EFFECT OF CALCIUM PRETREATMENTS, VACUUM LEVELS, AND APPLE VARIETIES, ON THE TEXTURE OF VACUUM MICROWAVE DEHYDRATED APPLE CHIPS

By

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Abstract

Apples were washed, sliced, steam blanched and dipped in 0-5% calcium chloride solution. These slices were air dried to a moisture content of ~50%db and then vacuum microwave dried (VMD) to a final moisture content of ~5%db. The effects of calcium pretreatment, vacuum levels, and apple varieties on the textural characteristics of VMD apple chips were determined by a TA XT2 Texture Analyzer using punch and die tests. The effect of different drying techniques (VMD, air drying and freeze drying) on apple chips' texture was also investigated. The calcium pretreated chips were found to be significantly ($p<0.05$) crispier than the non-treated ones. Application of vacuum during VMD was observed to have significant ($p<0.05$) effects on lowering the density and increasing the crispness in apple chips. Furthermore, results from instrumental analysis showed that Fuji apple chips were significantly ($p<0.05$) crispier than both Red Delicious and Golden Delicious apple chips. Fuji apple chips were also found to have a significantly ($p<0.05$) higher rating for crispness than the other two apple varieties. Results from sensory analysis illustrated that although a significant bitterness was not observed ($p>0.05$) in 1% $CaCl_2$ pretreated apple chips, this calcium pretreatment did significantly ($p<0.05$) affect the flavor (apple flavor, sweetness, and off flavor) of apple chips. Scanning electron microscopy was used to examine the structures of the dehydrated apple chips. The calcium pretreatment, the levels of vacuum employed, and the types of drying technology were all shown to have effects on the structural characteristics of apple chips.

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1. Introduction

In high-yield apple producing countries, serious economic losses are observed as a result of storage problems, poor marketing, and lack of appropriate processing technologies (Massey, 1989). Of the several apple-processing methods, dehydration is a significant technology for fruit preservation. Dehydrated fruit production represents a very important industry, and dehydration processes are attractive due to cost reductions in transportation and storage (Somogyi and Luh, 1986).

Recently, there has been increasing consumer interest in health food products; apples that are perceived as a healthy food (Lee and Mattick, 1989), are a desirable ingredient for fruit-based snacks. The production of crispy apple chips with low fat and high fiber content are expected to be highly desirable by consumers (Matz, 1993a, b). Apple chips can be dehydrated by various methods but a desirable product has not been produced by conventional methods. Reduction of nutritional value and developments of undesirable colors, off-flavors or non-typical and uneven textures are observed in conventional oil-fried or hot air-dried apple chips and other fruit and vegetables products (Matz, 1993a&b; Schadle et al., 1983; Yang and Atallah, 1985; Yongsawatdigul and Gunasekaran, 1996). Although freeze drying usually gives products with a good appearance, it results in a non-crispy sponge-like structure and causes large flavor losses (Flink, 1975). Also, freeze-drying is very time consuming, and thus very expensive.

Vacuum microwave dehydration (VMD) offers an alternative way to improve the quality of dehydrated products. The vacuum environment permits water to vaporize at a lower temperature and a faster rate than at atmospheric pressure (Petrucci and Clary, 1989). Since water boiling within the food results in a large vapor pressure differential between the center and the surface of the product, transfer of moisture out of the food is rapid during microwave drying. When vacuum and microwave heating are combined, foods can be dried rapidly without exposure to high temperatures. Further, the reduced exposure to air during drying may also help to reduce oxidative deterioration. Therefore, texture, color, flavor and nutrient properties of products can be largely preserved. Samples such as cranberries (Yongsawatdigul and Gunasekaran, 1996), shrimp (Lin et al., 1999) and krill (Durance, 1997), potato chips (Durance and Liu, 1996), carrots (Lin et al., 1998), and grapes (Petrucci and Clary, 1989) have also been successfully dried by VMD, resulting in high quality dried products. It has also been shown that vacuum microwave drying process can be utilized to expand the structure of some products to yield a puffy texture which is similar to that created by frying (Durance, 1997; Lin et al., 1998 &1999; Durance and Liu, 1996). Therefore, with the use of vacuum microwave drying, a unique oil free and crispy dehydrated apple chip product may be developed.

A better understanding of the physical and textural changes that foods undergo during vacuum microwave drying is needed, so that processing parameters can be readily manipulated to obtain the desired characteristic in the final product. In this study, the textural characteristics of vacuum microwave dehydrated apple chips were specifically analyzed in relation to calcium, variety, and vacuum level. Calcium has been widely reported to play an important role in preserving structural integrity of cell walls and providing mechanical strength (Knee and Bartley, 1981; Pooviah et al., 1988). Infiltration of calcium to increase the firmness of fresh and processed fruit products, particularly apples, is well documented (Glenn and Pooviah, 1990; Pooviah, 1986; Stow, 1989) but the impact of calcium on a dry crisp fruit product has not been reported. Therefore, the effects of a calcium pretreatment performed before dehydration on the textural characteristics of apple chips were studied. Also, the effects of vacuum level employed during VMD on apple chips' texture were investigated. Furthermore, since different varieties of apples have different structural features and processing qualities (Reeves and Leinbach, 1953; Reeves, 1970), the textural characteristics of apple chips made from three commonly available apple varieties (Golden Delicious, Red Delicious and Fuji) were also examined.

2. Literature Review

2.1 Apples

Apple (*Malus sylvestris*) has long been a popular fruit. An apple is composed of water, organic acids, vitamins, lipids, proteins, minerals and carbohydrates; these carbohydrates consist of sugars, starches, pectin, cellulose and hemicellulose. Carbohydrates account for the principal food value of apples, and about 75% of the carbohydrates consist of sugars that can be assimilated by people readily upon consumption. Apples have also been thought of as a good source of dietary fiber. "An apple a day keeps the doctor away," is an old popular rhyme that has served to emphasize the importance of apples in the diet from the standpoint of health (Lee and Mattick, 1989). The use of apples and apple products in maintaining a healthy digestive system and in the treatment of gastrointestinal disturbances has been studied in the classic literature (Smock and Neubert, 1950). Notably, apples have been recognized as a useful therapeutic agent in the dietary management of diarrhea (Am. Med. Assoc. Council on Food, 1939). This therapeutic value has been attributed to a high pectin content. Further, apple products, such as concentrated apple juice and apple syrup, dehydrated apple powder, and vinegar, have been recommended to reduce the curdling of milk used in infant feeding (Smock and Neubert, 1950).

2.1.1 Apple Production

Apples are probably the most important and most widely grown tree fruit in the world (Smock and Neubert, 1950). Both the United States and Canada are among the world's chief apple-producing nations. In 1982-84, about 3,748,000 metric tons (MT) and 473,000 MT were produced annually in the United States and Canada, respectively (FAO, 1985). The mean annual per-capita consumption of apples (1978-1981) in Canada and the United States was 13.6 and 8.2 kg, respectively (Anon. 1984). Apples are the third most important fruit crop grown in the United States, the world's second largest apple-producing country. The USSR was the world's largest apple-producing nations (FAO, 1985).

About ten thousand apple varieties are recognized, but only a few dozen are grown by the world's apple producers on a commercial scale. Among all the varieties, the Red Delicious is the most widely and heavily produced apple in the world: it represents approximately 40% of the production of the North American apple crop, while the Golden Delicious is second only to the Red Delicious in world production (Fisher and Kitson, 1991). Both of these varieties originated in the United States and have been widely adopted in many other apple-producing countries (Way and McLellan, 1989). In the early 1970s, another one of the world's chief apple-producing countries, Japan, greatly expanded its production of a new cultivar, the Fuji apple (Mink, 1973).

Apples do possess high moisture content and are, therefore, highly perishable. The storage problems, poor marketing, and the lack of appropriate processing technologies may, therefore, result in economic losses in some high-yield apple producing countries (Massey, 1989). In the United States, about 40,000 MT apples were not marketed (Way and McLellan, 1989). Processing such a perishable fruit crop can convert apples into more stable products that can be stored for longer periods, so that they can be available in times of shortage, out of season, and in places where production is limited. Processing also allows new or more usable forms of apples to be produced, and makes them more convenient to prepare. Therefore, the use of appropriate technologies for the processing and preservation of apples is of great importance in the apple industry (Fisher and Kitson, 1991; Somogyi and Luh, 1986).

2.1.2 Processed Apple Products

About 60-70% of the total apple production is marketed fresh, while the remaining apple crop, approximately 30-40%, is utilized for processing (Fisher and Kitson, 1991). A variety of apple products are produced; the five main products are juice, canned sauce, canned slices, dried apple slices, and frozen slices. Among these products, apple juice and canned sauce and slices are commonly used in institutional feeding units, such as hospitals, restaurants and bakery shops and are the dominant products, accounting for more than 50% of all the processed apple products (Hall, 1989a). Other apple products include vinegar, jelly, apple butter, mincemeat, fresh slices, apple wine, apple nectar, and apple cider (Way and McLellan, 1989). Some commercially processed apples, such as dried apples, are used for further manufacturing operations; these apple products may be used in baking, breakfast cereal confection, preserves, or as flavor carriers (Hall, 1989b).

2.2 Dehydration of Apples

Among all the apple-processing methods, such as canning, freezing and dehydration, dehydration is probably the oldest and one of the most effective methods used commercially for preserving apples. Dehydration is defined as the removal of water by means of mechanical equipment and artificial heating methods under carefully controlled conditions of temperature, humidity and air flow (Cruess, 1958). As a result of moisture removal, dehydrated fruits are shelf stable under proper storage due to the inhibition of the growth and reproduction of microorganisms and the minimization of moisture mediated deterioration reactions. Dehydrated fruits, on average, weight only 10-15% of their raw, canned or frozen counterparts; this significant reduction in the weight of the products substantially lowers packaging, transportation, handling, and storage costs. Further, since dehydration enables the storage of products under ambient temperature, costly refrigeration during transportation and storage is not required; this advantage is especially important in developing countries (Somogyi and Luh, 1986).

Dehydrated apple products comprise two main groups. The first group, commercially dried apples, consists of dried apple slices, rings, and, infrequently, other kinds of cuts with a moisture content around 20% by weight. A high sulfur dioxide content is added to these products to preserve color and prevent spoilage. They may be used directly or further dried to produce the second group. The second group usually consists of apple products with a moisture content of 5% or less. This second group includes products such as low moisture apple pieces in expanded (puffed) or regular form and various forms of apple powder or dehydrated apple sauce (Fisher and Kitson, 1991).

2.2.1 Apple Chips as a Healthy Snack

Consumption of snack food is large and rapidly rising. In 1991, a 5.6 % jump over 1990 in the retail sales of savory snacks was reported by the Snack Food Association (Davis, 1993). In the United States, snack food sales were close to $60 billion, and about 3.48 billion pounds of salty snacks such as potato chips, tortilla chips, extruded and fabricated chips, and multigrain chips were consumed by Americans in 1993 (Shukla, 1994). In recent years, consumers have been increasely concerned about their health and well-being; this concern has led to more healthy ways of eating (Buisson, 1995). Most conventional chip products are high in fat content but low in protein and fiber content and are generally considered to be relatively unhealthy (Shukla, 1994). A tremendous increase in consumer interest in "New generation" snacks containing lower fat, baked-not fried, and higher fiber has been observed. It is estimated that in 1992, about $400 million was spent by consumers on these healthy and 'lite' snack food products. Therefore, great interest exists in the development of new health food snacks for the food industry (Davis, 1993). Fruit-based snacks, which are nutritious, low in fat and high in fiber, are, in many ways, ideal snacks. Apples, which cost less than many other fruits, are relatively easy to process and have always been perceived as a healthy food (Smock and Neubert, 1950); hence, apples are a desirable ingredients for fruit-based snacks. The production of crispy apple chips by dehydration may, therefore, provide an alternative to the conventional less healthy type of snack chips.

