8	3519.4	439.9	5.45	<0.001
PT*CR*ST	4	2339.5	1538.4	384.6	4.77	0.001
PT*CR*St	8	4109.9	2167.9	271	3.36	0.001
PT*CR*Form	4	2155.3	1552.6	388.1	4.81	0.001

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT*ST*St	16	8337.2	6611.6	413.2	5.12	<0.001
PT*ST*Form	8	4123.1	3611.1	451.4	5.59	<0.001
PT*St*Form	16	7412.6	6526.1	407.9	5.05	<0.001
CR*ST*St	8	3968.8	3519.7	440	5.45	<0.001
CR*ST*Form	4	1825.9	1882.2	470.6	5.83	<0.001
CR*St*Form	8	3829.1	3521.6	440.2	5.45	<0.001
ST*St*Form	16	7402.8	7711.1	481.9	5.97	<0.001
PT*CR*ST*St	16	8831.2	6606.9	412.9	5.12	<0.001
PT*CR*ST*Form	8	3964.3	3624.9	453.1	5.61	<0.001
PT*CR*St*Form	16	8585.3	6518	407.4	5.05	<0.001
PT*ST*St*Form	32	15609.1	15118.2	472.4	5.85	<0.001
CR*ST*St*Form	16	7294.4	7701.2	481.3	5.96	<0.001
PT*CR*ST*St*Form	32	15094.6	15094.6	471.7	5.84	<0.001
Error	5976	482293.3	482293.3	80.7		
Total	6245	614934.3				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice in Table IX is that not all the process variables ('PT' (P=0.038) and 'CR' (P=0.042)) have a strong effect on cohesiveness. The other process variables affect cohesiveness in the following order of importance 'St'(P=0.002), 'Form' (P=0.006), and 'ST'(P=0.008). 'St' is the process variable that affects cohesiveness the most as seen in Figure 9. After performing the MCB comparison test we are also able to observe (Figure 9) which of each of the independent variables' means are statistically significant among each other for cohesiveness. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

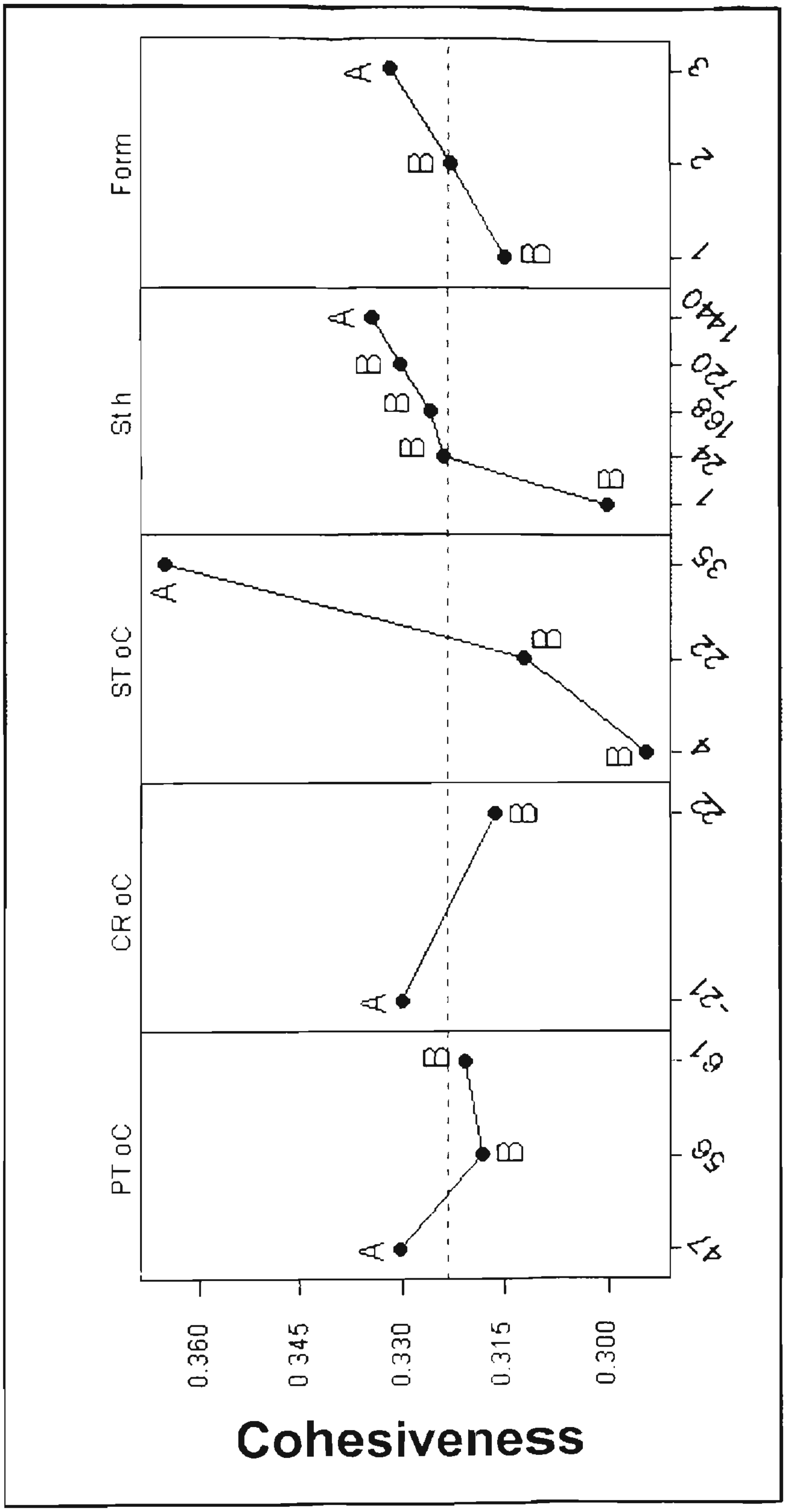

Figure 9. Main Effects Plot – Data Means for Cohesiveness

Form Figure 9, it can be observed that 'ST' is the main factor that affects the most the texture of the slice the most. The slice is more cohesive as the temperature of storage increases. From the MCB test (see Appendix D) we can see that the best treatment combination for cohesiveness is.

PT=61°C, CR=22°C, ST=4°C, St=168 hrs, Form=1.

The linear equation obtained from the 'Multiple Regression Analysis' is a mathematical model of the relation of the independent variables on the dependant variable, cohesiveness.

The regression equation is:

$$\textit{Cohesiveness} = -\,0.82 + 0.05PT + 0.01CR - 0.03ST - 0.0003St - 0.40\,Form$$

Further details on the Regression Analysis performed on the response variable , cohesiveness are presented in Appendix C3.

The second thing to notice in Table IX is that there are strong two-way ($P<0.001$), three-way ($P<0.001$), four-way ($P<0.001$), and five-way interaction terms ($P<0.001$). All interactions are very strong.

The best way to understand the effects of these interactions on cohesiveness is thorough an interaction plot. As an example, the interaction between the most significant terms in cohesiveness (St*Form) is analyzed in Figure 10. In this case, the interaction of these terms is also greatly significant ($P<0.001$).

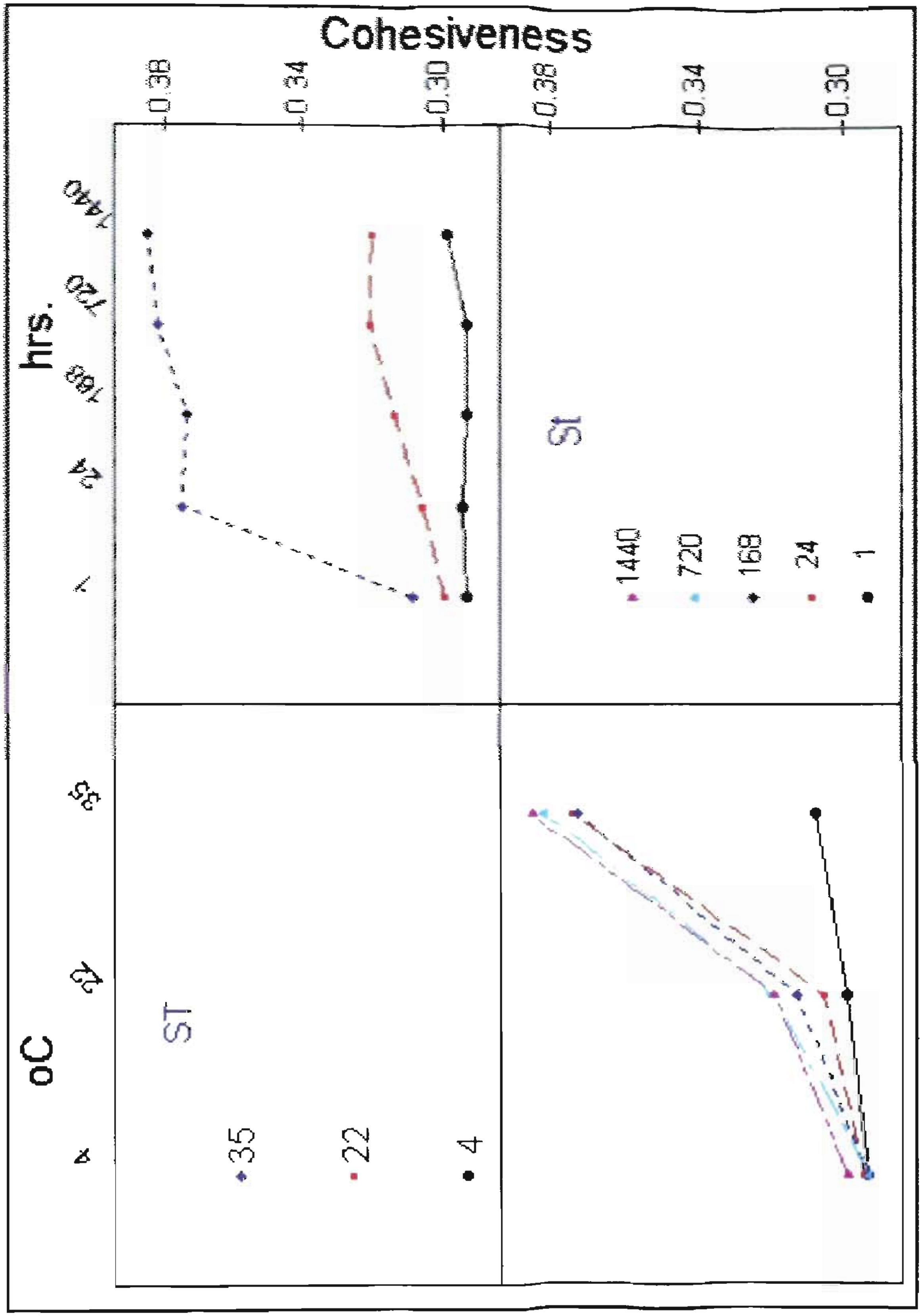

Figure 10. Interaction Plot (ST*St) – Data Means for Cohesiveness

From Figure 10, it is observed (ST*St) that cohesiveness increases as the temperature of storage increases and as the storage time increases. This same behavior is found for adhesiveness. Both plots, the Main Effects Plot and the Interaction Plot substantiate the initial observation that the slice is more cohesive when it is stored at warm temperatures (35°C). However, from the interaction plot (ST*St) the changes in cohesiveness as time elapses are observed.

The third thing to notice in Table IX is that all the two-way interactions are strongly significant ($P<0.05$). A two-way interaction plot for all the independent variables is shown in Figure 11.