2.2.2 Pre-drying Treatments to Inhibit Enzymatic Browning

2.2.2.1 Enzymatic Browning

Before drying, apples are cut into slices, cubes or other forms, thereby disorganizing the natural structure of the surface cells. The cut surfaces of the fruits which are exposed to the air will then undergo a rapid darkening, usually accompanied by the softening of fruit tissues, the development of off-flavor, and the alteration of nutritive value. These deteriorative changes are attributed to various chemical reactions catalyzed by the enzyme, polyphenol oxidase (PPO), which is naturally present in plant tissues. Upon the disorganization of the fruit structure during processing, the natural segregation of substrates and enzymes are disrupted, thus permitting enzymatic browning to occur. This enzymatic browning reaction is attributed to a mechanism wherein the plant tissue's phenolic compounds are oxidized through PPO catalyzed reactions to ortho quinones which subsequently polymerize to produce dark colored substances (Joslyn and Pointing, 1951; Mayer and Hanel, 1979; Vamos Vigiyazo, 1981). The rapid browning of apples is a serious problem during dehydration when a disrupted fruit structure is exposed to high temperature; appropriate treatments should be made during processing in order to control this undesirable enzymatic reaction and to produce an acceptable product.

2.2.2.2 Control of Enzymatic Browning

Various methods have been used to inhibit polyphenol oxidase in dried fruits; the major ones include blanching, the use of sulfur dioxide and sulfites, and the addition of acids. These compounds inhibit enzymatic browning by reacting with the substrates or subsequent reaction products. Ascorbic acid reduces the o-quinone back to the original compounds before polymerization occurs, thus preventing the browning reaction. These reagents however, have several disadvantages. For example, it has been found that 300mg of ascorbic acid is required to prevent the browning of 1 lb of apples (Labuza and Schmidl, 1986). Sulfiting agents, which inhibit PPO and may combine with quinones or reduce quinones to phenols, have been conventionally used to inhibit browning in fruits and vegetables (Labuza and Schmidl, 1986). However, sulfites can produce acute allergic reactions in some asthmatics. As a result, the use of sulfites as inhibitors of enzymatic browning in foods has been restricted by the Food and Drug Administration (Anon., 1986 & 1987). Also, an increasing demand for sulfur dioxide-free dried fruits has been observed in the United States (Roberts and McWeeny, 1972). This concern over the possible harmful effects of sulfites on sensitive consumers indicates the need for safer antibrowning treatments (Labuza and Schmidl, 1986).

Since PPO is a protein and is therefore easily denatured by heat, blanching is probably the simplest and most effective method of inactivating the PPO (Vamos-Vigyazo, 1981). In the food industry, it is common to subject raw fruit to steam or hot water blanching to prevent enzymatic browning (Gutterson, 1971). It has also been reported that blanching is always necessary for making dried fruit chips to ensure long storage life (Nafisi-Movaghar, 1991).

2.2.3 Methods of Dehydration

2.2.3.1 Hot Air Drying

Air drying involves the passage of heated air over the food to be dried, thereby supplying the necessary heat for evaporation (Hall, 1989b). The simplest and most economical of the various dehydration methods, hot air drying is one of the major processing methods for drying apples (Somogyi and Luh, 1986). However, hot air drying is a slow process which operates at relatively high temperatures. This results in irreversible textural changes in air dried products due to structural shrinkage. During air drying, water is initially transferred rapidly from the interior to the surface of the food product by capillary suction and diffusion and is then carried away by the moving heated air. However, the drying rate during the last stage of air drying is limited by the low concentration gradient and the low diffusivity of water (Ozilgen et al., 1995). Furthermore, the diffusion of solutes during drying causes the formation of a tough and leathery skin described as ' case hardening' (Holdsworth, 1986). Other quality changes have also been observed in air dried fruits, including the loss of characteristic flavors due to the vaporization of volatile compounds and the degradation of the products' original colors and nutritional substances due to excessive thermal damage (Van Arsdel et al., 1973).

2.2.3.2 Freeze Drying

Unlike other conventional drying processes in which moisture in the foods is evaporated from the liquid to the vapor phase, freeze drying removes moisture from the product by sublimation. Freeze drying is carried out under vacuum, so that the product is kept frozen during the removal of moisture. Ice in the frozen product is converted directly into water vapor, transferred through the partially dried layer to the product's surface and, finally, removed from the atmosphere by the condenser. Thus, the whole drying process is performed at a low temperature, and no liquid transfer occurs from the center of the mass to the surface. As a result, better dried food quality can be obtained with notably higher color and nutritional value retention, minimal structural and textural damage, little change in shape and appearance, and a fast and complete rehydration rate as a result of an open structure. Freeze drying is applicable to a wide range of fruit products and has proven to be the superior method for dehydrating many fruits (Somogyi and Luh, 1986). It is possible to produce low moisture apple snacks by freeze drying (Fisher and Kitson, 1991). However, since a rather long period of time is required for freeze drying, processing costs are high compared to other conventional dehydration methods (Somogyi and Luh, 1986). Furthermore, freeze drying is a generally batch method and is rarely found as a continuous process in commercial operations.

2.2.3.3 Osmotic Dehydration

Osmotic dehydration is a two-stage dehydration process. The first step consists of the immersion of fresh fruit pieces in a hypertonic solution, usually sugar or salt, to remove water from the fruit by osmosis (Jayaraman and Das Gupta, 1992). This first step will remove about 50% of the initial weight of the fruit as water (Farkas and Lazar, 1969). In order to produce a stable dehydrated product, the partially dehydrated fruit piece is then further dried by other conventional dehydration techniques, including freeze drying (Hawkes and Flink, 1978), vacuum drying (Dixon and Jen, 1977) and air drying (Nanjundaswamy et al., 1978), to a lower moisture content. Osmotic dehydration reduces the length of time which the product is exposed to high temperatures so that thermal damage to texture and nutritional value is minimized. Further, sugar syrup protects the color and flavor of fruit pieces during drying (Somogyi and Luh, 1986). It has been reported that apples that have been osmotically dehydrated display significantly improved flavor, excellent color, and a porous and crisp texture (Ponting, 1973). The osmotically dehydrated apples, which possess a pleasingly sweet taste, are appropriate as a snack items (Dixon and Jen, 1977). However, Nanjundaswamy et al. (1978) reported that fruits dried using sugar are in fact candy, due to the addition of high percentages of sugar. This addition of sugar may be disadvantageous in a supposedly healthy snack product.

2.2.3.4 Explosion Puffing

Explosion puffing is another method for dehydrating apples; it was developed at the USDA Eastern Regional Research Laboratory (Eisenhardt et al., 1964). Using the explosion puffing method, crisp dry apple products can also be made. The fruit pieces are first partially dried in a preliminary stage by conventional methods such as air drying, and then heated in a pressure vessel with a quick-opening lid. When the water contained within the fruit pieces is heated above its atmospheric boiling point in the vessel and the pressure builds up and reaches a predetermined value, the pieces are then instantly discharged to atmospheric pressure. The flashing of the water vapor from within the pieces then creates a porous structure that enables much faster dehydration and rapid rehydration compared to conventional air drying and freeze drying methods. Products produced by means of explosion puffing have many of the desirable attributes of freeze dried products but at a significantly reduced cost (Somogyi and Luh, 1986). In order to create a chip like product, the explosion puffed fruit pieces are then further dried in an air oven or the like (Matz, 1993a). Explosion puffing has been found to be particularly successful with apples and blueberries (Eisenhardt et al., 1964).

2.2.3.5 Deep Fat Frying

Deep fat frying in vegetable oils is popular in snack food production. The oil used for deep fat frying serves as a medium for transferring heat from a thermal source and becomes an ingredient of the finished product (Matz, 1993b). Apples can be thinly sliced and deep fried in oils to yield potato chip like products. However, browning, development of off-flavor, and uneven texture are the most common defects in conventional deep fried apple chips. Moreover, the oily flavors and greasy texture resulting from the immersion in the hot oil are generally not compatible with fruit characteristics (Matz, 1993a). Also, another disadvantage of deep fat frying is the oxidation of the oil that results in the development of rancid odors and adversely affects the product's taste (Matz, 1993b). In addition, these deep fat fried chips have relatively large proportion (~ 20-30% by weight) of fat (Farrer, 1990).

2.2.3.6 Others Dehydration Processes

Another method for producing crispy apple chips involves partially drying the apple pieces by hot air drying, followed by oil frying, to further dehydrate the pieces before they are placed in a reduced chamber pressure to produce a porous and crisp snack product (Matz, 1993a).

Kitson (1973), stated that vacuum frying of thinly cut apple pieces in oil at 99-104^{0}C and cooling of the fried pieces at said pressure until they harden could produce crisp apple chips that retain much of the color and flavor of fresh apples. Since the porous cell structure of an apple tends to absorb an excessive amount of fat, saturation of the apple slices with a maltodextrin solution is usually performed before frying.

Matsumura *et al.* (1989) described another method for producing fruit chips, involving the steps of first heating the fruit in sugar syrup having a Brix of 12^0 to 30^0, then cutting the heated fruit into small pieces, subjecting the pieces to a temperature conditioning treatment (holding at 20^0C for 20 minutes), expanding and then heating the pieces under reduced pressure. It was stated that this process yields expanded crisp chips having a fresh taste and excellent appearance and is particularly suitable for making snack foods.

Although all of the three methods mentioned above could be used to produce crispy apple chips, the apple pieces do absorb some of the oil during vacuum frying or have an increased amount of sugar content as a result of the pre-drying treatment in sugar syrup. As well, these methods are rather complicated and time-consuming.

2.2.3.7 Vacuum Microwave Dehydration

Vacuum Microwave Dehydration (VMD) offers an alternative way to improve the quality of dehydrated fruits and to produce a crispy apple snack with a puffed structure (Petrucci and Clary, 1989; Huxsoll and Morgan, 1968). The use of vacuum during drying allows the removal of moisture at a lower temperature than at atmospheric conditions; thus, fruits can be dried without exposure to high temperatures. In addition, the absence of air during vacuum drying may also help to reduce oxidative deterioration. As a result, color, texture, flavor and nutritional properties of the products can be largely preserved. In order to provide the necessary latent heat of evaporation during drying and to remove the vapor evolved from the product, an efficient means of heat transfer to the product is important (Somogyi and Luh, 1986). However, in the vacuum environment, heat transfer to the solid phase is slowed down significantly due to the absence of convection (Drouzas and Schubert, 1996).

Recently, due to the rapid and efficient heat transfer achieved by microwaves, microwave applications to drying and other types of food processing have gained popularity in the food industry (Rosenberg and Boegl, 1987; Giese, 1992). During microwave drying, heat is generated inside the food materials by the selective absorption of electromagnetic energy by water molecules and ionic salts with little direct heating of most solids, thereby by-passing the surface-to-centre diffusion stage of air drying. As a result, rapid drying can be achieved throughout the product at relatively low temperatures (Khraisheh et al., 1997).

Therefore, when vacuum and microwave heating are combined, the advantages of both vacuum drying and microwave drying can be obtained. The vacuum lowers the boiling point of water in the product and serves to withdraw the moisture vapor during drying, while microwave power delivers the energy to accelerate the heating of the product resulting in improved energy efficiency and product quality. Yongsawatdigul and Gunasekaran (1996) reported that vacuum microwave-dried cranberries had a redder color and softer texture compared to hot air dried cranberries. Other vacuum microwave dehydrated products, such as dried shrimp and krill, potato chips, and dried carrots and grapes, have also been successfully produced with desirable texture, color, and nutrient properties (Durance, 1997; Durance and Liu, 1996; Lin et al., 1998 & 1999; Petrucci and Clary, 1989). It has also been shown that the VMD process can be utilized to expand the structure of some products to yield a puffy texture which is similar to that created by frying (Durance, 1997; Lin et al., 1998 & 1999; Durance and Liu, 1996; Huxsoll and Morgan, 1968). Food materials that have been successfully dried by means of VMD, in addition to those mentioned above, include apples, peanuts, rice, asparagus, mushrooms and soybeans (Delwiche, et al., 1986; Wadsworth et al., 1990; Slater, 1975).

However, because of the high operational costs of vacuum microwave dehydration, this technique is more likely to be used in the last stage of drying when conventional drying is very slow, rather than for the complete dehydration process (Somogyi and Luh, 1986). It might also be used in cases where the drying of final products has to meet high quality specifications (Drouzas and Schubert, 1996).

2.2.3.7.1 Mechanisms of Microwave Heating and Drying

Microwaves are electromagnetic waves generated by magnetrons and are composed of electric and magnetic fields. Microwaves have a frequency range between 300MHz to 300GHz (Khraisheh et al., 1997). While penetration of thermal energy occurs from the products' surface to their center; heating of foods by microwaves is much faster than conventional heating methods (Khraisheh et al., 1997). The major mechanisms that govern microwave heating of food are ionic polarization and dipole rotation (Decareau and Peterson, 1986). When ions in solution move in response to the electric field, ionic polarization occurs. Being accelerated by an alternating electric field at microwave frequencies, these ions collide with other molecules and convert kinetic energy into heat. Dipole rotation heating mechanism is dependent on the existence of polar molecules. The polar material of highest concentration in food is water. When a moist food sample is subjected to a electrical field that rapidly changes in direction, the polar molecules rotate as they try to align their dipoles with the direction of the rapidly changing electric field. The energy provided by the electric field is thus converted into kinetic energy of the water. The rotation of these water molecules will then result in the disruption of hydrogen bonds between neighboring water molecules; heat is thus generated by "molecular friction" and transferred throughout the product by conventional thermal conduction (Khraisheh et al., 1997).

Microwaves can thoroughly and rapidly heat even thick materials and selectively heat areas with higher moisture contents. When the internal temperature of the moist food samples reaches the boiling point of water during microwave heating, free moisture evaporates inside the sample, resulting in a vapor pressure gradient (Bouraoui et al., 1993). This pressure gradient will then expel the unevaporated water from within the material to the surface under a type of pumping action, thereby, speeding up drying (Khraisheh et al., 1995). The microwave power dissipated in a sample can be increased by either increasing the microwave's frequency or dielectric field strength or both (Khraisheh et al., 1997).

Apart from the intensity and the frequency of the field, the electrical and physical properties of the material will also affect the volumetric power absorption and the rate of heat generation during microwave heating (Khraisheh et al., 1997). Microwave penetration depth is defined as the distance from the surface of the material at which the incident power drops to about 37% (Decareau and Peterson, 1986). Microwave penetration depths within a product are also determined by its own electrical and physical properties and can vary with the chemical composition and the temperature of the product and the processing frequency. Among the electrical and physical properties of foods, the dielectric constant and the loss factor are the most important factors which determine the microwave penetration, the conventional heat transfer, and the overall heating rate. The dielectric constant is a measure of the ability to store electrical energy in the material, and the loss factor reflects its ability to dissipate electrical energy in the form of heat. These dielectric properties of the food are primarily determined by the moisture and salt contents. Products that have higher solids and lower moisture or salt contents have larger penetration depths and, consequently, the more uniform the heating rate throughout the product (IFT, 1989).

2.2.3.7.2 Historical Commercial VMD Processes

The first industrial equipment combining microwave heating with vacuum drying was developed by International Microwaves Industries, Epone, France in 1978 to produce a high quality and readily rehydratable orange powder from pre-concentrated juice. The high quality of vacuum microwave dehydrated orange juice and the high ascorbic acid retention are unattainable by means of either spray drying or freeze drying (Decareau and Peterson, 1986).

Grain drying was another VMD process that had once been performed in commercial-scale plants. This process was developed by the MacDonnell Douglas Company. A pilot plant unit has been tested by the U.S. Department of Agriculture. In modern farming, grain crops are often harvested while still relatively wet; thus, spoilage time is relatively short. However, due to the resistance of the hulls to the passage of moisture, grain drying by means of conventional hot air is usually a long and slow process that takes a few days, but is, nonetheless, imperative. However, lengthy exposure of the product to high temperatures during hot air drying may result in adverse effects on germination capability as well as on nutritive value. Microwaves can penetrate directly and heat the center of the grain, thereby establishing a temperature profile with a slight negative gradient from the center to the surface of the grain, and eliminating the need for moisture equilibration by the time-consuming tempering process that takes 3-5 days. Therefore, the application of VMD permits grain drying to be accomplished more rapidly, uniformly and efficiently at lower temperatures than usual, so that the dry seeds' germination capability will not be impaired nor damaged (Decareau, 1985).

2.3 Texture of Chips

Texture is one of the four principal quality factors in food. Texture of food can be defined as a group of physical properties that derive from the structure of the food, are sensed by the feeling of touch usually in the mouth or between the fingers. It is related to the deformation, disintegration, and flow of food under a force (Bourne, 1982). It is generally recognized that texture of food is one of the attributes that affect consumer acceptance (Szczesniak and Kleyn, 1963).

In a previous study, it was demonstrated that many foods were poorly identified by people when both the texture and color of the food were concealed and flavor was the only attribute that could be used to identify the food (Bourne, 1982). This indicated the importance of texture in food.

A word-association test was given to one hundred people in order to determine their degree of texture consciousness and the terms they used to describe texture (Szczesniak and Kleyn, 1963). It was concluded that texture is a discernible characteristic of food but that it is more evident in some foods than others. The awareness of texture was also found to be generally equivalent to that of flavor and color. Food that elicited the highest number of texture responses were either bland in flavor or possessed the characteristics of crunchiness or crispness. Other studies by Yoshikawa et al. (1970 a, b, c), similar to those conducted by Szczesniak's group, were carried out in Japan. These studies again showed the importance of textural properties as a factor of food quality and the enormous variety of textures found in food.

The importance of texture in the overall acceptability of foods varies widely among different type of food. In chips and some other dry snack food, texture is the dominant quality characteristic (Bourne, 1982).

2.3.1 Crispness of Chips

In the word association test mentioned above (Szczesniak and Kleyn, 1963), the term "crispness" was used more often than any other word to describe the texture of a food. Not only is it a useful descriptor, but crispness seems to be a highly valued and universally liked textural quality that has many positive connotations. Szczesniak and Kahn (1971) stated that: " Crispness appears to be the most versatile single texture (parameter). It is particularly appealing as a stimulant to active eating. It is notable as a relaxing or satiable texture. It appears to be universally liked and is often used as a popular accent-contributing or dramatizing characteristic. Crispness is very prominent in texture combinations that mark excellent cooking and is nearly synonymous with freshness and wholesomeness." Crispness was showed to go well with many other textural characteristics and is often used to create pleasing textural contrasts (Szczesniak and Kahn, 1984). In fact, crispness is an important and highly desirable quality attribute of dry snack food products (Katz and Labuza, 1981), such as apple chips.

In the early 1960s when the Sensory Texture Profile technique (Brandt et al., 1963) was developed, crispness was not specifically mentioned. It was regarded as part of the brittleness scale and was defined as the ease of force with which a food crumbles, cracks, and shatters. In potato chips, crispness was defined by Stier (1970) as " brittle, crushable, or friable as far as the initial sensation was concerned." In the study by Szczesniak (1988), consumers suggested that a crisp food may be defined as one that is firm (stiff) and snaps easily (rather than bends) when deformed emitting a crunchy sound. This "crunchy" sound is further characterized by a "snap", which is a very sudden, clean and total fracture that has a bearing on the quality and the short duration of the sound. It has been suggested in previous studies that acoustical sensations are involved in the perception of food crispness (Vickers and Bourne, 1976a) and a highly positive correlation was observed between the perceived loudness of the crushing sounds of foods and their perceived crispness (Vickers and Wasserman, 1980).

2.3.2 Factors Affecting Texture of Dehydrated Apple Chips

2.3.2.1 Calcium Chloride Pre-treatment

For most processed fruit products, the nature of the plant cell wall and the middle lamella (i.e. its structure and its composition) seems to be the most significant factors that affect the texture of the product (Sterling, 1963). The cell wall is a structure composed of a rigid skeleton of cellulose microfibrils embedded in a gel-like matrix composed mainly of pectic substances and hemicellulose with some protein. Each cell is cemented to the next one by a pectin-rich middle lamella (Poovaiah et al., 1988). The principal chain of pectin consists of polygalacturonic acid in which the carboxyl groups are methyl-esterified to various degree (Sterling, 1963). Depending upon their degree of methyl esterification, pectic substances cross linked inter- and intra- molecularly by calcium to maintain integrity of the cell wall matrix and thus, are thought to be largely responsible for tissue rigidity of plants (Grant et al., 1973; Clarkson and Hanson, 1980). However, these pectic substances are more chemically reactive and are brought into solution more easily than other cell wall polymers (Van Buren, 1979; Ilker and Szczesniak, 1990). During drying processes, depolymerization of pectin is promoted by heating which then leads to a reduction in both the mechanical strength of the cell wall and the adhesion between cells (Van Buren, 1979). This will then result in changes in product texture.

Calcium has widely been reported to confer rigidity and to provide mechanical strength to plant cell walls (Cormark, 1965; Rasmussen, 1966, Knee and Bartley, 1981; Pooviah et al., 1988). Calcium appears to serve as an intermolecular binding agent that stabilizes pectin-protein complexes of the middle lamella in plant tissue (Demarty et al., 1984; Dey and Brinson, 1984; Fry, 1986; Grant et al., 1973; Roux and Slocum, 1982). In fact, both pre- and post-harvest treatments by calcium have been reported to maintain post-harvest firmness of apples (Cooper and Bangerth, 1976; Poovaiah et al., 1988). Also, calcium treatment of apples is the logical and historical method for increasing firmness. It has been used for this purpose by Powers and Esselen (1946) for frozen or canned McIntosh apples, and by Archer (1962) and Wiley and Lee (1970) for canned apples. Ponting et al. (1971 & 1972), also demonstrated that a calcium dip was effective in preserving the texture of refrigerated apple slices over an extended storage period. Therefore, calcium pretreatment performed before dehydration might also have an effect on the textural characteristics of apple chips.

2.3.2.2 Dehydration Techniques

Texture of food products is also influenced by different processing methods (Somogyi and Luh, 1986). For the dehydration of apple, it had been shown that freeze drying produced minimal change in structure and texture when compared with hot air drying of freeze drying. Each dehydration techniques has its own drying mechanism and therefore, products dried with different dehydration methods are exposed to different degrees of drying temperatures and drying times; this will then result in different textural qualities of the product (Somogyi and Luh, 1986).

2.3.2.3 Apple Varieties

Structural features of fruits such as thickness of the cell wall, the size and shape of the cells, and the volume of intercellular spaces all play an important role in determining texture qualities associated with both the fresh and processed fruits (Reeve and Leinbach, 1953; Reeve, 1970). Since different varieties of apples have different structural features, apples of different varieties are different in textural characteristics (Summers, 1994) and processing qualities. Nogueira (1975) stated that the selection of the right apple variety for the right processing method is of great importance in order to get a good quality product. Varieties that are firm in texture are preferred for drying (Somogyi and Luh, 1986).