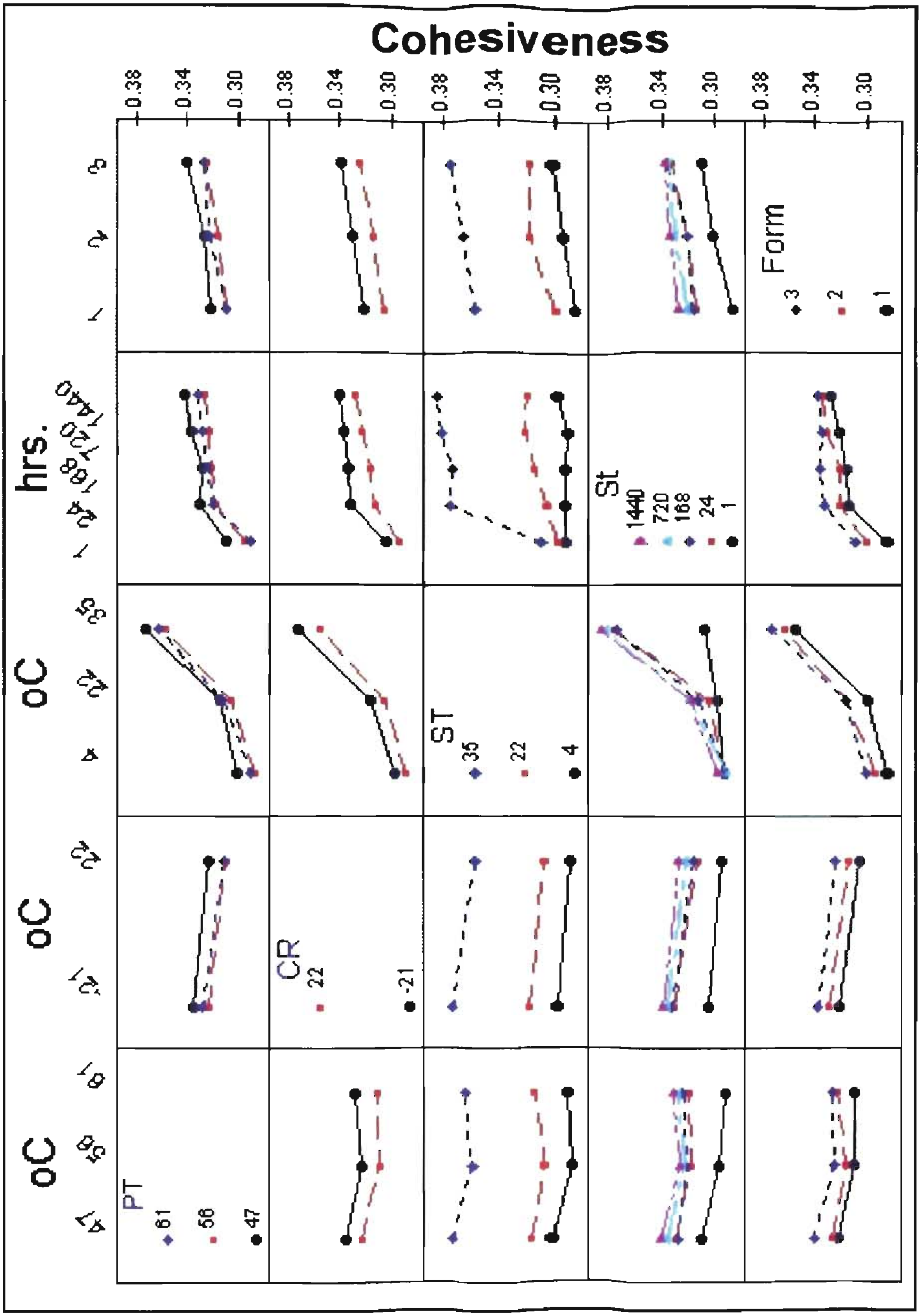

Figure 11 Full Interaction Plot – Data Means for Cohesiveness

From Figure 11, it is clear that another interaction that is also significant is PT*St and the slice seems to be more cohesive as the time elapses when it was processed at 47°C. It is concluded that the process variable that has the strongest effect on cohesiveness is Storage time (P=0.002), and the interaction terms that have the least effect on Cohesiveness are PT*CR (P=0.0037), CR*ST and CR*Form (P=0.005), and CR*St (P=0.002).

Gumminess

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction, on gumminess. Table X is an ANOVA table for Gumminess, using the adjusted sum of squares values for the statistical tests.

Table X. Analysis of Variance for Gumminess, using Adjusted SS for Tests

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT	2	70354	21227	10614	3.29	0.037
CR	1	15919	20174	20174	6.25	0.012
ST	2	11384637	8669168	4334584	1342.93	<0.001
St	4	246768	142387	35597	11.03	<0.001
Form	2	174473	140164	70082	21.71	<0.001
PT*CR	2	16765	10617	5308	1.64	0.193
PT*ST	4	62287	78675	19669	6.09	<0.001
PT*St	8	168074	106115	13264	4.11	<0.001
PT*Form	4	117029	84113	21028	6.51	<0.001
CR*ST	2	58042	26044	13022	4.03	0.018
CR*St	4	31231	26962	6740	2.09	0.080
CR*Form	2	25350	20481	10241	3.17	0.042
ST*St	8	3057160	2340092	292511	90.63	<0.001
ST*Form	4	20716	15809	3952	1.22	0.298
St*Form	8	126094	100931	12616	3.91	<0.001
PT*CR*ST	4	137938	83973	20993	6.5	<0.001
PT*CR*St	8	50361	18921	2365	0.73	0.663
PT*CR*Form	4	33669	22718	5679	1.76	0.134
PT*ST*St	16	225486	194827	12177	3.77	<0.001
PT*ST*Form	8	141466	116330	14541	4.51	<0.001
PT*St*Form	16	204736	199821	12489	3.87	<0.001
CR*ST*St	8	74977	75133	9392	2.91	0.003

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
CR*ST*Form	4	39311	29089	7272	2.25	0.061
CR*St*Form	8	26847	16170	2021	0.63	0.756
ST*St*Form	16	144668	132931	8308	2.57	0.001
PT*CR*ST*St	16	106259	90643	5665	1.76	0.031
PT*CR*ST*Form	8	79256	60078	7510	2.33	0.017
PT*CR*St*Form	16	103575	84649	5291	1.64	0.051
PT*ST*St*Form	32	164503	132657	4146	1.28	0.131
CR*ST*St*Form	16	83006	74046	4628	1.43	0.116
PT*CR*ST*St*Form	32	236759	236759	7399	2.29	<0.001
Error	5976	19288724	19288724	3228		
Total	6245	36716439				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice in Table X is that there are strong effects on the dependent variables by the process variables 'ST', 'St', and 'Form' (P<0.001). On the other hand, 'PT' and 'CR' do not affect the texture very strongly (P=0.037, and P=0.012). The impact of these variables on gumminess is seen in Figure 12. After performing the MCB comparison test we are also able to observe (Figure 12) which of each of the independent variables' means are statistically significant among each other for gumminess. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

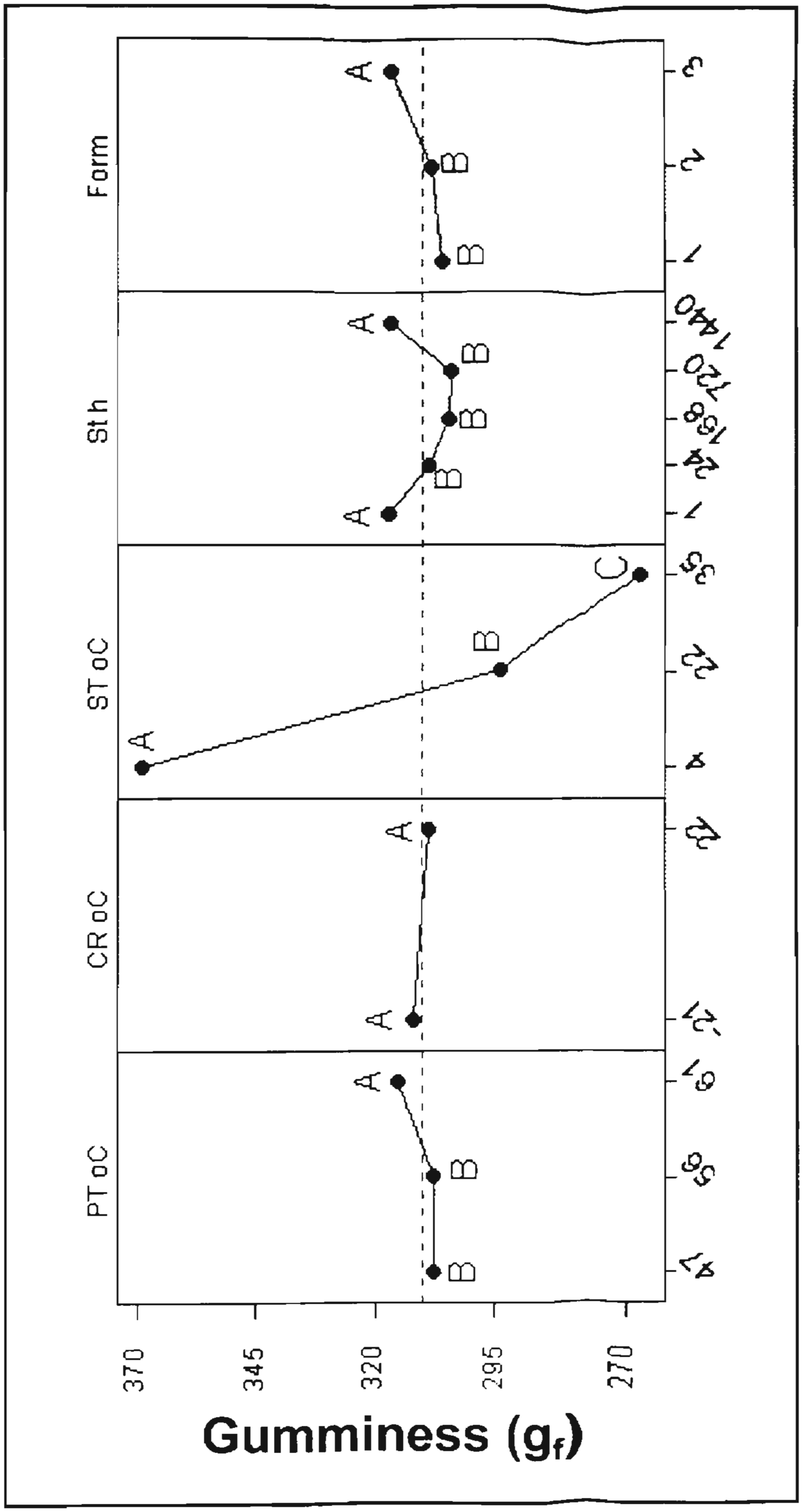

Figure 12. Main Effects Plot – Data Means for Gumminess

With Figure 12 as an example, it is observed that Storage Temperature is the process variable that affects the gumminess of the slice the most, since the range of variation on the values of gumminess is the widest ($345g_f$<gummines<$270g_f$). This effect can be attributed to the fact that the lower the temperature of storage the more gummy the slice is. On the other hand, it is also seen that 'PT' and 'CR' have minimal effect on gumminess, since the range of variation in the values of gumminess is not very wide. From the MCB test (see Appendix D) we can see that the best treatment combination for cohesiveness is.

PT=61°C, CR=-21°C, ST=4°C, St=1, 1440hrs, Form=3.

The linear equation obtained from the 'Multiple Regression Analysis' is a mathematical model of the relation of the independent variables on the dependant variable, gumminess.

The regression equation is:

$$\textbf{Gumminess}(g_f) = 346 + 0.35\,PT - 0.12\,CR - 3.36\,ST + 0.003\,St + 5.78\,Form$$

Further details on the Regression Analysis performed on the response variable , gumminess are presented in Appendix C4.

The second thing to notice in Table X is that there are strong two-way ($P<0.001$), three-way ($P<0.001$), four-way ($P<0.001$), and five-way interaction terms ($P<0.001$). The strongest interactions are presented in Table XI.

Table XI. Most Significant Interaction Terms for Gumminess

Interaction	Independent Variables						
two-way	PT* ST	PT*St	PT*Form	CR*ST	ST*St	St*Form	---
three-way	PT*CR*ST	PT*ST*St	PT*ST*Form	PT*St*Form	CR*ST*St	ST*St*Form	---
four-way	PT*CR*ST* Form	---	---	---	---	---	---
five-way	PT*CR*ST* St*Form	---	---	---	---	---	---

The best way to understand the effects of these interactions on gumminess is by an interaction plot. As an example, the ST*St interaction term is analyzed (since ST*St is one of the strongest interactions for gumminess, $P<0.001$) in the interaction plot shown in Figure 13.

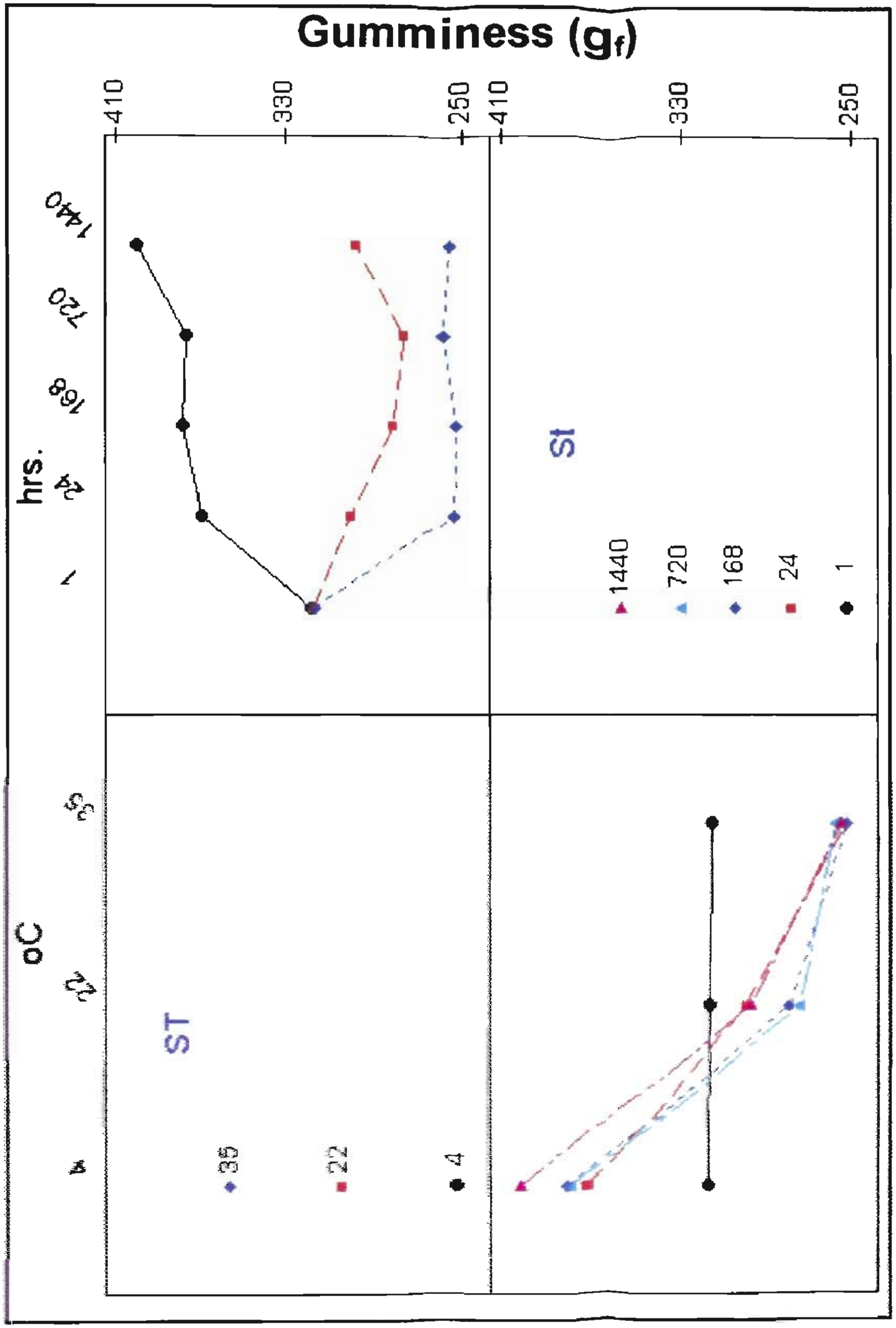

Figure 13 Interaction plot (ST* St) - Data Means for Gumminess

From the interaction plot in Figure 13 for the interaction ST*St, it is observed that the texture of the slice is quite different when it is stored at 4°C than when it is stored at 35°C. At 4°C, gumminess tends to increase as the time passes. The reverse happens at a storage temperature of 35°C. At a storage temperature of 22°C, the changes in texture occur less abruptly although gumminess also tends to increase as the time passes.