2.3.3 Measurements of Apple Chip Texture

Instrumental measurement has been used for over a hundred years in food texture analysis (Voisey, 1976). Two major advantages of instruments are their reproducibility, and the fact that they are relatively unaffected by their surroundings (Aguilera and Stanley, 1990a). They are not as subject to drift, or fatique and are more precisely calibratable than human sensors.

However, texture is a sensory attribute, and it is generally agreed that the concept of texture is meaningful only when viewed as an " interaction of the human with the mechanical properties of the material" (Corey, 1970). Although costly and time-consuming, sensory evaluation is extremely valuable in textural measurement of food because no instrument can perceive, analyze, integrated and interpret a large number of textural sensations all at the same time as a human does (Szczesniak, 1973).

Furthermore, the physical properties, and hence textural characteristics of foods, are reflections of the foods' structures. Therefore, the structural analysis of food by microscopic techniques is another way to study food texture (Sherman, 1973; Stanley and Tung, 1976).

2.3.3.1 Determination of Chip Texture by Instrumental Analysis

2.3.3.1.1 Mechanical

The mechanical properties of crispness in snacks have been investigated using various tests. Iles and Elson (1972) placed potato chips equilibrated to various moisture contents on a supporting ring and broke them with a 4.3mm diameter probe descending through the ring; they found that the deformation to breakdown to be the best indicator of crispness in friable food. A similar punch test was used by Bourne et al. (1966) in the study of the texture of potato chips. The researchers observed that the slope of the force-deformation curve appeared to increase as crispness increased. Other instrumental measures were made of the textures of biscuits using a center load, end support, snap test mounted on an Instron. The researchers found that sensory crispness was most highly correlated with the two instrumental parameters, bend deformation to fracture and the slope of a force-deformation curve. Also, by comparing the snap test and sensory measurements of carrots and baked goods, the snap test slope was again found to be a good indicator of crispness (Vickers and Bourne, 1976b). However, in another snap test carried out by Katz and Labuza (1981) to measure the crispness of potato chips, it was concluded that the analyses did not produce any useful quantitative information for indicating the intensity of crispness. They stated that due to the irregular size, shape, curvature, and inconsistent fracturing pattern of the potato chips, a consistently shaped force-deformation curve was not obtained. Szczesniak and Hall (1975) examined the texture of potato chips with the General Foods Texturometer, using a 17mm diameter plunger, and related the first peak height from a 2-bite compression cycle to crispness. Lastly, a needle test was used to study crispness (Vickers and Bourne, 1976b). A very thin cylindrical probe slightly smaller than the size of the average cell or cavity was pushed into a food sample and the force-deformation curve was obtained. The results showed that the initial slope of a force-deformation curve by a needle test is also a good indicator of sensory crispness of ginger snaps and baked Chee-tos.

2.3.3.1.2. Acoustical

Drake (1965) was the first to suggest the existence of a relationship between sensory crispness and acoustical measurements of food crushing sounds. He observed that the sounds made by crisp foods differ from those of non-crisp foods primarily in their amplitudes. The results of his study showed that the sound amplitude of a food increased along with increases in the sensory crispness of the food.

By placing a very fine needle directly on the bone surface, Kapur (1971) recorded bone-conducted sounds produced during the chewing of food. He found that sounds produced by chewing a crisp vanilla wafer were markedly louder than those produced by chewing a soggy one.

Vickers and Bourne (1976a), studied oscilloscope amplitude-time displays of the tape-recorded biting sounds of a variety of wet and dry crisp foods. The frequency spectra of the sounds were displayed on a spectrum analyzer. Amplitude-time plots of the same sounds were displayed on an oscilloscope. Crisp foods were observed to produce a characteristic sound that had a broad frequency range with low notes predominating and irregular and uneven variations in loudness. The researchers concluded that the amplitude-time plots of more crisp sounds could be distinguished from those of less crisp sounds by the amplitude of the sounds and the number of sounds produced in a given bite.

In a study conducted by Mohamed et al. (1982), sounds produced by the fracturing of some humidity treated friable foods in a constant loading rate texture-testing instrument were recorded. It was found that the equivalent sound level and the average sound energy correlate significantly with sensory crispness. Recently, Vickers (1987) found that a combination of acoustic and mechanical analysis provided an excellent measure of potato chip crispness.

2.3.3.2 Determination of Chip Texture by Sensory Analysis

The three fundamental types of sensory tests are the preference/acceptance test, the discriminatory test and the descriptive test. The preference/acceptance test measures the opinions of consumers. The discriminatory test determines whether there are any detectable differences among samples but does not indicate how large or what kind of differences exist. The descriptive test, which indicate the intensity or nature of differences among samples, is most commonly used when the effects of the studied variables on the food are of interest.

Descriptive scaling methods appear to be the most commonly used tests in the sensory analysis of snack foods' crispness. Magnitude estimation (Moskowitz, 1977) is a method of ratio scaling and has been used to judge the crispness of various types of dry snack foods (Mohamed et al., 1982; Katz and Labuza, 1981; Vickers, 1980). Panelists are instructed to assign any number to the first sample and to rate each subsequent sample in relation to the first one. Another commonly used method, unstructured graphic interval scaling, has also been widely used in studies of crispness. Vickers (1987) has used an unstructured line scale to judge the crispness of potato chips. On an unstructured interval scale, the descriptive terms describing the two extremes of the attribute being studied are placed at or close to opposite ends of a horizontal line. Panelists record each evaluation by marking a vertical line across the horizontal line at the point that best reflects their perception of the magnitude of the attributes. Since verbal anchors are used at the ends of the line scale only, the problem of unequal intervals that is associated with structured scales is eliminated. Furthermore, word bias is minimized due to the limited use of words in the scale (Stone et al., 1974).

2.3.3.3 Determination of Chip Texture by Microscopic Techniques

Microscopy of foods and food products has been conducted for many years. A wide variety of microscopic techniques, such as light microscopy (LM), transmission electron microscopy (TEM) and scanning electron microscopy (SEM), are available for the examination of food microstructures (IFT, 1988). Among these microscopic techniques, SEM provides an important tool for the structural determination of food and its components; it has proven itself to be the best instrument for these purposes (Aguilera and Stanley, 1990b).

2.3.3.3.1 Scanning Electron Microscopy (SEM)

Since the commercial scanning electron microscope became available in 1965, food microstructure has been used to explain and predict the physical and chemical behaviors of foods (Lee and Rha, 1979). The use of SEM has grown at an enormous rate and is recognized by food scientists as the primary source of microstructural information (Aguilera and Stanley, 1990b). The stereo-structure and geometry shown by SEM provide valuable information for the selection and identification of the potential utilization of food resources, the optimization of food processing, and the quality evaluation of manufactured food (Lee and Rha, 1979).

The SEM yields three-dimensional images and can achieve a great depth of field, 500 times that of a LM at the same magnification. Also, it provides a wide range of usable magnifications (~20X to 100,000X). Compared with the TEM, the SEM can handle larger specimens, and sample preparation is easier and introduces fewer artifacts. Depending on the sample preparation techniques used, both surface and internal features can be studied (Aguilera and Stanley, 1990b).

In the scanning electron microscope, a focused beam of high energy electrons which is produced by an electron gun in a vacuum, transverses an evacuated column and is focused obliquely on the surface of the specimen. It is then made to repeatedly scan across the surface in raster form. The interaction of the beam with the specimen results in the production of a large number of lower energy electrons, termed secondary electrons, at or near the specimen surface. These secondary electrons are then gathered by a collector, conveyed to an amplifier and then onto the screen of a cathode ray tube where the raster of the electron beam is reproduced, and an image is formed (Aguilera and Stanley, 1990b).

The specimen is fixed and dehydrated; then a thin film of conductive heavy metal such as gold or palladium is coated onto the sample. Since biological tissue is not an adequate conductor of electrons, the presence of the metal conductive surface is important that it provides a means for conducting the absorbed electrons from the sample to ground. If this is not done, a buildup of charges on the sample surface with a consequent deflection of electron beam results, leading to serious image distortion and makes photography difficult (Aguilera and Stanley, 1990b).

The SEM has been applied in a few studies of the physical properties of apple cells (Diehl et al., 1979; Simons and Chu, 1980; Bolin and Huxsoll, 1987; Kovacs et al., 1988, Trakootivakoran et al., 1988). Details such as cell concavity and cell arrangement of apple tissues can be observed. In addition, Stanley and Voisey (1979) used SEM to study the transformation of bacon from a soft, to a crisp, to a brittle food as cooking progresses.

3. Materials and Methods

3.1 Sample Preparation

3.1.1 Source of Materials

Apples (Golden Delicious, Red Delicious and Fuji) were purchased at the same time from local grocery stores for the study of each treatment effect and only the unbruised ones were selected for the experiment. Food grade calcium chloride was obtained from General Chemical Canada Ltd., Mississauga, Ontario. All other chemicals were of reagent grade.

3.1.2 Sample Preparation for the Study of the Effects of Calcium Pretreatments

1 kg of Golden Delicious apples was prepared for each drying process. Apples were washed, sliced to a thickness of 4mm, steam blanched for 2 minute and immediately dipped in 0, 1, 2, 3, 4, or 5% calcium chloride solutions (at room temperature) for one minute. These apple slices were first air dried on a Vers-a-belt dryer (Wal-Dor Industries Ltd., New Hamburg, Ontario) at 70^0C, with an air flow rate of $1.1m^3/min$ for about 30 mins to a moisture content of ~50% on a dry weight basis (db). Samples were then placed in the high density polyethylene drying drum in a 2 kW maximum power microwave vacuum chamber (EnWave Corporation, Vancouver, B.C., Canada). The drum was rotated at a rate of 5 revolutions per minute. After a vacuum of 28 inches of Hg was achieved, samples were first vacuum microwave dried at a microwave power of 1.5 kW for 4 minutes followed by an additional 1 to 2 minutes of drying until a final moisture content of ~5% db was obtained. Dehydrated samples were packed in individual cheesecloth bags, which were then placed in an air tight bag. They were allowed to

equilibrate at room temperature for 14 days to the same water activity prior to analysis. All experiments were performed in triplicate.

3.1.3 Sample Preparation for the Study of the Effects of Vacuum Levels and Drying Techniques

1 kg of Golden Delicious apples were first prepared as mentioned in section 3.1.2, with the following changes. Instead of a $CaCl_2$ solution, all apple slices were dipped in water (at room temperature) for one minute after steam blanching.

For the study of the effect of vacuum levels, blanched apple slices were air dried to ~50%(db). The partially dried apple slices were then VMD at various vacuum levels of 7, 14, 21, 24 and 28 inches of Hg with a constant microwave power of 1.5 kW to obtain apple chips with a moisture content of ~5%db.

For the study of the effect of drying techniques, preparation of air dried apple chips were carried out on a Vers-a-belt dryer (Wal-Dor Industries Ltd., New Hamburg, Ontario). Blanched apple slices were air dried at 70^0C with air flow rate at $1.1m^3$/min to a moisture content of ~5% db. For the preparation of freeze dried apple chips, blanched apple slices were freeze dried under vacuum (100 microns Hg) with a chamber temperature of 20^0C and a condenser temperature of -55^0C.

3.1.4 Sample Preparation for the Study of the Effects of Apple Varieties

Three varieties of apples (Red Delicious, Fuji and Golden Delicious) were used to prepare VMD apple chips as described above in section 3.1.2, except that blanched apple slices were dipped in 0 and 1 % $CaCl_2$ solutions for one minute.

3.2 Determination of water activity (a_w)

Water activity (a_w) of the dried samples was determined in triplicate using the Aqualab water activity meter (model CX-2, Decagon Devices, Inc., Pullman, WA, USA). Approximately 1g of apple chips was first placed into the miniature plastic dishes provided and then placed into the chamber of the water activity meter. The water activity was then recorded when equilibrium was reached at room temperature (~ 25^0C).

3.3 Determination of Moisture Content

Samples, in triplicate, were weighed into pre-weighed, labeled aluminum weigh boats and then dried in vacuum oven (Sorvall) at 70^0C and a vacuum level of 27 inches of Hg for 16 hours. Upon completion of the drying, weight boats were cooled in a desiccator and weighed. The moisture content of the sample on a dry weight basis (%db) was then calculated from the difference between the wet and dry weights divided by the dry weight of the sample.

3.4 Determination of Calcium Content in Apple Tissues

3.4.1 Determination of Dry Weights of Apple Chip Samples

Apple chip samples, in triplicate, were weighed into pre-weighed, labeled crucibles which had been pre-ashed for 24 hrs in a muffle furnace (62700 Furnace, Thermolyne) at 500^0C. These crucibles containing the weighed chip samples were then dried in vacuum oven (Sorvall) at 70^0C and a vacuum level of 27 inches of Hg for 16 hours. Upon completion of the drying, crucibles were cooled in a desiccator and weighed to obtain the dry weight of the sample.

3.4.2 Dry Ashing and Calcium Content Analysis

Previously vacuum oven dried apple chip samples from section 3.4.1 were ashed in a muffle furnace (62700 Furnace, Thermolyne) at 500^0C for 24 hours so that only white ash remained. The residues were cooled and dissolved in 5 ml of 6N HCl. The suspension was warmed to effect a complete solution. The samples were then diluted with 1% $LaCl_3$ solution (Fisher) and analyzed for total calcium content with a Perker Elmer Atomic Absorption Spectrophotometer. All calcium values were reported on a dry weight basis.

3.5 Determination of Texture by Instrumental Analysis

The TA XT2 Texture Analyzer (Stable Micro System Ltd., Surrey, England) was used to measure the slope (g/mm), the peak force (g) and the distance (mm) of the first peak produced during the punch and die test. A punch (No. 5 flat ended probe) and die (1 cm hole centered in 10.1cm X 8.8cm metal square) were used to break the chips. Each chip sample was centered on a metal base; the punch was used to break the chip. Prior to the beginning of analyses, calibration of the texture analyzer was carried out, using a 5.0kg load. The test speed was 7.0 mm/s, and the penetration of the probe was set at a depth that was deep enough to break through the chip samples. The slope, the peak force and the distance of the first peak recorded in the force/deformation curve were then obtained. Fifteen measurements were obtained from each of three replicate samples. Therefore, the slope, the peak force and the distance values were the mean of a total of 45 measurements.

3.6 Determination of Density

The density of apple chips was measured by immersing the weighted samples (~20g) in a 500 ml graduated cylinder prefilled with 200 ml of dried flax seeds. Volumes was obtained by measurement of the flax seed displacement. The data were expressed as the weight of sample (g) per volume (ml). Measurements were performed in triplicate.

3.7 Determination of Texture by Sensory Analysis

Sensory descriptive analysis (Stone et al., 1974) was carried out to determine the effect of both the calcium pretreatment and the variety of apple on the sensory qualities of apple chips. The sensory analysis was carried out in triplicate, one panel session per week, with a total of three panel sessions per study; a complete set of sample treatments was evaluated once per session by each panelist. All panels were performed in the morning from 10:00am to 12:00pm. For the study of the effect of calcium pretreatment, panelists were asked to evaluate the crispness and the bitterness of 0, 1, 2, 3, 4, 5% $CaCl_2$ treated apple chips. For the study of the effect of apple varieties, panelists were asked to evaluate the crispness, the apple flavor, the sweetness and the off-flavor of both the non-calcium treated and 1% calcium treated Golden Delicious, Red Delicious and Fuji apple chips. A 15 cm unstructured line scale, with anchor points at 1.5 cm from each end and at the midpoint was used to evaluate the sensory attributes. Panelists indicated the intensity of each attribute by making a vertical line across the unstructured line. Quantification was then made by measuring the distance from the left end point of the line to each point marked by the panelist. The sensory evaluation score sheets used in the study of the effect of calcium pretreatment and the study of effect of apple varieties are shown in Figure 1 and Figure 2A&B, respectively.

Sensory evaluation scoresheet for VMD apple chips

Name: ______________________ **Date:**___________________

Please evaluate the texture and flavor of these sample of apple chips.
Make a vertical line on the horizontal line to indicate your rating of the crispness and bitterness of each sample. Label each vertical line with the code number of the sample it represents.

Please bite the whole chip with the front teeth to evaluate the crispness and then chew twice with the molar teeth to evaluate the bitterness. Rinse your mouth with water between samples. A reference standard of moderately crispy chip has been given, please feel free to refer back to it whenever you need.

Please taste the samples in the following order:

______ ______ ______ ______ ______ ______

Texture:

1. Crispness

not crisp | moderately crisp | very crisp

Flavor:

1. Bitterness

none | medium | strong

Comments:

Figure 1. Sensory scoresheet for the study of the effect of calcium pretreatment.

Sensory evaluation scoresheet for VMD apple chips

Name: ______________________ **Date:** ____________________

Part I

Please evaluate the texture of these samples of apple chips.
Make a vertical line on the horizontal line to indicate your rating of the crispness of each sample. Label each vertical line with the code number of the sample it represents.

Please bite the whole chip with the front teeth to evaluate the crispness. Rinse your mouth with water between samples. A reference standard of moderately crispy chip has been given, please feel free to refer back to it whenever you need.

Please taste the samples in the following order:

______ ______ ______ ______ ______ ______

Texture:

1. Crispness

not crisp —————— moderately crisp —————— very crisp

Comments:

Figure 2A. Sensory scoresheet for the study of the effect of apple varieties on texture of apple chips.

Part II

Please taste the samples in the order indicated and evaluate the apple flavor, sweetness and off flavor of these samples of apple chips.

Make a vertical line on the horizontal line to indicate your rating of each sample. Label each vertical line with the code number of the sample it represents.

Rinse your mouth with water between samples. A reference standard which has apple flavor and sweetness level midway between none and moderate, and with none off flavor has been given, please feel free to refer back to it whenever you need.

Please taste the samples in the following order:

______ ______ ______ ______ ______ ______

Flavor:

1. Apple Flavor

none moderate intense

2. Sweetness

none moderate intense

3. Off Flavor

none moderate intense

Comments:

Figure 2B. Sensory scoresheet for the study of the effect of apple varieties on flavor of apple chips.

3.7.1 Selection and Training of Sensory Panelists

A group of seven panelists with sensory evaluation experience were recruited from the staff and students of the University of British Columbia. All panelists who were selected generally enjoyed eating snacks and showed interest in the experiment. Selected panelists were then trained in sensory descriptive evaluation.

The training was carried out in a total of four sessions. The purpose of the training was to familiarize the panelists with the test method, the descriptive terms and the scale used on the evaluation score sheets, the sensory panel environment, and the use of reference standard. Training sessions were conducted in a round table format as described by Rutledge and Hudson (1990); open discussions among the panelists were encouraged. During the four training sessions, food samples and chip samples with various degree of crispness were presented to the panelists. Commercial deep fried Golden Delicious apple chips (Seneca Foods Corp., Marion, NY, U.S.A.) were used as a reference standard for a moderately crisp texture. Calcium chloride solution (0, 1, 3, 5%) and sucrose solution (0, 5, 10%) were also presented to the panelists to expose them to a range of bitterness and sweetness, respectively. Further, pieces of fresh apples (Golden Delicious, Red Delicious, and Fuji apples) were presented to the panelists to familiarize them with apple flavor. Commercial unsulfured air dried apple slices (Choices Market, Vancouver) were used as reference standards for both the apple flavor and the sweetness at the midway point between the anchors for the "none" and the "moderate" level, and for a sample with no off flavor.

During training, the panelists were asked to bite through the whole samples with their front teeth to evaluate the crispness, and to chew the samples around in the mouth to assess the flavor attributes. Distilled water was provided to the panelists for rinsing between samples. The panelists were asked to evaluate the sensory attributes using the unstructured line scales.

3.7.2 Sampling Procedure during Sensory Evaluation

The sensory panels were conducted in the sensory panel room of the Food Science Building at the University of British Columbia. Apple chip samples were individually placed in a paper disk that was labeled with random 3-digit code. One chip sample from each treatment group was presented. Each panelist received the complete set of treatment samples at the same time on a paper tray. Panelists were asked to evaluate the apple chip samples using the same technique that was used during the training sessions except that the evaluations were carried out individually in booths and no communication was allowed. Commercial deep fried Golden Delicious apple chips (Seneca Foods Corp., Marion, NY, U.S.A.) were provided as a reference standard for moderately crisp chips. Commercial unsulfured air dried apple slices (Choices Market, Vancouver) were used as reference standards for both the apple flavor and the sweetness at the midway point between the anchors for the "none" and the "moderate" level, and for a sample with no off flavor. Panels were conducted under red fluorescent light to minimize the effect of the apple chip color on the assessment of the texture and flavor attributes. After each panel session, a small treat was given to the panelists.

3.8 Determination of Structure by Scanning Electron Microscopy (SEM)

The structure of the dehydrated apple chips was examined using scanning electron microscopy. Apple chips were first dipped in liquid nitrogen and then fragmented into small pieces while frozen. Apple chip fragments were attached to SEM stubs and subsequently coated with gold (~25nm), using the Nanotech SEMPREP II Sputter Gold Coater, and, finally, stored under desiccation (1 to 2 days) until examined by the scanning electron microscope (Stereoscan 250, Cambridge Instruments Ltd., Cambridge, UK). Polaroid pictures were taken and processed as specified by the manufacturer.

3.9 Determination of Moisture Sorption Isotherm (MSI)

Samples were taken out from the apple chips throughout the drying process for freeze drying, air drying and VMD. The water activities were determined as described in section 3.2. Each sample was weighted after each a_w measurement and, using the vacuum oven method described in section 3.3, the equilibrium moisture content on a dry basis was then calculated. By plotting the equilibrium moisture content (%db) against the a_w, the moisture sorption isotherms (MSIs) of apple chips produced by different drying techniques (VMD, air drying and freeze drying) were obtained. Each MSI was constructed by a total of 20 experimental points.

It has been shown by comparative analysis that the GAB (Guggenheim-Anderson-de-Boer) equation best describes sorption isotherms of most foods for the widest a_w range (Van Den Berg, 1985) and is the most widely accepted model for sorption isotherms in recent years (Labuza et al., 1985). The GAB equation can be written in the following form (Lomauro et al., 1985):

$$M = M_m Cka_w/[(1-ka_w)(1-ka_w+Cka_w)] \qquad (1)$$

Where M is the equilibrium moisture content, M_m is the monolayer moisture content, aw is the water activity, C is the Guggenheim constant related to heat of sorption of the first layer and k is a factor related to the total heat of sorption of multilayer.

The experimental moisture and water activity data obtained were then fitted to the GAB equation by multiple nonlinear regression using the SYSTAT 5.03 (Systat, Inc.) computer program.

3.10 Determination of Drying Curves

Weighs were monitored during drying at timed intervals until the samples reached a constant weight. Drying curves were then constructed based on the final moisture content of the samples.

3.11 Statistical Analysis

Data were analyzed using ANOVA (Minitab Inc., 1994). Differences among mean values were established using Tukey's multiple comparison test (Peterson, 1985). Mean values were considered significantly different when $P < 0.05$. Pearson correlations were done on treatment means.