Both plots, the Main Effects Plot and the Interaction Plot lead to the same conclusion that the slice is more gummy when it is stored at low temperatures but the interaction plot also tells us how fast this change takes place.

The third thing to notice in Table X is that the terms that do not interact are PT*CR (P=0.193) (similar case with hardness), ST*Form (P=0.298), and CR*St (P=0.080). An interesting observation is that although 'PT' and 'CR' by themselves do not affect gumminess strongly, when they interact with some other variable such as 'ST' (PT*ST) then this interaction is strongly significant P<0.001 (see Table X).

The interaction plot showing all the two-way interactions among the independent variables is shown in Figure 14.

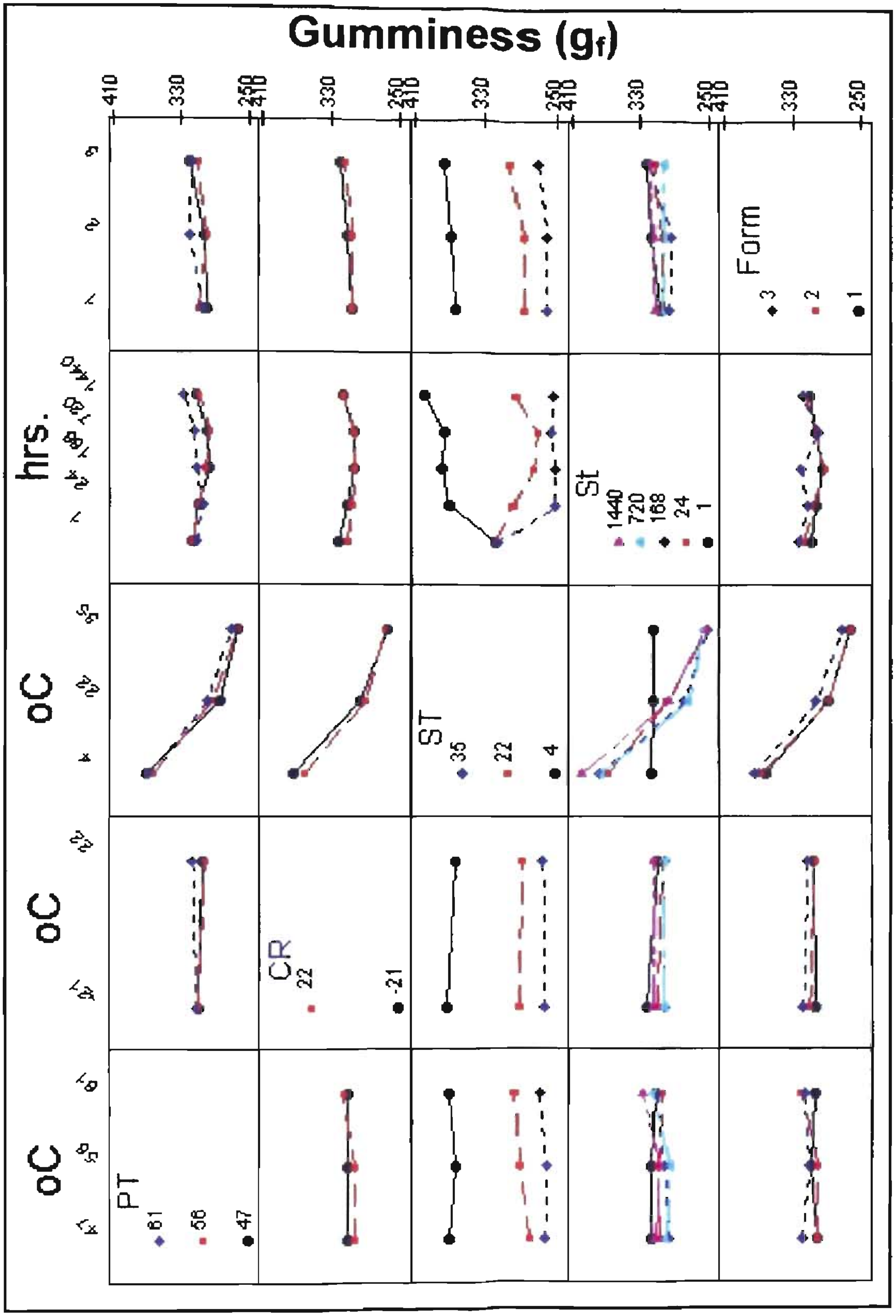

Figure 14. Full Interaction Plot – Data Means for Gumminess

From Figure 14, it can be observed that the interaction term ST*Form (P=0.298) is not significant (parallel lines). It is concluded that the process variable that affects gumminess the most is 'ST' (largest range of variation of the values of gumminess), and the interaction terms that do not have much effect are CR*Form (P=0.042), and CR*ST (P=0.018).

Chewiness

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction, on chewiness. Table XII is an ANOVA table for chewiness, using the adjusted sum of squares values for the statistical tests.

Table XII. Analysis of Variance for Chewiness, using Adjusted SS

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT	2	90676	31226	15613	5.17	0.006
CR	1	20164	23539	23539	7.79	0.005
ST	2	10662194	8187467	4093734	1354.72	<0.001
St	4	277919	166700	41675	13.79	<0.001
Form	2	164622	127920	63960	21.17	<0.001
PT*CR	2	17551	10938	5469	1.81	0.164
PT*ST	4	55206	67493	16873	5.58	<0.001
PT*St	8	124370	80995	10124	3.35	0.001
PT*Form	4	95888	71021	17755	5.88	<0.001
CR*ST	2	83124	41458	20729	6.86	0.001
CR*St	4	27994	24327	6082	2.01	0.090
CR*Form	2	20752	17422	8711	2.88	0.056
ST*St	8	2842493	2155615	269452	89.17	<0.001
ST*Form	4	17471	14981	3745	1.24	0.292
St*Form	8	111812	93429	11679	3.86	<0.001
PT*CR*ST	4	98124	63783	15946	5.28	<0.001
PT*CR*St	8	48441	17998	2250	0.74	0.652
PT*CR*Form	4	30633	20025	5006	1.66	0.157
PT*ST*St	16	230858	204218	12764	4.22	<0.001
PT*ST*Form	8	111161	91564	11445	3.79	<0.001
PT*St*Form	16	210624	197668	12354	4.09	<0.001
CR*ST*St	8	55237	59538	7442	2.46	0.012
CR*ST*Form	4	36713	28333	7083	2.34	0.052
CR*St*Form	8	26240	15249	1906	0.63	0.753

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
ST*St*Form	16	128480	117039	7315	2.42	0.001
PT*CR*ST*St	16	99725	87914	5495	1.82	0.024
PT*CR*ST*Form	8	80931	65860	8232	2.72	0.005
PT*CR*St*Form	16	97632	82658	5166	1.71	0.038
PT*ST*St*Form	32	180347	156895	4903	1.62	0.015
CR*ST*St*Form	16	67806	54855	3428	1.13	0.315
PT*CR*ST*St*Form	32	178073	178073	5565	1.84	0.003
Error	5976	18058435	18058435	3022		
Total	6245	34351697				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice in Table XII is that there are strong effects on the dependent variables by the process variables 'ST', 'St', and 'Form'. On the other hand 'PT' and 'CR' do not affect the texture very strongly (P=0.006, and P=0.005). The impact of these variables on chewiness is seen in Figure 15. After performing the MCB comparison test we are also able to observe (Figure 15) which of each of the independent variables' means are statistically significant among each other for chewiness. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

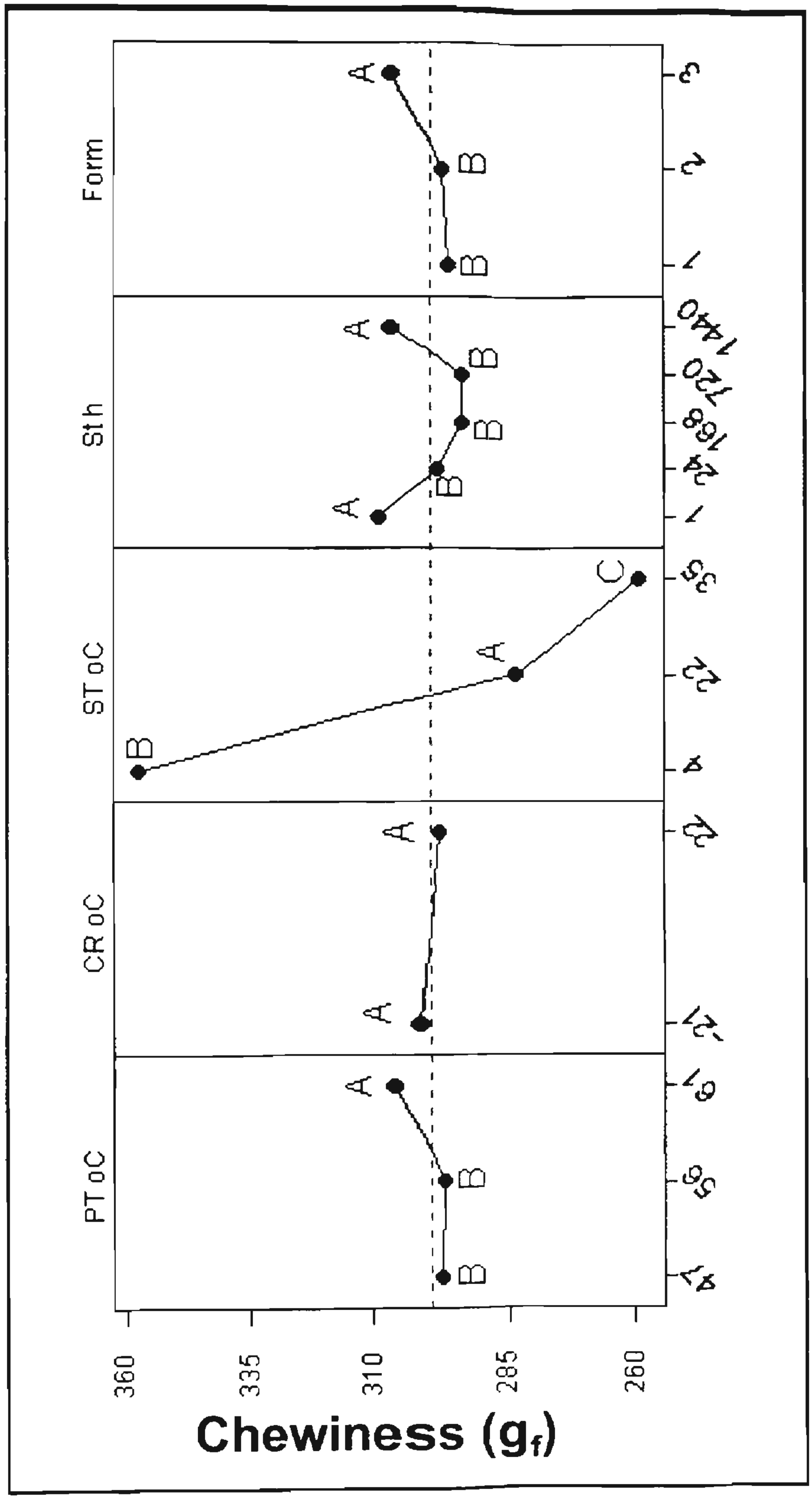

Figure 15. Main Effects Plot – Data Means for Chewiness

From Figure 15. It is observed that the peanut butter slice becomes more chewy as the temperature of storage decreases, (The same behavior was found from hardness and gumminess). 'ST' is the variable that affects chewiness the most, since the range of variation on chewiness values is the widest. The other process variables: 'PT', 'CR' and 'Form', and 'St' do not have a strong effect on chewiness (their range of variation is not very wide). From the MCB test (see Appendix D) we can see that the best treatment combination for cohesiveness is.

PT=61°C, CR=-21°C, ST=22°C, St=1, 1440hrs, Form=3.

The linear equation obtained from the 'Multiple Regression Analysis' is a mathematical model of the relationships between the independent and the dependant variable, chewiness.

The regression equation is:

$$\boldsymbol{Chewiness(g_f) = 332.11 + 0.39\ PT - 0.13\ CR - 3.24\ ST + 0.0027\ St + 5.40\ Form}$$

Further details on the Regression Analysis performed on the response variable , chewiness are presented in Appendix C5.

The second thing to notice from Table XII is that there are strong two-way ($P<0.001$), three-way ($P<0.001$), four-way ($P<0.001$), and five-way interaction terms ($P<0.001$). The most strong interactions are presented in Table XIII.