3.11.1 Z-Score Transformation of Data from Sensory Analysis

The significant panelist effect was observed when statistical analysis of the sensory results was carried by ANOVA. This suggested that the panelists were using different parts of the scale during the sensory trials. Therefore, in order to standardize the sensory scores from different panelists, z transformation using Equation (2) was then performed on the sensory data (Reid and Durance, 1992).

$$z = (x - X) / s.d. \qquad (2)$$

where z is the transformed score, x is the actual scores from a panelist for a sensory attribute, X and s.d. are the mean and the standard deviation of all the sensory scores for that sensory attribute from the same panelist, respectively. The transformed scores (i.e. z scores) were calculated and analyzed statistically using ANOVA to assess the effect of different treatments on the sensory characteristics of the apple chip products.

4. Results and Discussion

4.1 The Effect of Calcium Pretreatment on Texture of VMD Apple Chips

After equilibration for 14 days, the water activity of the VMD Golden Delicious apple chips for the study of the effect of calcium pretreatment was found to be 0.26 at 25^0C.

During the drying process, the turgid state of live cells with organized cytoplasmic membranes is lost because drying almost universally kills the cell. Therefore, the factor that most significantly affects the texture of processed plant products is the nature of the plant cell wall (Sterling, 1963). Calcium is an essential element for structure and function of cell walls and membranes. It plays a special role in maintaining the cell wall structure in fruits by interacting with the pectic acid in the cell wall to form calcium pectate that leads to additional firmness of the plant tissue (Poovaiah, 1986). The pectic substances, which are polymers of 1,4-linked α-galacturonic acid in various degrees of esterification or neutralization, are a principal constituent of the cell wall, both in the middle lamella and in the primary cell wall (Sterling, 1963).

Dipping the apple slices in solutions with increasing calcium chloride ($CaCl_2$) concentrations resulted in apple chip samples with higher calcium (Ca) contents in a biphasic manner (Figure 3). At the lower $CaCl_2$ concentrations (0 to 2% $CaCl_2$), a linear increased in sample Ca content was observed (Figure 3). At the higher $CaCl_2$ concentrations (3 to 5% $CaCl_2$), the increase in sample Ca content was still linear but with a much lower slope, than that in the lower $CaCl_2$ concentration range. This was probably due to the saturation of available Ca binding sites in the samples.

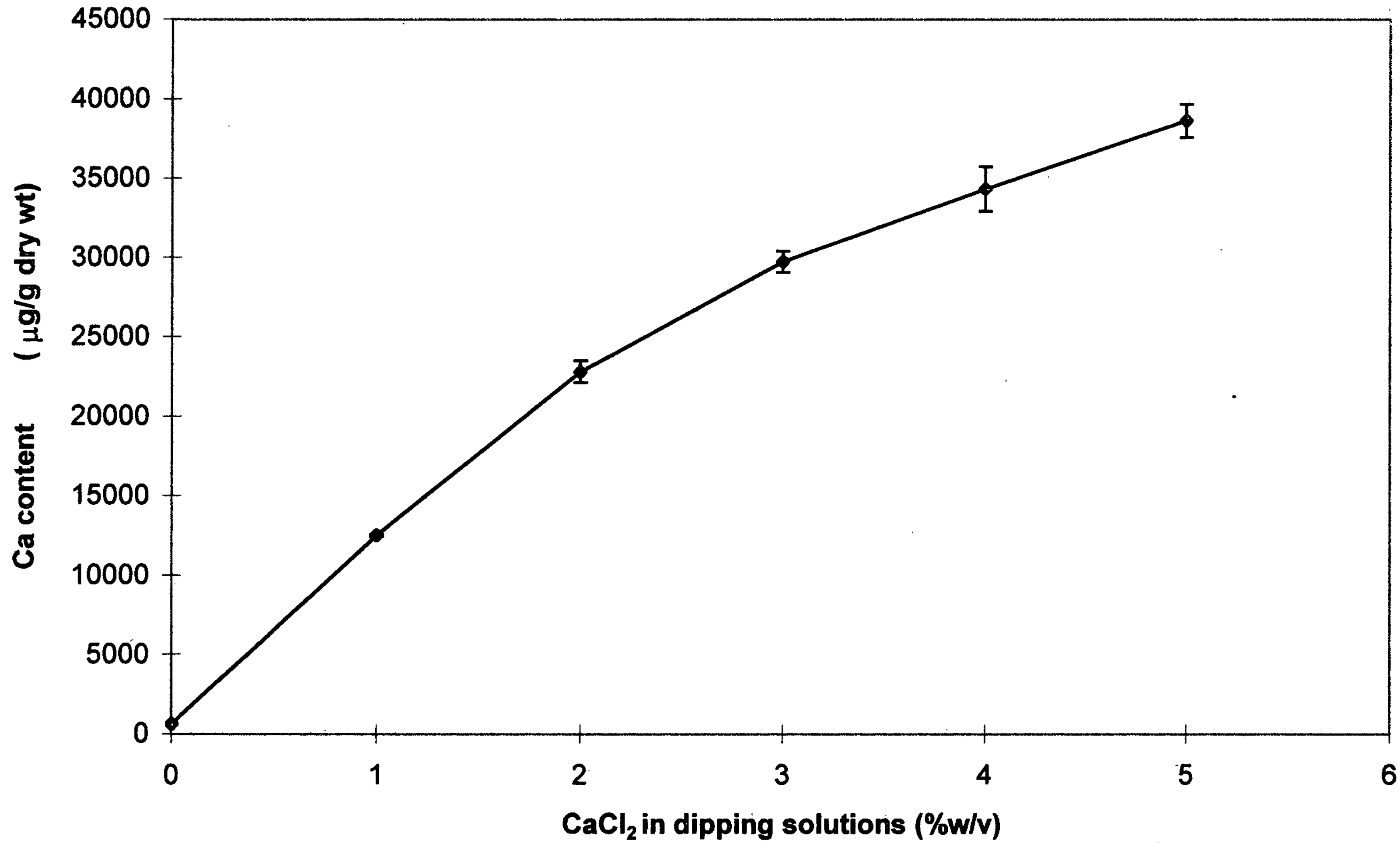

Figure 3. Calcium content in Golden Delicious apple chips vs %$CaCl_2$ in predrying dip. The calcium content of the apple chips is the mean of three samples. Error bars represent the standard error of the mean.

In previous studies, it was observed that infiltration of $CaCl_2$ into apples resulted in the immediately deposition of calcium at the cell wall sites (Gielink, et al.; 1966; Glenn and Pooviah, 1990; Siddiqui and Bangerth, 1996) and the promotion of cross-linking of pectic polymers. Ca can be bound to the carboxylic group of pectins or the hydroxylic group of diverse polysaccharides by electrostatic or cooperative linkages (Wuytack and Gillet; 1978). Grant and his group (1973) postulated an 'egg - box' model for the inclusion of calcium, wherein the calcium ions can fit between two or more chains of nonesterified galacturonic residues in such a fashion that they chelate to the oxygen atoms of four galacturonic residues distributed between two galacturonan chains, thus packing the ions like eggs within a box composed of galacturonans. Such cooperative, sequential insertion of Ca ion into the chain results in cross-linking of the galacturonan chains, and increased rigidity. The degree of Ca ion bonding will depend to the degree of methyl-esterification of galacturonan chains. Further, it was also suggested that binding of pectins of middle lamella is not merely by electrostatic forces but through some specific action of calcium (Siddiqui and Bangerth, 1995). Tepfer and Taylor (1981) investigated the interaction of divalent cations with pectic substances and their influence on cell wall loosening. Their results also support the idea that a specific action of calcium was involved in its interaction with pectins of cell walls.

Results from sensory analysis demonstrated that positive and significant linear relationships of $r^2 = 0.944$ (Figure 4) and $r^2 = 0.936$ (Figure 5) were obtained when the raw crispness score means and the raw bitterness score means were regressed against the Ca content in apple chips, respectively. This indicates that increasing Ca content in VMD apple chips would result in significantly higher sensory crispness and bitterness in the

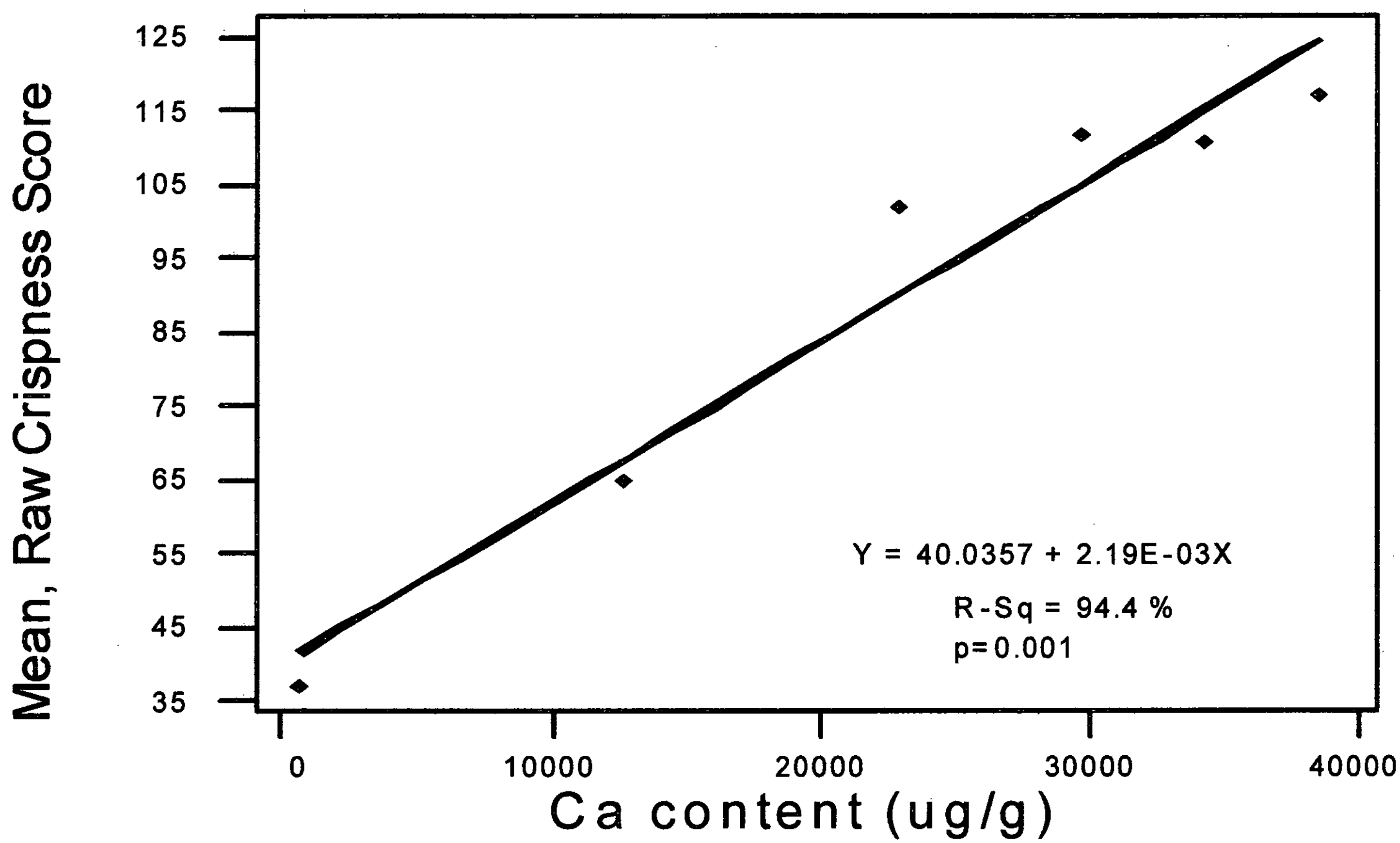

Figure 4. Effect of Ca content on mean, raw sensory crispness of VMD apple chips. n=21.