Table XIII. Most Significant Interaction Terms for Chewiness

Interaction	Independent Variables						
two-way	PT* ST	PT*St	PT*Form	CR*ST	ST*St	St*Form	---
three-way	PT*CR*ST	PT*ST*St	PT*ST*Form	PT*St*Form	CR*ST*St	ST*St*Form	---
four-way	PT*CR*ST* Form	CR*ST*St* Form	---	---	---	---	---
five-way	PT*CR*ST* St*Form	---	---	---	---	---	---

The best way to understand the effects of these interactions on chewiness is by an interaction plot. As an example, the ST*St interaction term is analyzed in the interaction plot shown in Figure 16, since ST*St is one of the interactions that is strongly statistically significant for chewiness ($P<0.001$).

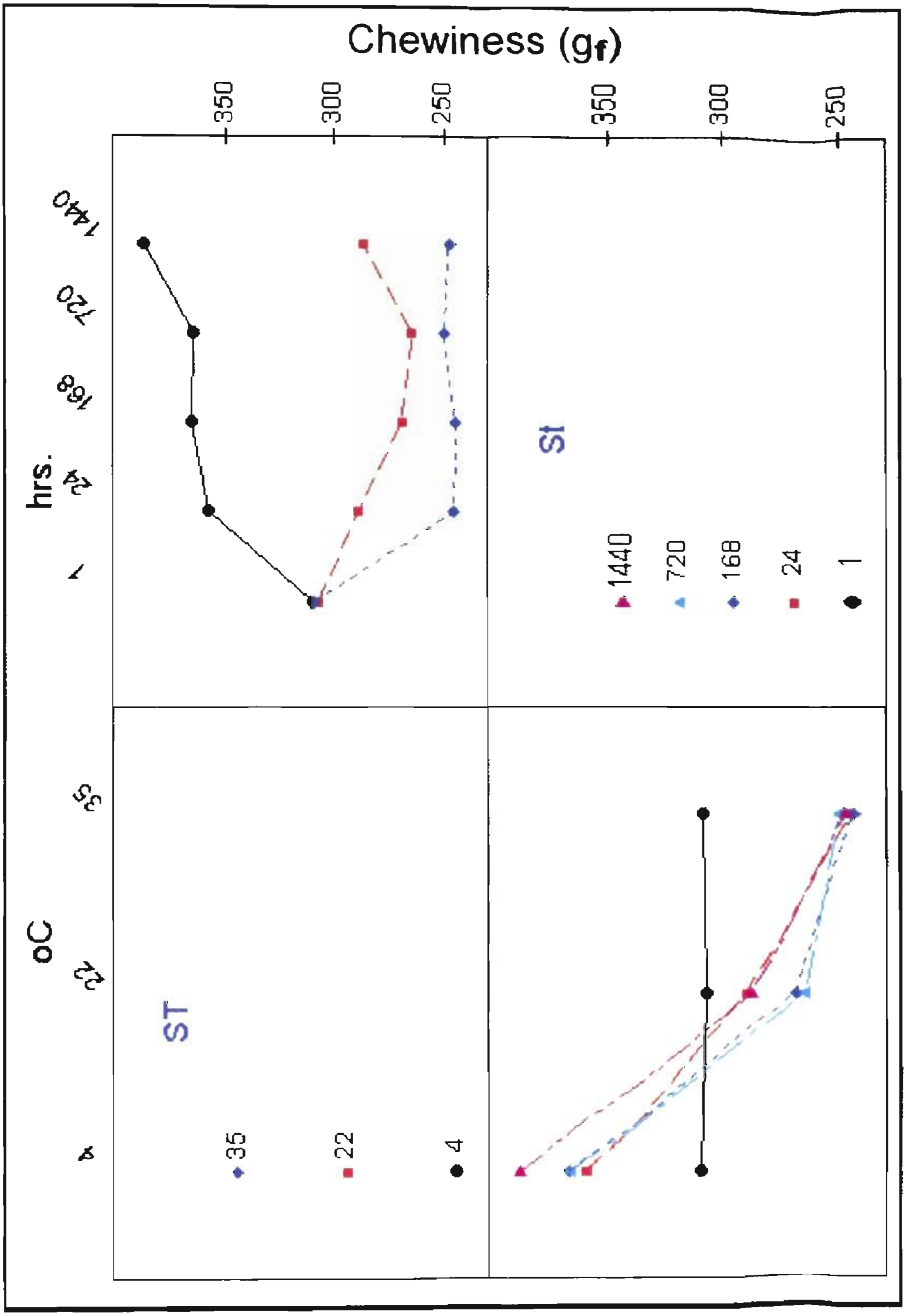

Figure 16. Interaction Plot (ST*St) - Data Means for Chewiness

In Figure 16, it is observed that chewiness is strongly affected by the interaction term ST*St in the following manner. At 4°C, chewiness tends to increase as the time elapses. The reverse happens at a storage temperature of 35°C. At a storage temperature of 22°C, the changes in texture occur less abruptly although chewiness also tends to increase as the time elapses (the same behavior was found for hardness and gumminess).

The third thing to notice in Table XII is that the terms that do not interact are ST*Form (P=0.292), PT*CR (P=0.164), CR*St (P=0.090), and CR*Form (P=0.056). This is also observed in Figure 16. An interesting observation is that although the process variables by themselves have a big effect on chewiness, their interaction may not be significant. This can be seen in Table XII where it is shown that 'ST' and 'Form' affects chewiness, but when they (ST*Form) interact the effect on chewiness is not significant anymore (P=0.292).

The interaction plot showing all the two-way interactions among the independent variables is shown in Figure 17.

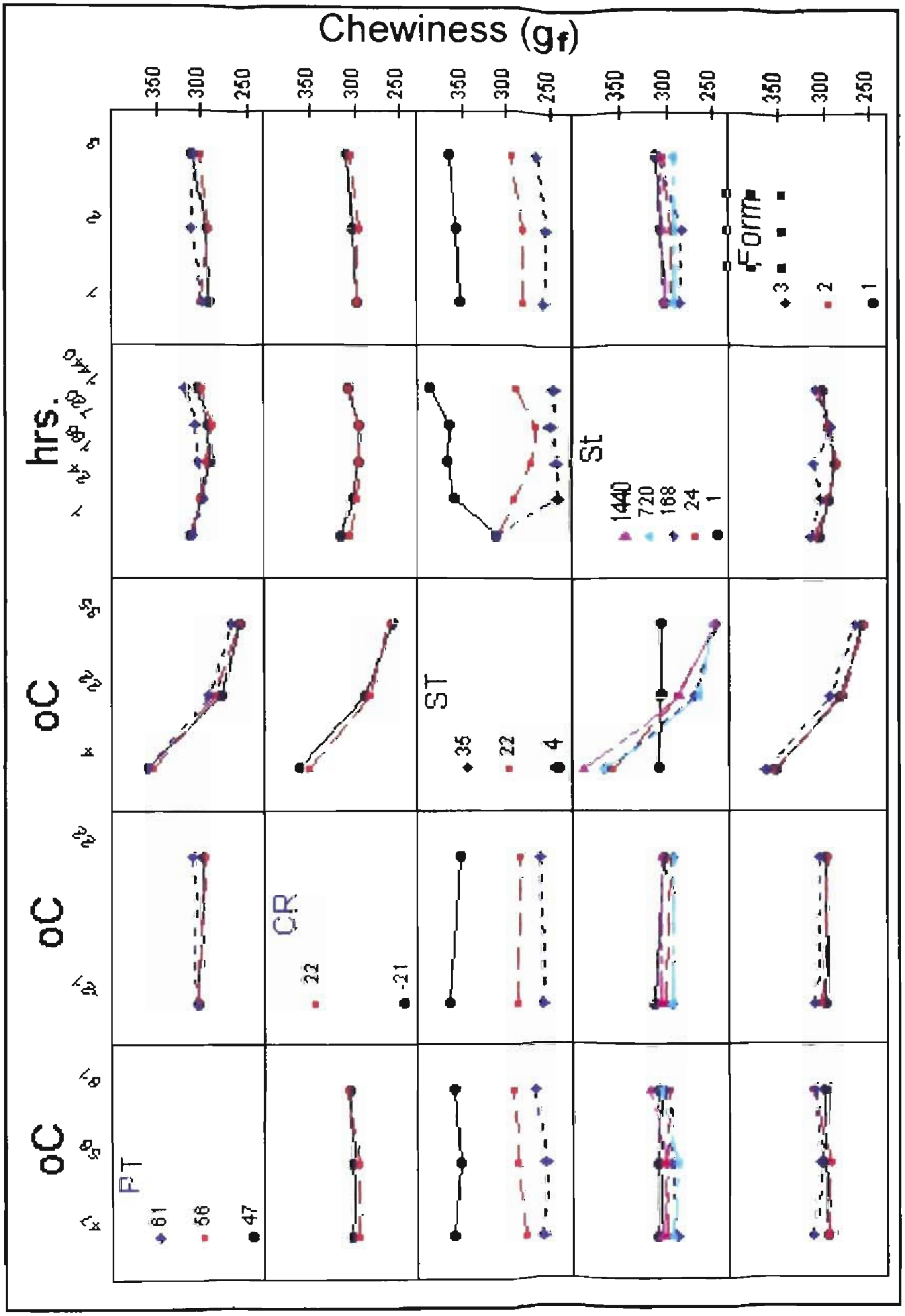

Figure 17. Full Interaction Plot – Data Means For Chewiness

In Figure 17, it can be observed that for the interaction terms PT*Form there is not much of a real difference in chewiness when the slice is processed at either 61°C, 56°C, or 47°C using formulation 1 or 3. On the other hand, with formulation 2 at a process temperature 61°C, the texture of the slice is quite different. It is concluded that the process variable that has the strongest effect on chewiness is Storage Temperature (widest range of variation of the values of chewiness), and the interaction terms that have the strongest effect are PT*ST, PT*Form, ST*St, St*Form (P=0.000), and PT*St and CR*St (P=0.001).

Resilience

The GLM analysis for multiple variables presents the degree of significance of the process variables and their interaction on resilience, Table XIV is an ANOVA table for resilience, using the adjusted sum of squares values for the statistical tests.

Table XIV. Analysis of Variance for Resilience, using Adjusted SS

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT	2	0.002112	0.0010315	0.0005157	13.19	<0.001
CR	1	0.001935	0.0013925	0.0013925	35.61	<0.001
ST	2	0.007799	0.0073549	0.0036774	94.05	<0.001
St	4	0.002766	0.0022	0.00055	14.07	<0.001
Form	2	0.000232	0.0000888	0.0000444	1.14	0.321
PT*CR	2	0.000354	0.000197	0.0000985	2.52	0.081
PT*ST	4	0.000416	0.000429	0.0001072	2.74	0.027
PT*St	8	0.000519	0.0003656	0.0000457	1.17	0.314
PT*Form	4	0.001254	0.0010643	0.0002661	6.8	<0.001
CR*ST	2	0.001275	0.0013793	0.0006897	17.64	<0.001
CR*St	4	0.002278	0.0020161	0.000504	12.89	<0.001
CR*Form	2	0.000459	0.0002388	0.0001194	3.05	0.047
ST*St	8	0.00805	0.0064266	0.0008033	20.54	<0.001
ST*Form	4	0.000238	0.0002437	0.0000609	1.56	0.183
St*Form	8	0.001363	0.0013884	0.0001736	4.44	<0.001
PT*CR*ST	4	0.000187	0.0002468	0.0000617	1.58	0.177
PT*CR*St	8	0.000527	0.0001751	0.0000219	0.56	0.812
PT*CR*Form	4	0.000252	0.0002505	0.0000626	1.6	0.171

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
PT*ST*St	16	0.000986	0.0010467	0.0000654	1.67	0.044
PT*ST*Form	8	0.000388	0.0003338	0.0000417	1.07	0.383
PT*St*Form	16	0.001827	0.0018244	0.000114	2.92	<0.001
CR*ST*St	8	0.000774	0.000699	0.0000874	2.23	0.022
CR*ST*Form	4	0.000503	0.000421	0.0001052	2.69	0.029
CR*St*Form	8	0.000406	0.0003274	0.0000409	1.05	0.398
ST*St*Form	16	0.001275	0.0012068	0.0000754	1.93	0.014
PT*CR*ST*St	16	0.000898	0.0008717	0.0000545	1.39	0.134
PT*CR*ST*Form	8	0.000559	0.0005654	0.0000707	1.81	0.071
PT*CR*St*Form	16	0.000829	0.0008136	0.0000509	1.3	0.186
PT*ST*St*Form	32	0.001551	0.0012698	0.0000397	1.01	0.444
CR*ST*St*Form	16	0.00118	0.0009419	0.0000589	1.51	0.088
PT*CR*ST*St*Form	32	0.001968	0.0019683	0.0000615	1.57	0.021
Error	5976	0.233673	0.2336732	0.0000391		
Total	6245	0.278833				

Significant at 0.05 level.(P<0.05)

A detailed statistical output from the General Linear Model for each of the process variables is presented in Appendix B.

The first thing to notice from Table XIV is that there are strong effects on resilience of the slice by all process variables with the exception of formulation. Formulation is not statistically significant on resilience (P=0.321). The impact of these variables on resilience is seen in Figure 18. After performing the MCB comparison test we are also able to observe (Figure 18) which of each of the independent variables' means are statistically significant among each other for resilience. Means with the same letter are not statistically significant. For more statistical analysis on MCB refer to Appendix D.

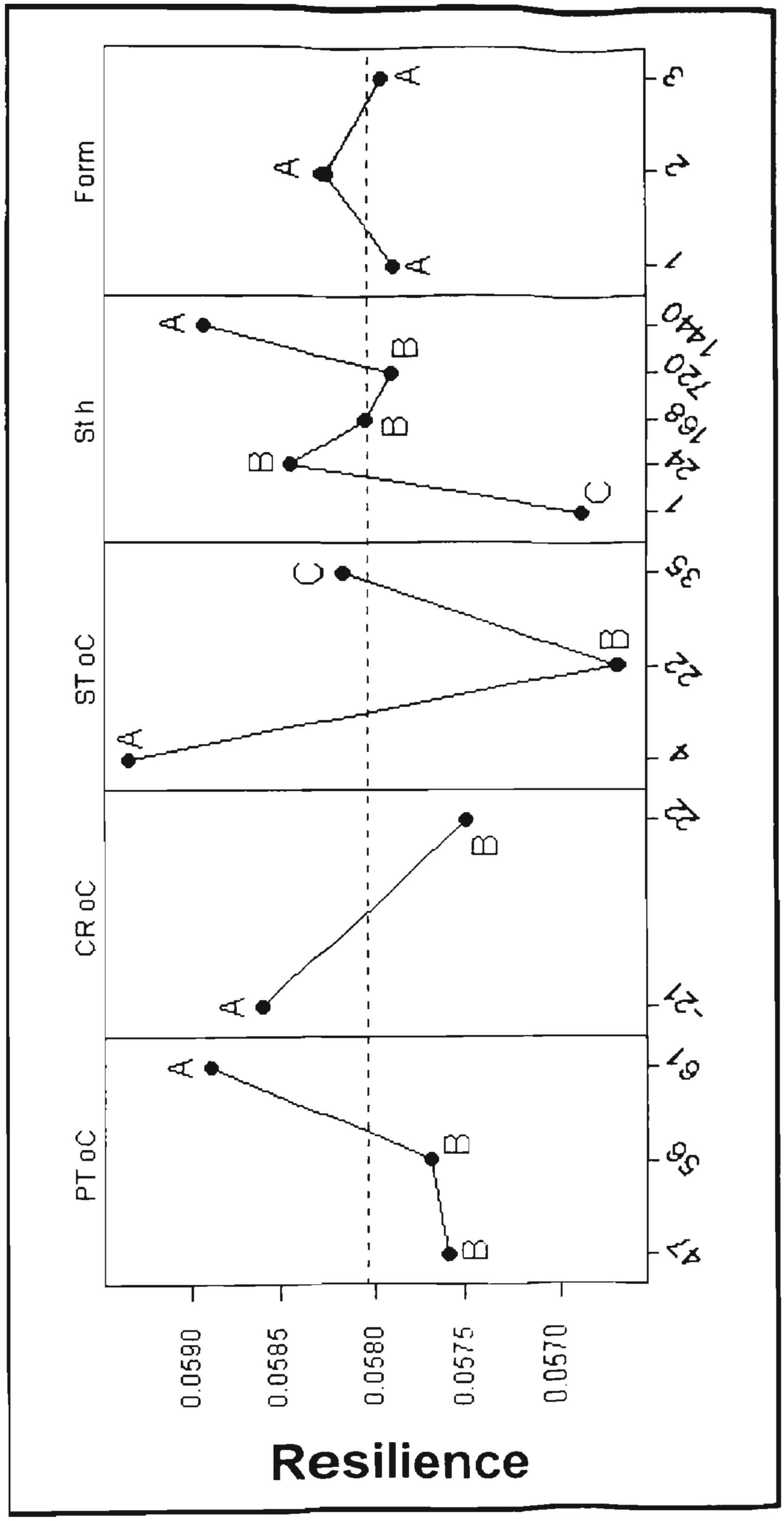

Figure 18. Main Effects Plot – Data Means for Resilience

From Figure 18, it is observed that the resilience of the slice is affected by all the process variables. As a preliminary observation, it can be stated that the slice is more resilient as the temperature of process increases. Because of the range in variation of the values of resilience it is noted that the variables that affect resilience the most are 'ST' and 'St', while the next biggest effect on resilience is by 'PT' and 'CR'. From the MCB test (see Appendix D) we can see that the best treatment combination for cohesiveness is.

PT=61°C, CR=-21°C, ST=4°C, St=1440, 24, 168hrs, Form=2.

The linear equation obtained from the "Multiple Regression Analysis' is a mathematical model of the relationship between the independent variables and the dependent variables, resilience.

The regression equation is:

$$\textit{Resilience} = 0.05 + 0.000081\,PT - 0.000027\,CR - 0.000047\,ST + 0.000001\,St + 0.000057\,\textit{Form}$$

Further details on the Regression Analysis performed on the response variable , resilience are presented in Appendix C6.

The second thing to notice from Table XIV is that there are strong two-way (P<0.001), three-way (P<0.001), and five-way interaction terms (P<0.001) but no significant four-way interaction terms. The most strong interactions are presented in Table XV.

Table XV. Most Significant Interaction Terms for Resilience

Interaction	Independent Variables						
two-way	PT* ST	PT*Form	CR*ST	CR*St	ST*St	St*Form	---
three-way	PT*St*Form	CR*ST*St	ST*St*Form	---	---	---	---
four-way	---	---	---	---	---	---	---
five-way	PT*CR*ST*St*Form	---	---	---	---	---	---

The best way to understand the effects of these interactions on Resilience is by an interaction plot. As an example, the PT*Form interaction term is analyzed in the interaction plot in Figure 19, since PT*Form is one of the strongly statistically significant interactions for resilience ($P<0.001$).

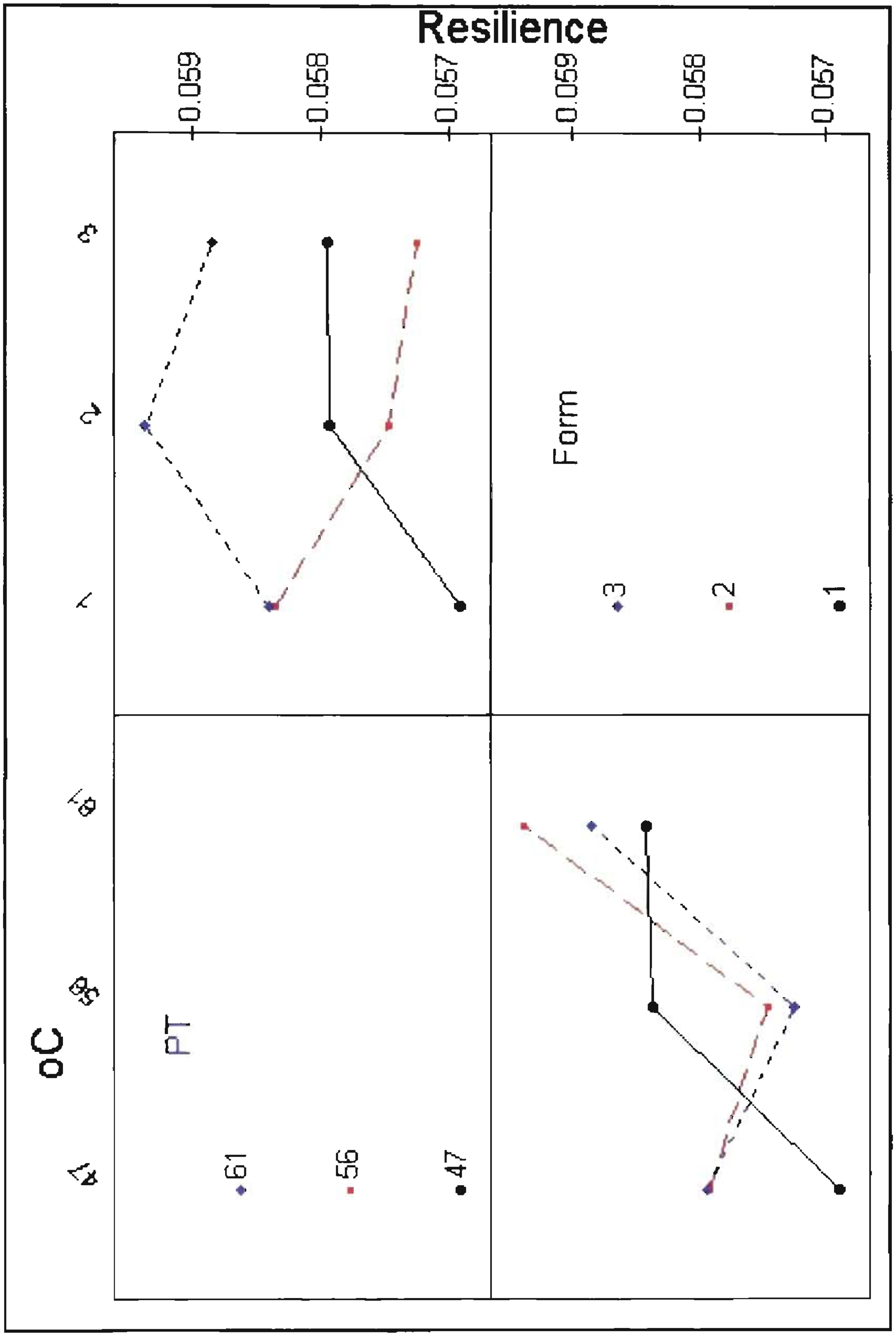

Figure 19. Interaction Plot (PT*Form) - Data Means for Resilience

In Figure 19, it is observed (Form*PT) that for Formulation 1, resilience is highest at Process Temperatures of 61°C and 56°C and is a minimum at 47°C. For Formulation 2 and 3, resilience is at its maximum at 61°C, while at 56°C the value of resilience is minimum. The Main Effects Plot and the Interaction Plot indicate that the higher the Process Temperature, the higher resilience is. However, from the interaction plot it can be noted that this is true for formulation 1, but not for formulation 2 and 3.

The third thing to notice from table XIV is that the terms that do not interact are PT*St (P=0.314), ST*Form (P=0.183), PT*CR (P=0.081), and that CR*Form (P=0.047) is not very significant. Although the process variables by themselves have a great effect on resilience, Their interactions may not be significant. This can be observed in table XIV where 'PT', and 'St ' (P<0.001) strongly affect resilience, but when they interact PT*St this effect is not significant anymore (P=0.314). The two-way interaction among the independent variables is shown in Figure 20.

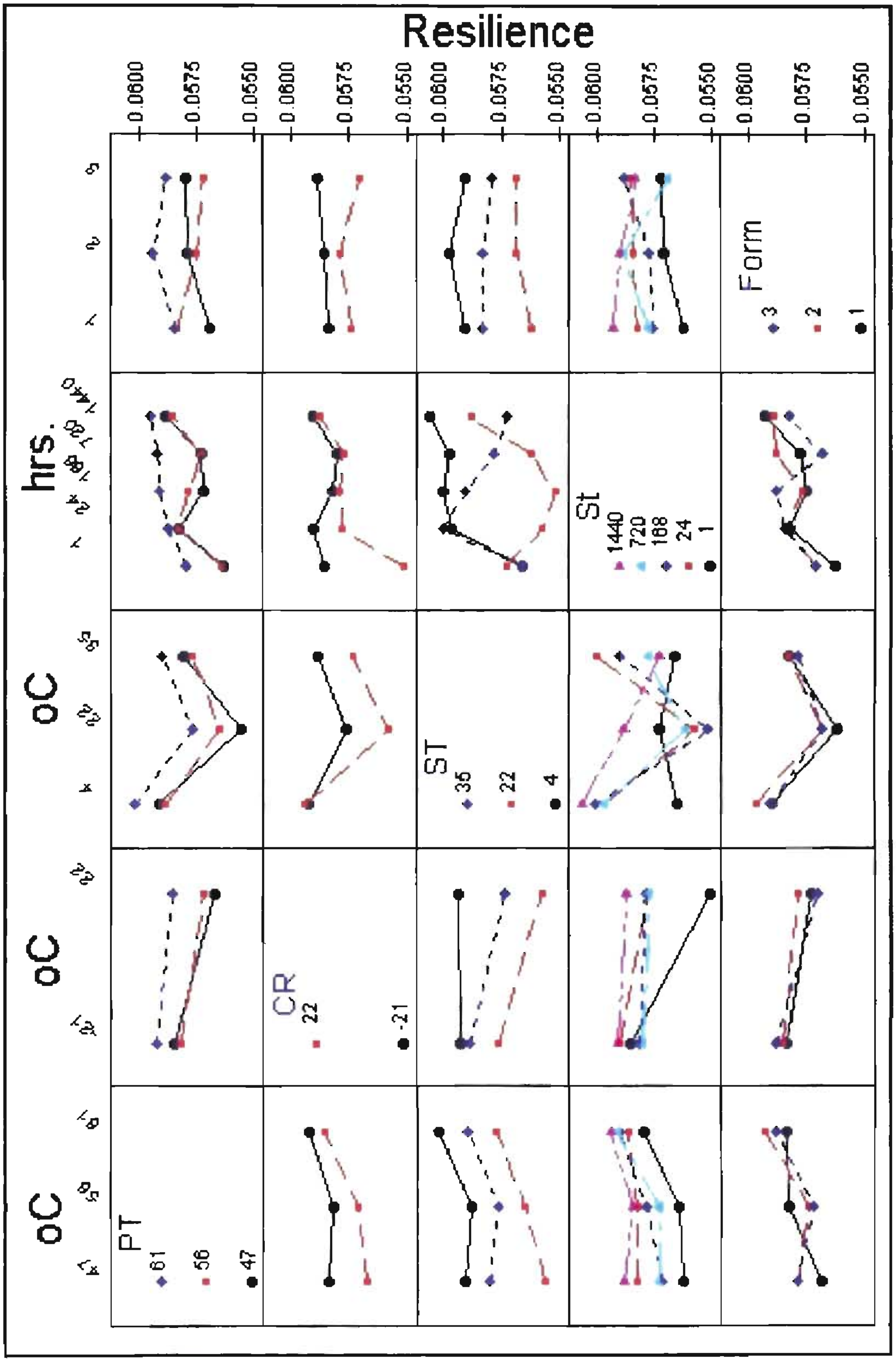

Figure 20. Full Interaction Plot – Data Means For Resilience

In Figure 20, it is very easily observed that ST*Form do not interact (parallel lines). It is concluded that the process variable that has the strongest effect on resilience is Storage Temperature (widest rage of variation of the values of resilience), and the interaction terms that do not affect resilience very strongly are CR*Form (P=0.047) and PT*ST (P=0.027).