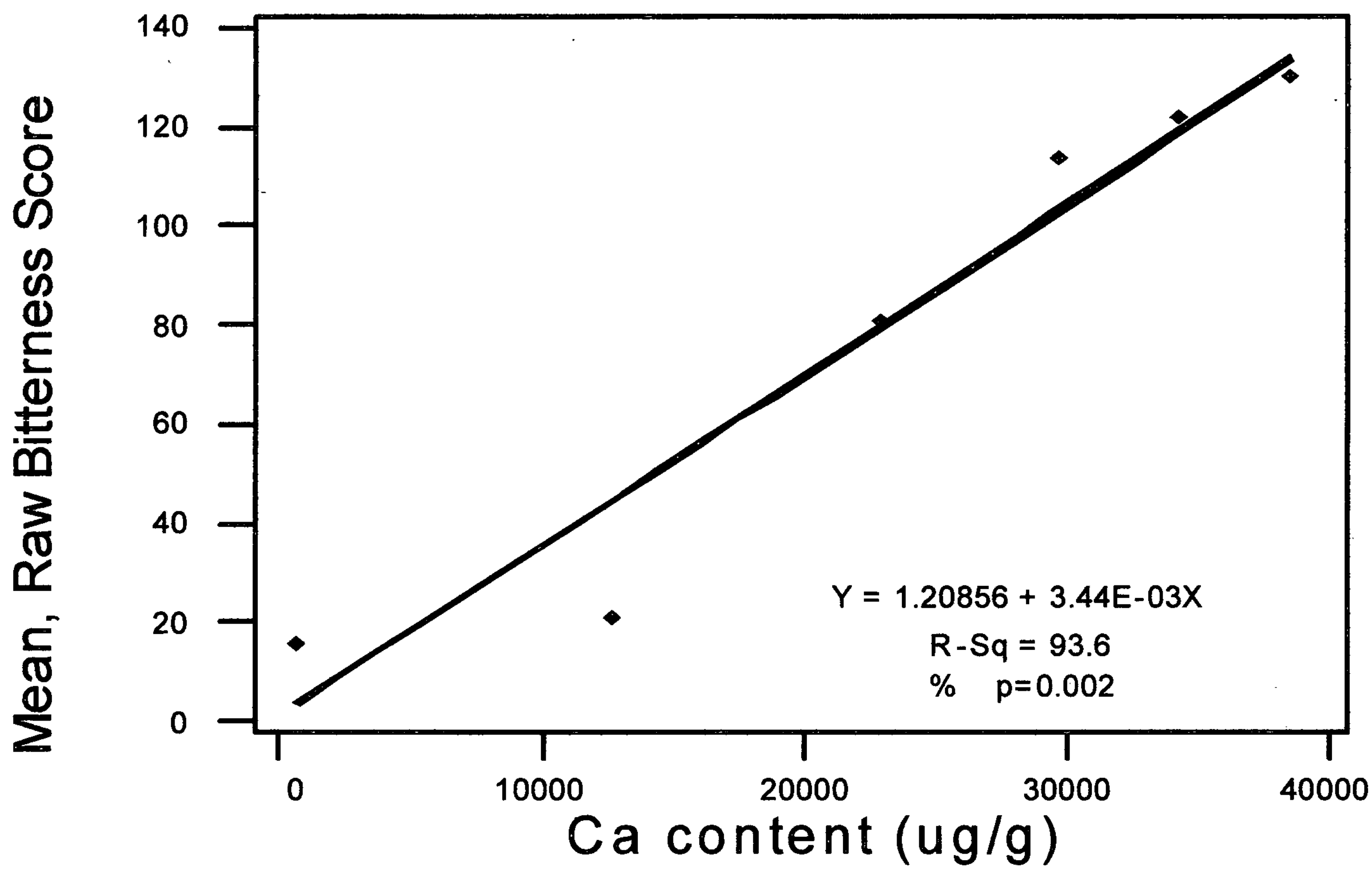

Figure 5. Effect of Ca content on mean, raw sensory bitterness of VMD apple chips. n=15.

chips. Analysis of variance (ANOVA) of raw sensory scores indicated significant differences between Ca pretreatment for both the sensory crispness (Figure 6) and the sensory bitterness (Figure 7). However, both panelist effects and Ca pretreatment by panelist interaction were significant for both sensory attributes (Table 1). The examination of individual scoring patterns of panelists showed that despite the training and the use of reference samples, panelists tended to use different portions of the line scale. For instance, panelist 'A' used only the right half of the line scale while panelist 'B' used the full scale. Therefore, standardization of raw sensory scores within each panelist was performed using z transformation and thereby, forced all panelist scores into the same scale. Although for both sensory attributes, results of Ca effect from both the ANOVA and the Tukey's multiple comparison tests of standardized scores (i.e. z scores) (Figure 8 & 9) remained the same as that carried out using raw sensory scores (Figure 6 & 7), standardization removed the panelist effect by calculations and Ca pretreatment by panelist interaction were nonsignificant when ANOVA were carried out using z scores (Table 2). Further, positive and significant linear relationships of $r^2 = 0.954$ (Figure 10) and $r^2 = 0.941$ (Figure 11) were again obtained when the crispness rating and the bitterness rating were regressed against the Ca content in apple chips, respectively.

A typical force/deformation curve from the instrumental analysis with the settings of the texture analyzer was shown in Figure 12. Results from the instrumental analysis demonstrated that a positive and significant linear relationship was found between the slope of the force/deformation curve and the Ca content of chips ($r^2 = 0.98$) (Figure 13). Further, significant linear relationships were observed between the distance ($r^2 = 0.89$) (Figure 14) and peak force ($r^2 = 0.87$) (Figure 15) of the force/deformation curve and the

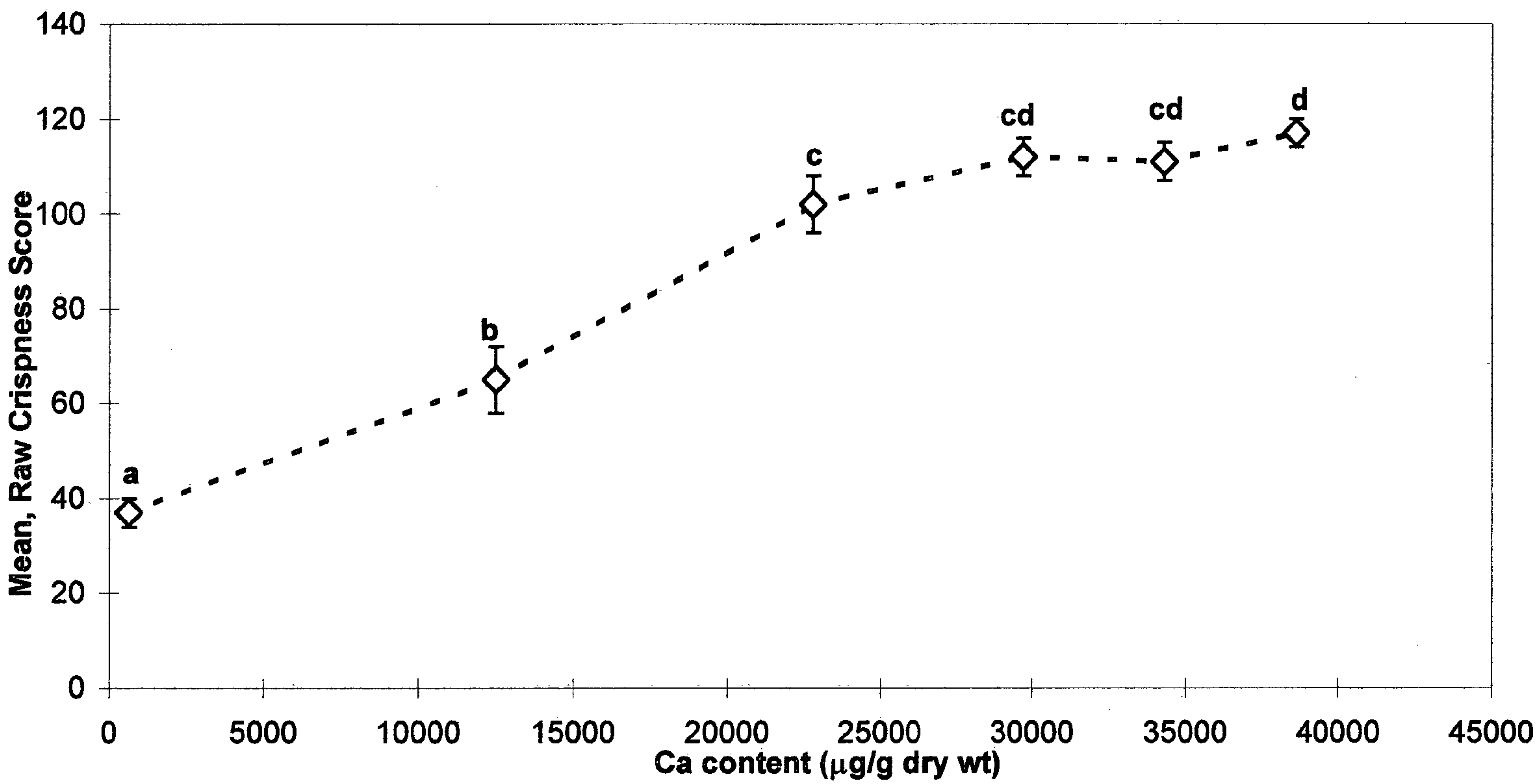

Figure 6. Mean, raw sensory crispness scores of VMD apple chips with different Ca content. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean. n= 21 for crispness.