Effect of Various Ingredients on the Peanut Butter Slice

In this section, a discussion of the effect of the various ingredients, namely wax, gum, and starch is presented.

Effect of wax on the slice

Hardness of the slice is mainly influenced by the quantity of wax added to it. As discussed previously, refined paraffin wax was used in the making of the slice which is mainly formed by plate type crystals which represents a straight chain of hydrocarbons (Bennet, 1963). The type of crystals that formed the wax and it's melting point greatly affected the textural behavior of the slice when it was exposed to changes in temperature. When the mixture was poured into the molds the wax was in a liquid state with little or no hardness. After a while solidification of the wax started. During solidification, the wax gave up its latent heat of fusion and the rate of drop in temperature considerably reduced, causing crystallization of plate-type crystals. The cooling rate affected the size of the crystals formed but did not affect the type of crystal formed (Bennet, 1963). This explained the insignificance of the interaction terms PT*CR and CR*ST (P=0.519, and P=0.062 in Table V). As the temperature of exposure of the slice decreased, the density of the slice consequently increased and the size of the wax crystals also increased causing an increase in hardness. On the other hand as the temperature of the slice increased, hardness decreased. This decrease in hardness was due to a decrease in the density of the slice, because density decreased as it approached the melting point (temperature at which the wax changes from a solid to a liquid state) (Bennet, 1963) of the wax. In this case the melting point of the refined paraffin wax was around 50°C. This explained why the interaction between ST*St (see Table V) was very significant for hardness ($P<0.001$). When the melting point of the wax was reached the slice became liquid due to a change in crystal structure.

Effect of gums on the slice

Gellan gum and Agar gum are major gelling agents which give firm gel characteristics to the slice due to its high modulus property (modulus indicates how firm a the gel appears when lightly squeeze) as well as texture and stability. In the slice gellan gum formed the gel with the peanut butter's sodium ions Na^+(from the sodium chlorine NaCl) which promoted chain association in forming gels. The gel formed with these sodium ions was not as strong as the gel that formed with calcium ions Ca^{2+} (divalent ions have much stronger affinity than monovalent ions) (Sanderson and Clark, 1983).The gum formed the gel when it was added to the mixture of peanut butter and wax which was being heated. The strength of the gel, which was given by its hardness, was dependent on the gum concentration, which became stronger as the concentration increased. High modulus gel was desirable in the slice, since this would make the slice firm to the touch and would also improve it's peelability.

The cooling rate and storage time had little effect on the gel texture. As a consequence gumminess and chewiness were not affected by the interaction of these terms (CR*St). This could be observed in Tables X and XII (P= 0.080, P=0.090) and also in Figure 6 and 7. Agar gum also formed the gel with the Na^+ ions. The difference with using either of the two gums was that the slice obtained with agar gum was not as firm as the one obtained with gellan gum (due to low modulus property of the agar gum), but it was more elastic (resilient).

Effect of starch in the slice

It is known that the chemical composition of starch consists of a mixture of predominantly linear α-(1→4)-glucan, amylose, and the highly branched, high molecular weight amylopectin- an α-glucan, based on 1→4 glycosidic linkages with α-(1→6) branch points. The process of gelatinization is a consequence of the breaking of the hydrogen bonds between poly-(1→4)- α-glucan chains in the crystallites and the swelling of the starch granules. The rupture of these bonds occurs when the starch is hydrated while being heated in the mixture (Blanshard, 1987).. When making the peanut butter slice the mixture was heated so the process of gelatinization took place. In this case since Tapioca starch was used in the formulation, it increased the viscosity of the mixture because of its high content in amylopectin 75%, when it gelatinized. However, because of it low content in amylose the gelling properties of the slice were not strong. This explains why the slice was not as resilient as when gums were used in the formulation. The effect of the starch as compared to the effect of the gums on the resilience the slice can be observed in Figure 17.

CHAPTER VI

CONCLUSIONS

This study proposes the development of a new product: peanut butter slices. This new product is made out of peanut butter, gum, or starch, and wax. The conclusions drawn from this study were as follows.

1. It is possible to make a peanut butter slice, from peanut butter having 'ideal' characteristics which are shear-thinning texture, acceptable shelf life, color and flavor identical to peanut butter, easily peeled from the wrapper, and ability to maintain the identity of peanut butter (which requires it to be 90% peanuts).
2. All independent variables (Process Temperature, Cooling Rate, Storage Temperature, Storage time, and Formulation) are statistically significant (see Appendix B).
3. Storage Temperature is the process variable that has the biggest effect on the textural behavior of the peanut butter slice for the three formulations studied.
4. The interaction term that affects the texture of the slice the most is the interaction between Storage Temperature and Storage time (ST*St P=0.000) since it strongly affects all the dependent variables.
5. Another interaction term that affects almost all the textural variables, with the exception of resilience, is the interaction between Process Temperature and Storage Time (PT*St, P<= 0.009)

6. The textural behavior of the slice with respect to two-way interactions on hardness, gumminess, and chewiness is almost the same. Therefor it may not be necessary to study both gumminess and chewiness.
7. It is clearly seen that the best Process Temperature for all the treatment combinations is 61°C.
8. The peanut butter slice should be cooled at 22°C not only for textural reasons but also for economical reasons.
9. Since hardness is the dependent variable that affects the most the texture of the slice storing it at 4°C will be the best choice for its textural stability.
10. From the author's point of view the best texturally stable slice is obtained when it's formulation is as follows: Peanut butter 92.30%,Gellan Gum 2.4%, and paraffin wax 3.07%, and the process variables are as follows: Process Temperature 61°C, Cooling Rate 22°C, and Storage Temperature 4°C.

CHAPTER VII

RECOMMENDATIONS FOR FUTURE STUDY

Further studies would most likely involve determining the texture characteristics that an ideal peanut butter slice should have. The only type of wax used in the formulation was paraffin wax. It will be interesting to do further studies of the slice texture experimenting with other kind of waxes, such as beeswax. The study of three, four and five-way interaction may present a better way of dealing with the process variables. It will be interesting to research an "ideal" packaging material and also an "ideal" atmosphere. The shelf-life of the slice needs to be studied. Peanut butter is not easily affected by mold because of its low water activity but it is easily affected by oxygen.

Other further studies will be the production of the peanut butter slice on large scale such as in a manufacturing plant, and finally the marketing of the slice.

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APPENDIXES

APPENDIX A

Least Squares Means for Texture variables

	Hardness (g_f)		Adhesiveness (g_f - sec)		Cohesiveness (cm^2/cm^2)	
	Mean	StDev	Mean	StDev	Mean	StDev
PT (°C)						
47	956.8	3.95924	-686.7	4.15707	0.3	0.19665
56	995.5	3.90474	-637.6	4.09985	0.3	0.19394
61	1001.8	6.0374	-630.1	6.33907	1.2	0.29986
CR (°C)						
-21	975.9	3.3194	-677.7	3.48527	0.3	0.16487
22	993.4	4.35029	-625.2	4.56766	0.9	0.21607
ST (°C)						
4	1257	4.12037	-701.4	4.32626	1.1	0.20465
22	947.2	3.92072	-683.4	4.11663	0.3	0.19473
35	749.8	5.91804	-569.6	6.21376	0.4	0.29393
St (hrs.)						
1	1056.3	6.09781	-657	6.40251	0.3	0.30286
24	982.6	6.05626	-639.5	6.35888	0.3	0.3008
168	961.4	6.05573	-646.4	6.35833	1.7	0.30077
720	942.3	6.06884	-638.9	6.37209	0.3	0.30142
1440	980.8	6.3073	-675.3	6.62247	0.3	0.31327
Form						
1	998.6	3.93087	-648.5	4.12729	1.2	0.19524
2	971.3	5.84009	-636.6	6.13191	0.3	0.29006
3	984.1	4.2207	-669.2	4.4316	0.3	0.20963

	Gumminess (g_f)		Chewiness (g_f)		Resilience (cm^2/cm^2)	
	Mean	StDev	Mean	StDev	Mean	StDev
PT (°C)						
47	308.3	1.2436	298.5	1.20328	0.0576	0.00014
56	307.8	1.22648	297.7	1.18672	0.0577	0.00013
61	313.4	1.89635	304.5	1.83487	0.0588	0.00021
CR (°C)						
-21	312	1.04263	302.6	1.00883	0.0586	0.00011
22	307.7	1.36643	297.9	1.32213	0.0575	0.00015
ST (°C)						
4	368.9	1.29421	357.6	1.25225	0.0593	0.00014
22	294.3	1.2315	284.4	1.19158	0.0566	0.00014
35	266.4	1.85886	258.7	1.7986	0.0581	0.0002
St (hrs.)						
1	316.7	1.91532	308.7	1.85324	0.0568	0.00021
24	307.6	1.90227	297.8	1.84061	0.0585	0.00021

	Gumminess (g_f)		Chewiness (g_f)		Resilience (cm^2/cm^2)	
	Mean	StDev	Mean	StDev	Mean	StDev
168	304.4	1.90211	294.1	1.84045	0.0581	0.00021
720	303.9	1.90622	294.1	1.84443	0.0580	0.00021
1440	316.7	1.98112	306.4	1.9169	0.0589	0.00022
Form						
1	305.9	1.23469	296.8	1.19466	0.0579	0.00014
2	306.6	1.83437	296.6	1.77491	0.0582	0.0002
3	317.1	1.32572	307.3	1.28275	0.0580	0.00015

APPENDIX B

B1. MANOVA For Process Temperature (PT°C)

MANOVA for PT	s = 2	m = 1.5	n = 2984.5	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.94975	25.986	(12, 11942)	<0.1
Lawley-Hotelling	0.05258	26.16	(12, 11940)	<0.1
Pillai's	0.05056	25.812	(12, 11944)	<0.1
Roy's	0.04548			

B2. MANOVA For Cooling Rate (CR°C)

MANOVA for CR	s = 1	m = 2.0	n = 2984.5	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.96297	38.272	(6, 5971)	<0.1
Lawley-Hotelling	0.03846	38.272	(6, 5971)	<0.1
Pillai's	0.03703	38.272	(6, 5971)	<0.1
Roy's	0.03846			

B3. MANOVA For Storage Temperature (ST°C)

MANOVA for ST	s = 2	m = 1.5	n = 2984.5	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.44605	494.889	(12, 11942)	<0.1
Lawley-Hotelling	1.16723	580.695	(12, 11940)	<0.1
Pillai's	0.58725	413.738	(12, 11944)	<0.1
Roy's	1.09931			

B4. MANOVA For Storage Time (St h)

MANOVA for St	s = 4	m = 0.5	n = 2984.5	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.91158	23.342	(24, 20831)	<0.1
Lawley-Hotelling	0.09569	23.8	(24, 23878)	<0.1
Pillai's	0.08962	22.82	(24, 23896)	<0.1
Roy's	0.08029			

B5. MANOVA For Form (F)

	MANOVA for Form	**s = 2 m = 1.5**	**n = 2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.94155	30.422	(12, 11942)	<0.1
Lawley-Hotelling	0.0618	30.746	(12, 11940)	<0.1
Pillai's	0.0587	30.098	(12, 11944)	<0.1
Roy's	0.05701			

B6. MANOVA For Interaction between PT and CR (PT*CR)

	MANOVA for PT*CR	**s =2 m =1.5**	**n =2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.99602	1.987	(12, 11942)	0.021
Lawley-Hotelling	0.00399	1.987	(12, 11940)	0.021
Pillai's	0.00399	1.987	(12, 11944)	0.021
Roy's	0.00225			

B7. MANOVA For Interaction between PT and ST (PT*ST)

	MANOVA for PT*ST	**s =4 m =0.5**	**n =2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.96784	8.172	(24, 20831)	<0.1
Lawley-Hotelling	0.03298	8.204	(24, 23878)	<0.1
Pillai's	0.0324	8.131	(24, 23896)	<0.1
Roy's	0.023			

B8. MANOVA For Interaction between PT and St (PT*St)

	MANOVA for PT*St	**s =6 m =0.5**	**n =2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.9777	2.812	(48, 29383)	<0.1
Lawley-Hotelling	0.02262	2.814	(48, 35816)	<0.1
Pillai's	0.02248	2.809	(48, 35856)	<0.1
Roy's	0.0099			

B9 MANOVA For Interaction between PT and Form (PT*Form)

	MANOVA for PT*Form	**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.97996	5.052	(24, 20831)	<0.1
Lawley-Hotelling	0.02032	5.054	(24, 23878)	<0.1
Pillai's	0.02018	5.048	(24, 23896)	<0.1
Roy's	0.00781			

B10. MANOVA For Interaction between CR and ST (CR*ST)

	MANOVA for CR*ST	**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.97106	14.72	(12, 11942)	<0.1
Lawley-Hotelling	0.02972	14.785	(12, 11940)	<0.1
Pillai's	0.02902	14.655	(12, 11944)	<0.1
Roy's	0.02657			

B11. MANOVA For Interaction between CR and St (CR*St)

	MANOVA for CR*St	**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.9763	5.987	(24, 20831)	<0.1
Lawley-Hotelling	0.02417	6.011	(24, 23878)	<0.1
Pillai's	0.0238'	5.959	(24, 23896)	<0.1
Roy's	0.019			

B12 MANOVA For Interaction between CR and F (CR*F)

	MANOVA for CR*Form	**s = 2 m = 1.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.99127	4.373	(12, 11942)	<0.1
Lawley-Hotelling	0.00879	4.373	(12, 11940)	<0.1
Pillai's	0.00875	4.374	(12, 11944)	<0.1
Roy's	0.00552			

B13. MANOVA For Interaction between ST and St (ST*St)

	MANOVA for ST*St	**s = 6 m = 0.5**	**n = 2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.76081	34.973	(48, 29383)	<0.1
Lawley-Hotelling	0.29777	37.031	(48, 35816)	<0.1
Pillai's	0.25205	32.756	(48, 35856)	<0.1
Roy's	0.23292			

B14. MANOVA For Interaction between ST and Form (ST*F)

	MANOVA for ST*Form	**s = 6 m = 0.5**	**n = 2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98846	2.894	(24, 20831)	<0.1
Lawley-Hotelling	0.01164	2.895	(24, 23878)	<0.1
Pillai's	0.01158	2.892	(24, 23896)	<0.1
Roy's	0.00594			

B15. MANOVA For Interaction between St and Form (St*F)

	MANOVA for St*Form	**s = 6 m = 0.5**	**n = 2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.96205	4.832	(48, 29383)	<0.1
Lawley-Hotelling	0.03889	4.836	(48, 35816)	<0.1
Pillai's	0.03849	4.822	(48, 35856)	<0.1
Roy's	0.01475			

B16. MANOVA For Interaction between PT, CR, and ST (PT*CR*ST)

	MANOVA for PT*CR*ST	**s = 4 m = 0.5**	**n = 2984.5**	
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98539	3.67	(24, 20831)	<0.1
Lawley-Hotelling	0.01477	3.674	(24, 23878)	<0.1
Pillai's	0.01467	3.666	(24, 23896)	<0.1
Roy's	0.00914			

B17. MANOVA For Interaction between PT, CR and St (CR*St)

MANOVA for PT*CR*St		**s = 6 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98889	1.391	(48, 29383)	0.038
Lawley-Hotelling	0.01119	1.392	(48, 35816)	0.038
Pillai's	0.01115	1.391	(48, 35856)	0.038
Roy's	0.00556			

B18. MANOVA For Interaction between PT, CR and F (PT*CR*F)

MANOVA for PT*CR*Form		**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98878	2.812	(24, 20831)	<0.1
Lawley-Hotelling	0.01132	2.816	(24, 23878)	<0.1
Pillai's	0.01124	2.807	(24, 23896)	<0.1
Roy's	0.00856			

B19. MANOVA For Interaction between PT, ST and St (PT*ST*St)

MANOVA for PT*CR*Form		**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.96219	2.406	(96, 33835)	<0.1
Lawley-Hotelling	0.03876	2.41	(96, 35816)	<0.1
Pillai's	0.03833	2.402	(96, 35856)	<0.1
Roy's	0.01553			

B20. MANOVA For Interaction between PT, ST and F (PT*ST*F)

MANOVA for PT*ST*Form		**s = 6 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.9722	3.518	(48, 29383)	<0.1
Lawley-Hotelling	0.02832	3.522	(48, 35816)	<0.1
Pillai's	0.02807	3.511	(48, 35856)	<0.1
Roy's	0.01234			

B21. MANOVA For Interaction between PT, St and F (PT*St*F)

	MANOVA for PT*St*Form	**s = 6 m = 4.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.94429	3.584	(96, 33835)	<0.1
Lawley-Hotelling	0.05777	3.592	(96, 35816)	<0.1
Pillai's	0.05688	3.575	(96, 35856)	<0.1
Roy's	0.02322			

B22. MANOVA For Interaction between PT, CR and St (CR*St)

	MANOVA for CR*ST*St	**s = 6 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.9771	2.888	(48, 29383)	<0.1
Lawley-Hotelling	0.02324	2.891	(48, 35816)	<0.1
Pillai's	0.02308	2.884	(48, 35856)	<0.1
Roy's	0.01033			

B23. MANOVA For Interaction between CR, ST and F (CR*ST*F)

	MANOVA for CR*ST*Form	**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98401	4.02	(24, 20831)	<0.1
Lawley-Hotelling	0.01618	4.024	(24, 23878)	<0.1
Pillai's	0.01606	4.013	(24, 23896)	<0.1
Roy's	0.01035			

B24. MANOVA For Interaction between CR, St and F (CR*St*F)

	MANOVA for CR*St*Form	**s = 4 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.98583	1.778	(48, 29383)	0.001
Lawley-Hotelling	0.01431	1.78	(48, 35816)	0.001
Pillai's	0.01424	1.777	(48, 35856)	0.001
Roy's	0.00755			

B25. MANOVA For Interaction between ST, St and F (ST*St*F)

MANOVA for ST*St*Form		**s = 6 m = 4.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.95796	2.682	(96, 33835)	<0.1
Lawley-Hotelling	0.04319	2.686	(96, 35816)	<0.1
Pillai's	0.04271	2.678	(96, 35856)	<0.1
Roy's	0.01724			

B26. MANOVA For Interaction between PT, CR, ST and St (PT*CR*ST*St)

MANOVA for PT*CR*ST*St		**s = 6 m = 4.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.96506	2.22	(96, 33835)	<0.1
Lawley-Hotelling	0.03574	2.222	(96, 35816)	<0.1
Pillai's	0.0354	2.217	(96, 35856)	<0.1
Roy's	0.01495			

B27. MANOVA For Interaction between PT, CR, ST and Ft (PT*CR*ST*F)

MANOVA for PT*CR*ST*Form		**s = 6 m = 0.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.97023	3.771	(48, 29383)	<0.1
Lawley-Hotelling	0.03042	3.782	(48, 35816)	<0.1
Pillai's	0.03003	3.757	(48, 35856)	<0.1
Roy's	0.01822			

B28. MANOVA For Interaction between PT, CR, St, and F (PT*CR*St*F)

MANOVA for PT*CR*St*Form		**s = 6 m = 4.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.97373	1.66	(96, 33835)	<0.1
Lawley-Hotelling	0.02677	1.665	(96, 35816)	<0.1
Pillai's	0.02648	1.656	(96, 35856)	<0.1
Roy's	0.01581			

B29. MANOVA For Interaction between PT, ST, St, and F (PT*ST*St*F)

MANOVA for PT*ST*St*Form		**s = 6 m = 12.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.9301	2.268	(192, 35302)	<0.1
Lawley-Hotelling	0.07323	2.277	(192, 35816)	<0.1
Pillai's	0.07171	2.259	(192, 35856)	<0.1
Roy's	0.03207			

B30. MANOVA For Interaction between CR, ST, St, and F (CR*ST*St*F)

MANOVA for CR*ST*St*Form		**s = 6 m = 4.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.95445	2.912	(96, 33835)	<0.1
Lawley-Hotelling	0.04697	2.921	(96, 35816)	<0.1
Pillai's	0.04626	2.902	(96, 35856)	<0.1
Roy's	0.02305			

B31. MANOVA For Interaction between PT, CR, ST, St, and F (PT*CR*ST*St*F)

MANOVA for PT*CR*ST*St*Form		**s = 6 m = 12.5 n = 2984.5**		
Criterion	Test Statistic	Approx F	DF	P
Wilk's	0.90922	2.984	(192, 35302)	<0.1
Lawley-Hotelling	0.09641	2.997	(192, 35816)	<0.1
Pillai's	0.09396	2.971	(192, 35856)	<0.1
Roy's	0.04003			

APPENDIX C

C1. Regression Analysis for Hardness

Predictor	Coef	StDev	T	P
Constant	1147.58	27.11	42.33	<0.001
PT oC	3.5226	0.4691	7.51	<0.001
CR oC	0.3643	0.1257	2.9	0.004
ST oC	-16.2539	0.2154	-75.45	<0.001
St h	-0.025161	0.004913	-5.12	<0.001
Form	-6.463	3.341	-1.93	0.053
S = 213.5	R-Sq = 48.3%		R-Sq(adj) = 48.3%	

C2. Regression Analysis for Adhesiveness

Predictor	Coef	StDev	T	P
Constant	-926.92	26.15	-35.45	<0.001
PT oC	4.0661	0.4524	8.99	<0.001
CR oC	1.2991	0.1212	10.72	<0.001
ST oC	4.123	0.2078	19.84	<0.001
St h	-0.021086	0.004738	-4.45	<0.001
Form	-10.628	3.222	-3.3	0.001
S = 206.0	R-Sq = 8.8%		R-Sq(adj) = 8.7%	

C3. Regression Analysis for Cohesiveness

Predictor	Coef	StDev	T	P
Constant	-0.818	1.258	-0.65	0.516
PT oC	0.05221	0.02176	2.4	0.016
CR oC	0.012361	0.005831	2.12	0.034
ST oC	-0.025402	0.009994	-2.54	0.011
St h	-0.0002631	0.0002279	-1.15	0.248
Form	-0.4044	0.155	-2.61	0.009
S = 9.906	R-Sq = 0.4%		R-Sq(adj) = 0.3%	

C4. Regression Analysis for Gumminess

Predictor	Coef	StDev	T	P
Constant	345.881	8.113	42.63	<0.001
PT oC	0.3482	0.1404	2.48	0.013
CR oC	-0.1224	0.03761	-3.25	0.001
ST oC	-3.35501	0.06446	-52.05	<0.001
St h	0.003417	0.00147	2.32	0.02
Form	5.7756	0.9997	5.78	<0.001
S = 63.90	R-Sq = 30.60%		R-Sq(adj) = 30.60%	

C5. Regression Analysis for Chewiness

Predictor	Coef	StDev	T	P
Constant	332.113	7.854	42.28	<0.001
PT oC	0.3995	0.1359	2.94	0.003
CR oC	-0.12995	0.03641	-3.57	<0.001
ST oC	-3.23783	0.06241	-51.88	<0.001
St h	0.002658	0.001423	1.87	0.062
Form	5.408	0.9678	5.59	<0.001
S = 61.86	R-Sq = 30.50%		R-Sq(adj) = 30.40%	

C6. Regression Analysis for Resilience

Predictor	Coef	StDev	T	P
Constant	0.0541164	0.0008387	64.53	<0.001
PT oC	8.069E-05	1.451E-05	5.56	<0.001
CR oC	-2.654E-05	3.89E-06	-6.83	<0.001
ST oC	-4.686E-05	6.66E-06	-7.03	<0.001
St h	7.8E-07	1.5E-07	5.16	<0.001
Form	0.0000574	0.0001033	0.56	0.579
S = 0.006605	R-Sq = 2.40%		R-Sq(adj) = 2.30%	

APPENDIX D

D1. Hsu's MCB Multiple Comparison test with the Best.

	Hardness (g_f)		Adhesiveness (g_f sec)		Cohesiveness (cm^2/cm^2)	
	Mean	Grouping	Mean	Grouping	Mean	Grouping
PT (°C)						
47	956.3	B	-685.3	B	0.331	B
56	994.7	A	-637.6	A	0.318	B
61	1011.7	A	-632.7	A	1.193	A
CR (°C)						
-21	974.4	B	-678.7	A	0.330	B
22	1000.2	A	-625.2	B	0.875	A
ST (°C)						
4	1257.7	A	-701.4	C	1.143	A
22	944.2	B	-679.4	B	0.312	B
35	754.5	C	-569.6	A	0.364	B
St (hrs.)						
1	1057.8	A	-653.5	A	0.300	B
24	988.9	B	-639.7	A	0.324	B
168	963.4	BC	-648.0	A	1.718	A
720	946.8	CD	-639.9	A	0.331	B
1440	980.3	ECB	-679.6	B	0.335	B
Form						
1	998.2	A	-649.3	B	1.140	A
2	982.8	A	-638.1	B	0.323	B
3	980.3	A	-670.0	A	0.332	B

	Gumminess (g_f)		Chewiness (g_f)		Resilience (cm^2/cm^2)	
	Mean	Grouping	Mean	Grouping	Mean	Grouping
PT (°C)						
47	308.3	B	298.01	B	0.0576	B
56	307.8	B	297.57	B	0.0577	B
61	313.4	A	304.95	A	0.0588	A
CR (°C)						
-21	311.67	A	302.18	A	0.0586	A
22	308.53	A	298.64	A	0.0575	B
ST (°C)						
4	368.98	A	357.59	B	0.0593	A
22	293.68	B	283.78	A	0.0566	B
35	267.18	C	259.49	C	0.0581	C
St (hrs.)						
1	317.20	A	309.06	A	0.0568	C
24	308.60	B	298.73	AB	0.0585	AB
168	304.28	B	293.99	B	0.0581	B
720	303.74	B	293.92	B	0.0580	B
1440	316.72	A	306.41	A	0.0589	A
Form						
1	305.9	B	296.80	B	0.0579	A
2	308.3	B	298.27	B	0.0582	A
3	316.4	A	306.64	A	0.0582	A

D2. One-way ANOVA for Hardness using PT as source

```
Source     DF         SS         MS        F        P
PT oC       2    3321704    1660852    18.96    0.000
Error    6254  547977918      87620
Total    6256  551299622
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N       Mean      StDev  ---+---------+---------+---------+---
47       2094      956.3      291.7  (-----*----)
56       2156      994.7      287.2                 (----*----)
61       2007     1011.7      309.4                        (----*----)
                                     ---+---------+---------+---------+---
Pooled StDev =     296.0               950       975      1000      1025

Hsu's MCB (Multiple Comparisons with the Best)

    Family error rate = 0.0500

Critical value = 1.92
```

D3. One-way ANOVA for Hardness using CR as source

Source	DF	SS	MS	F	P
CR oC	1	1043200	1043200	11.86	0.001
Error	6255	550256422	87971		
Total	6256	551299622			

```
                                  Individual 95% CIs For Mean
                                  Based on Pooled StDev
Level       N      Mean    StDev  --------+---------+---------+--------
-21      3122     974.4    306.6   (------*------)
 22      3135    1000.2    286.3                     (------*------)
                                  --------+---------+---------+--------
Pooled StDev =    296.6                  975       990      1005
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.64

D4. One-way ANOVA for Hardness using ST as source

Source	DF	SS	MS	F	P
ST oC	2	262729707	131364854	2846.99	0.000
Error	6254	288569914	46142		
Total	6256	551299622			

Level	N	Mean	StDev
4	2064	1257.7	238.3
22	2204	944.2	179.9
35	1989	754.5	224.3

```
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  -+---------+---------+---------+-----
 4        2064    1257.7     238.3                                    (*
22        2204     944.2     179.9                (*)
35        1989     754.5     224.3   *)
                                    -+---------+---------+---------+-----
Pooled StDev =     214.8           750       900      1050      1200
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D5. One-way ANOVA for Hardness using St as source

Source	DF	SS	MS	F	P
St h	4	9016703	2254176	25.99	0.000
Error	6252	542282919	86738		
Total	6256	551299622			

Level	N	Mean	StDev
1	1242	1057.8	197.0
24	1256	988.9	301.6
168	1258	963.4	298.5
720	1249	946.8	319.1
1440	1252	980.3	335.6

```
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level        N      Mean     StDev  --------+---------+---------+--------
   1      1242    1057.8     197.0                                (---*----
  24      1256     988.9     301.6                (---*---)
 168      1258     963.4     298.5          (---*---)
 720      1249     946.8     319.1      (---*---)
1440      1252     980.3     335.6              (---*---)
                                    --------+---------+---------+--------
Pooled StDev =     294.5                   960      1000      1040
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 2.16

D6. One-way ANOVA for Hardness using Form as source

Source	DF	SS	MS	F	P
Form	2	392897	196448	2.23	0.108
Error	6244	550062949	88095		
Total	6246	550455846			

```
                                         Individual 95% CIs For Mean
                                         Based on Pooled StDev
Level       N      Mean     StDev   -----+---------+---------+---------+-
1        2123     998.2     297.9                  (----------*---------)
2        2157     982.8     298.3      (---------*---------)
3        1967     980.3     294.0   (----------*----------)
                                    -----+---------+---------+---------+-
Pooled StDev =    296.8                972       984       996      1008
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D7. One-way ANOVA for Adhesiveness using PT as source

Source	DF	SS	MS	F	P
PT oC	2	3498003	1749002	38.10	0.000
Error	6254	287106587	45908		
Total	6256	290604590			

```
                                         Individual 95% CIs For Mean
                                         Based on Pooled StDev
Level       N      Mean     StDev   --------+---------+---------+--------
47       2094    -685.3     216.4   (---*----)
56       2156    -638.0     208.7                           (----*----)
61       2007    -632.7     217.8                              (----*---)
                                    --------+---------+---------+--------
Pooled StDev =    214.3                  -680      -660      -640
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D8. One-way ANOVA for Adhesiveness using CR as source

Source	DF	SS	MS	F	P
CR oC	1	4387269	4387269	95.88	0.000
Error	6255	286217321	45758		
Total	6256	290604590			

```
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level       N      Mean     StDev   ----+---------+---------+---------+--
-21      3122    -678.7     215.8    (---*--)
 22      3135    -625.7     212.0                                (---*---)
                                    ----+---------+---------+---------+--
Pooled StDev =    213.9                -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

    Family error rate = 0.0500

Critical value = 1.64

D9. One-way ANOVA for Adhesiveness using ST as source

Source	DF	SS	MS	F	P
ST oC	2	20053735	10026867	231.78	0.000
Error	6254	270550855	43260		
Total	6256	290604590			

```
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level       N      Mean     StDev   ---+---------+---------+---------+---
 4       2064    -701.9     285.7    (-*)
22       2204    -679.4     168.9       (-*-)
35       1989    -570.3     140.7                                (-*-)
                                    ---+---------+---------+---------+---
Pooled StDev =    208.0               -700      -650      -600      -550
```

Hsu's MCB (Multiple Comparisons with the Best)

    Family error rate = 0.0500

Critical value = 1.92

D10. One-way ANOVA for Adhesiveness using St as source

Source	DF	SS	MS	F	P
St h	4	1345589	336397	7.27	0.000
Error	6252	289259001	46267		
Total	6256	290604590			

```
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level      N       Mean    StDev   ------+---------+---------+---------+
    1   1242     -653.5    215.9               (-----*-----)
   24   1256     -639.7    222.2                      (-----*-----)
  168   1258     -648.0    216.9                  (-----*-----)
  720   1249     -639.9    195.7                      (-----*-----)
 1440   1252     -679.6    223.6   (-----*-----)
                                   ------+---------+---------+---------+
Pooled StDev =    215.1               -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 2.16

D11. One-way ANOVA for Adhesiveness using Form as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Level      N       Mean    StDev   ---+---------+---------+---------+---
1       2123     -649.3    221.5                (-----*-----)
2       2157     -638.1    214.8                       (-----*-----)
3       1967     -670.0    208.7   (-----*------)
                                   ---+---------+---------+---------+---
Pooled StDev =    215.2            -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D12. One-way ANOVA for Gumminess using PT as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

Level	N	Mean	StDev
1	2123	-649.3	221.5
2	2157	-638.1	214.8
3	1967	-670.0	208.7

Pooled StDev = 215.2

```
Individual 95% CIs For Mean
Based on Pooled StDev
---+---------+---------+---------+---
                  (-----*-----)
                            (-----*-----)
(-----*------)
---+---------+---------+---------+---
 -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D13. One-way ANOVA for Gumminess using CR as source

Source	DF	SS	MS	F	P
CR oC	1	4387269	4387269	95.88	0.000
Error	6255	286217321	45758		
Total	6256	290604590			

Level	N	Mean	StDev
-21	3122	-678.7	215.8
22	3135	-625.7	212.0

Pooled StDev = 213.9

```
Individual 95% CIs For Mean
Based on Pooled StDev
----+---------+---------+---------+--
 (---*--)
                              (---*---)
----+---------+---------+---------+--
  -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.64

D14. One-way ANOVA for Gumminess using ST as source

Source	DF	SS	MS	F	P
ST oC	2	20053735	10026867	231.78	0.000
Error	6254	270550855	43260		
Total	6256	290604590			

Level	N	Mean	StDev
4	2064	-701.9	285.7
22	2204	-679.4	168.9
35	1989	-570.3	140.7

```
Individual 95% CIs For Mean
Based on Pooled StDev
---+---------+---------+---------+---
 (-*)
      (-*-)
                                 (-*-)
---+---------+---------+---------+---
 -700      -650      -600      -550
```

Pooled StDev = 208.0

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D15. One-way ANOVA for Gumminess using St as source

Source	DF	SS	MS	F	P
St h	4	1345589	336397	7.27	0.000
Error	6252	289259001	46267		
Total	6256	290604590			

Level	N	Mean	StDev
1	1242	-653.5	215.9
24	1256	-639.7	222.2
168	1258	-648.0	216.9
720	1249	-639.9	195.7
1440	1252	-679.6	223.6

```
Individual 95% CIs For Mean
Based on Pooled StDev
------+---------+---------+---------+
             (-----*-----)
                    (-----*-----)
                (-----*-----)
                    (-----*-----)
(-----*-----)
------+---------+---------+---------+
    -680      -660      -640      -620
```

Pooled StDev = 215.1

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 2.16

D16. One-way ANOVA for Gumminess using Form as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level        N       Mean     StDev    ---+---------+---------+---------+---
1         2123     -649.3     221.5                  (-----*-----)
2         2157     -638.1     214.8                          (-----*-----)
3         1967     -670.0     208.7    (-----*------)
                                       ---+---------+---------+---------+---
Pooled StDev =      215.2              -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D17. One-way ANOVA for Chewiness using PT as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level        N       Mean     StDev    ---+---------+---------+---------+---
1         2123     -649.3     221.5                  (-----*-----)
2         2157     -638.1     214.8                          (-----*-----)
3         1967     -670.0     208.7    (-----*------)
                                       ---+---------+---------+---------+---
Pooled StDev =      215.2              -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D18. One-way ANOVA for Chewiness using CR as source

Source	DF	SS	MS	F	P
CR oC	1	4387269	4387269	95.88	0.000
Error	6255	286217321	45758		
Total	6256	290604590			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level       N      Mean     StDev  ----+---------+---------+---------+--
-21      3122    -678.7     215.8  (---*--)
 22      3135    -625.7     212.0                               (---*---)
                                   ----+---------+---------+---------+--
Pooled StDev =    213.9             -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.64

D19. One-way ANOVA for Chewiness using ST as source

Source	DF	SS	MS	F	P
ST oC	2	20053735	10026867	231.78	0.000
Error	6254	270550855	43260		
Total	6256	290604590			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
 4       2064    -701.9     285.7  (-*)
22       2204    -679.4     168.9      (-*-)
35       1989    -570.3     140.7                               (-*-)
                                   ---+---------+---------+---------+---
Pooled StDev =    208.0            -700      -650      -600      -550
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D20. One-way ANOVA for Chewiness using St as source

Source	DF	SS	MS	F	P
St h	4	1345589	336397	7.27	0.000
Error	6252	289259001	46267		
Total	6256	290604590			

```
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N       Mean     StDev     ------+---------+---------+---------+
    1     1242     -653.5     215.9                  (-----*-----)
   24     1256     -639.7     222.2                        (-----*-----)
  168     1258     -648.0     216.9                     (-----*-----)
  720     1249     -639.9     195.7                        (-----*-----)
 1440     1252     -679.6     223.6     (-----*-----)
                                        ------+---------+---------+---------+
Pooled StDev =      215.1                  -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 2.16

D21. One-way ANOVA for Chewiness using Form as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level        N       Mean     StDev     ---+---------+---------+---------+---
1         2123     -649.3     221.5                  (-----*-----)
2         2157     -638.1     214.8                         (-----*-----)
3         1967     -670.0     208.7     (-----*------)
                                        ---+---------+---------+---------+---
Pooled StDev =      215.2               -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D22. One-way ANOVA for Resilience using PT as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                             Individual 95% CIs For Mean
                                             Based on Pooled StDev
Level        N      Mean     StDev   ---+---------+---------+---------+---
1         2123    -649.3     221.5                 (-----*-----)
2         2157    -638.1     214.8                        (-----*-----)
3         1967    -670.0     208.7   (-----*------)
                                     ---+---------+---------+---------+---
Pooled StDev =     215.2             -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D23. One-way ANOVA for Resilience using CR as source

Source	DF	SS	MS	F	P
CR oC	1	4387269	4387269	95.88	0.000
Error	6255	286217321	45758		
Total	6256	290604590			

```
                                             Individual 95% CIs For Mean
                                             Based on Pooled StDev
Level        N      Mean     StDev   ----+---------+---------+---------+--
-21       3122    -678.7     215.8    (---*--)
 22       3135    -625.7     212.0                                (---*---)
                                     ----+---------+---------+---------+--
Pooled StDev =     213.9               -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.64

D24. One-way ANOVA for Resilience using ST as source

Source	DF	SS	MS	F	P
ST oC	2	20053735	10026867	231.78	0.000
Error	6254	270550855	43260		
Total	6256	290604590			

```
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level       N       Mean     StDev   ---+---------+---------+---------+---
 4       2064     -701.9     285.7    (-*)
22       2204     -679.4     168.9        (-*-)
35       1989     -570.3     140.7                                (-*-)
                                     ---+---------+---------+---------+---
Pooled StDev =     208.0             -700      -650      -600      -550
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

D25. One-way ANOVA for Resilience using St as source

Source	DF	SS	MS	F	P
St h	4	1345589	336397	7.27	0.000
Error	6252	289259001	46267		
Total	6256	290604590			

```
                                        Individual 95% CIs For Mean
                                        Based on Pooled StDev
Level       N       Mean     StDev   ------+---------+---------+---------+
   1     1242     -653.5     215.9                (-----*-----)
  24     1256     -639.7     222.2                      (-----*-----)
 168     1258     -648.0     216.9                  (-----*-----)
 720     1249     -639.9     195.7                      (-----*-----)
1440     1252     -679.6     223.6   (-----*-----)
                                     ------+---------+---------+---------+
Pooled StDev =     215.1                 -680      -660      -640      -620
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 2.16

D26. One-way ANOVA for Resilience using Form as source

Source	DF	SS	MS	F	P
Form	2	1068710	534355	11.54	0.000
Error	6244	289200120	46316		
Total	6246	290268831			

```
                                     Individual 95% CIs For Mean
                                     Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
1        2123    -649.3     221.5              (-----*-----)
2        2157    -638.1     214.8                    (-----*-----)
3        1967    -670.0     208.7  (-----*------)
                                   ---+---------+---------+---------+---
Pooled StDev =    215.2            -675      -660      -645      -630
```

Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.0500

Critical value = 1.92

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