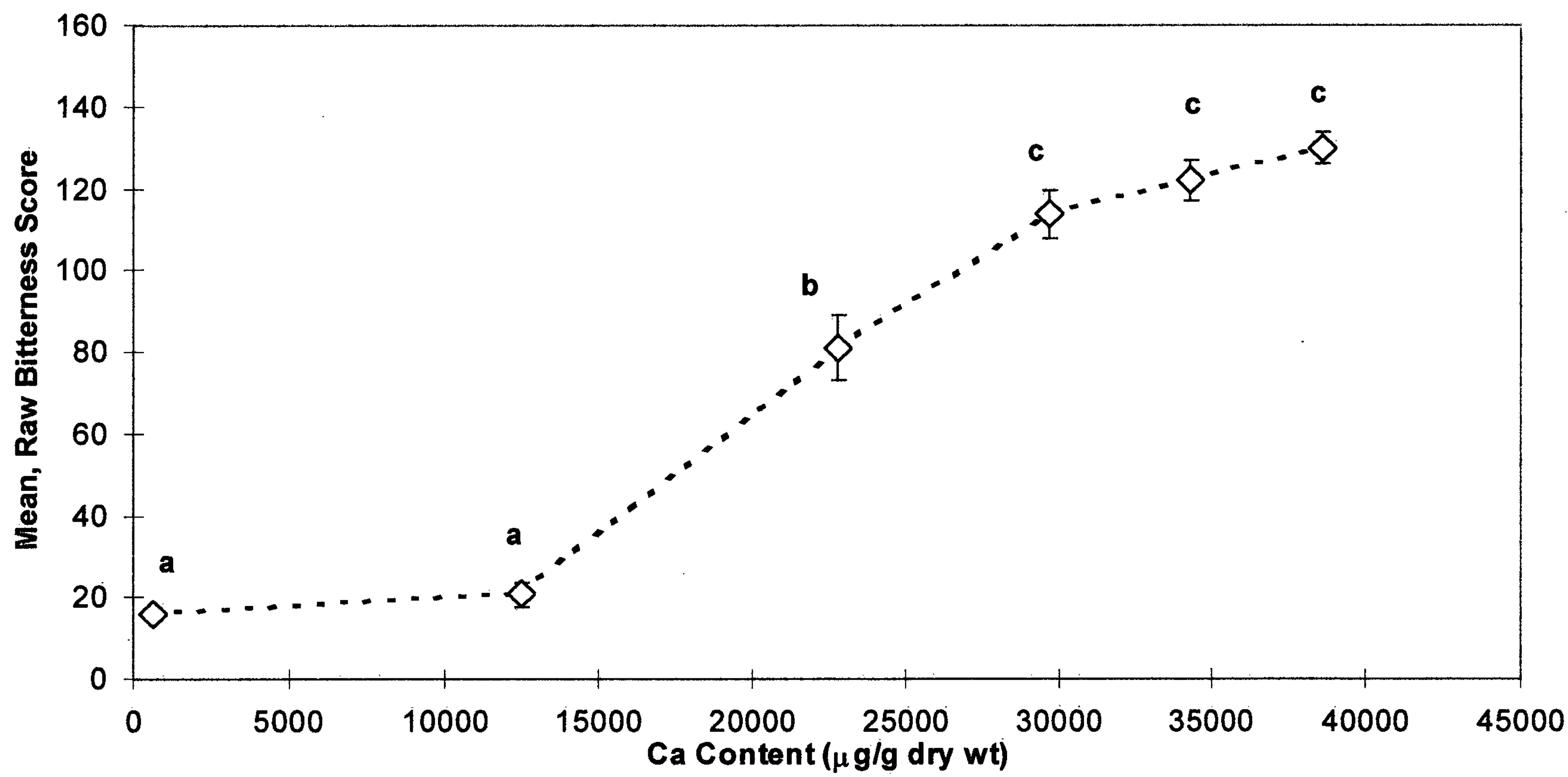

Figure 7. Mean, raw sensory bitterness scores of VMD apple chips with different Ca content. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean. n=15 for bitterness.

Table 1. Analysis of variance of raw sensory scores of VMD apple chips of different $CaCl_2$ pretreatment.

		Crispness	Bitterness
Ca pretreatment	**F-ratio**	71.86	146.21
	P-value	0.000	0.000
Panelist	**F-ratio**	2.14	3.12
	P-value	0.035	0.023
Replicate	**F-ratio**	10.18	1.22
	P-value	0.000	0.305
Replicate x Panelist	**F-ratio**	1.87	0.57
	P-value	0.054	0.797
Ca pretreatment x Panelist	**F-ratio**	1.65	2.59
	P-value	0.044	0.003

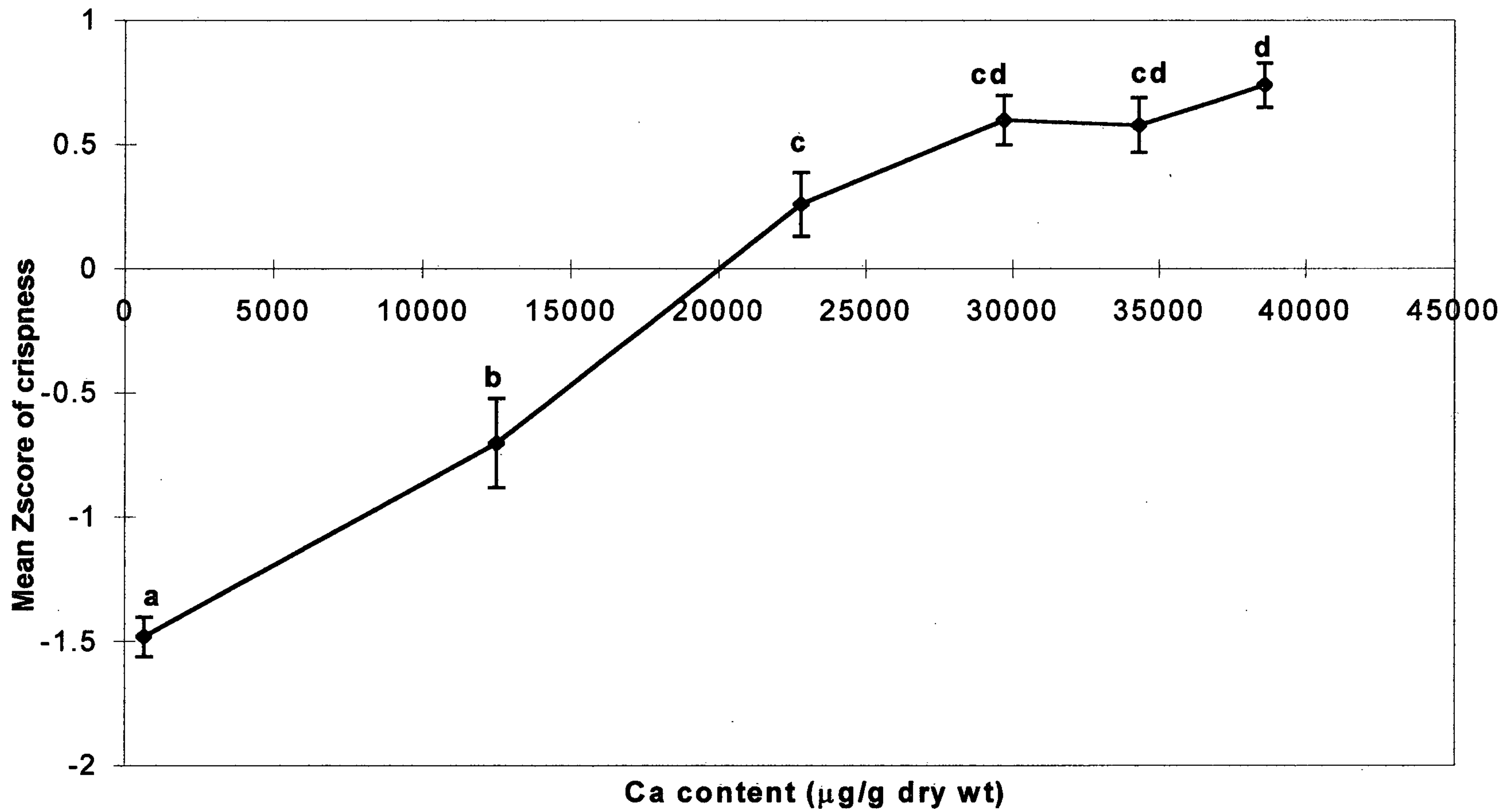

Figure 8. Mean crispness z scores of VMD apple chips with different Ca content. z score = (score - mean)/ std. dev. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean. n= 21 for crispness.

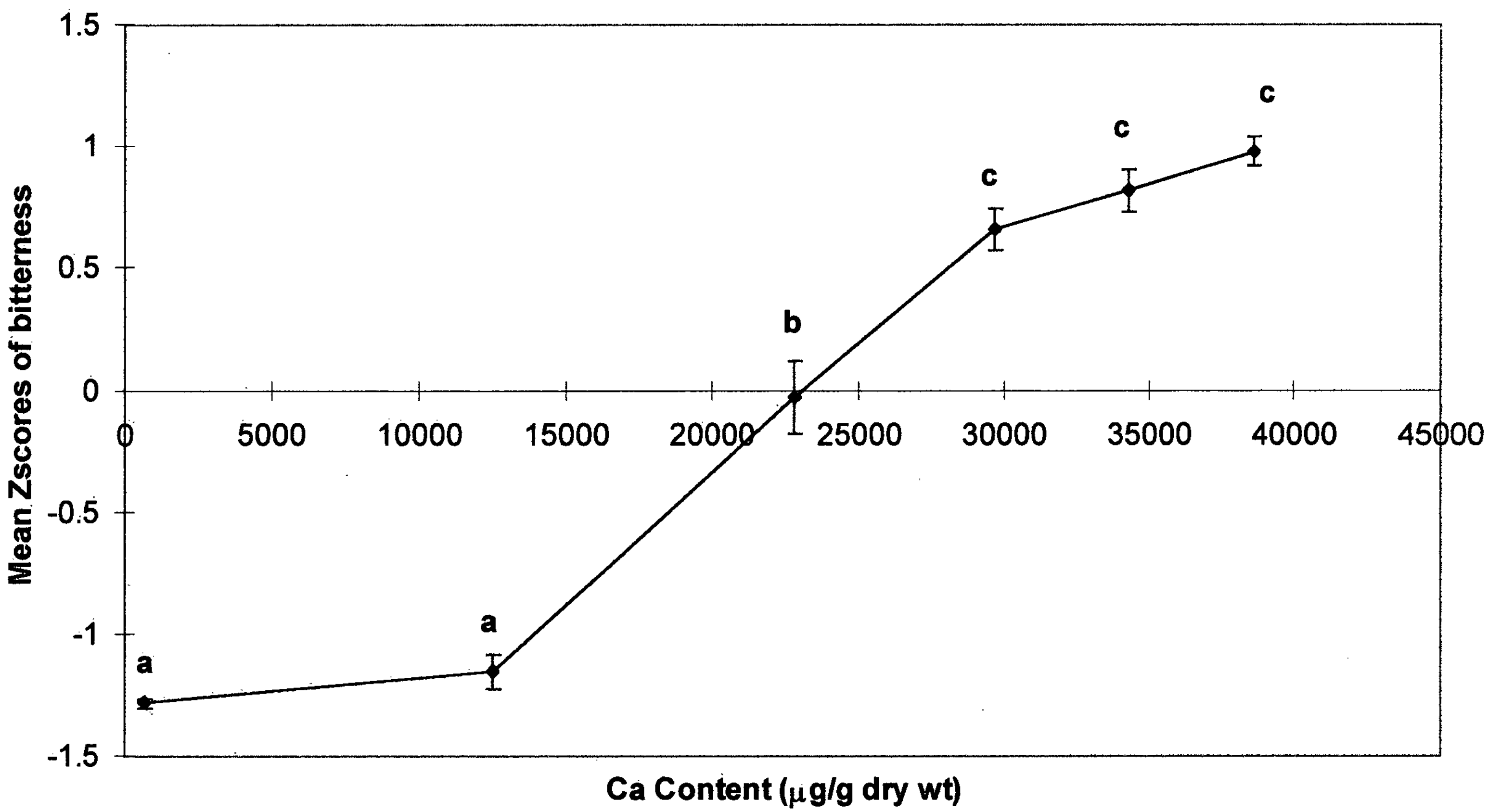

Figure 9. Mean bitterness z scores of VMD apple chips with different Ca content. z score = (score - mean)/ std. dev. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean. n=15 for bitterness.

Table 2. Analysis of variance of standardized[1] sensory scores (z score) of VMD apple chips of different $CaCl_2$ pretreatment.

		Crispness	Bitterness
Ca pretreatment	**F-ratio**	68.15	129.12
	P-value	0.000	0.000
Panelist	**F-ratio**	0.00	0.00
	P-value	1.00	1.00
Replicate	**F-ratio**	9.21	1.25
	P-value	0.000	0.296
Replicate x Panelist	**F-ratio**	1.78	0.56
	P-value	0.069	0.808
Ca pretreatment x Panelist	**F-ratio**	1.14	1.39
	P-value	0.320	0.173

[1] Scores of individual attributes were standardized within each panelist and z score =(score -mean)/std.dev.

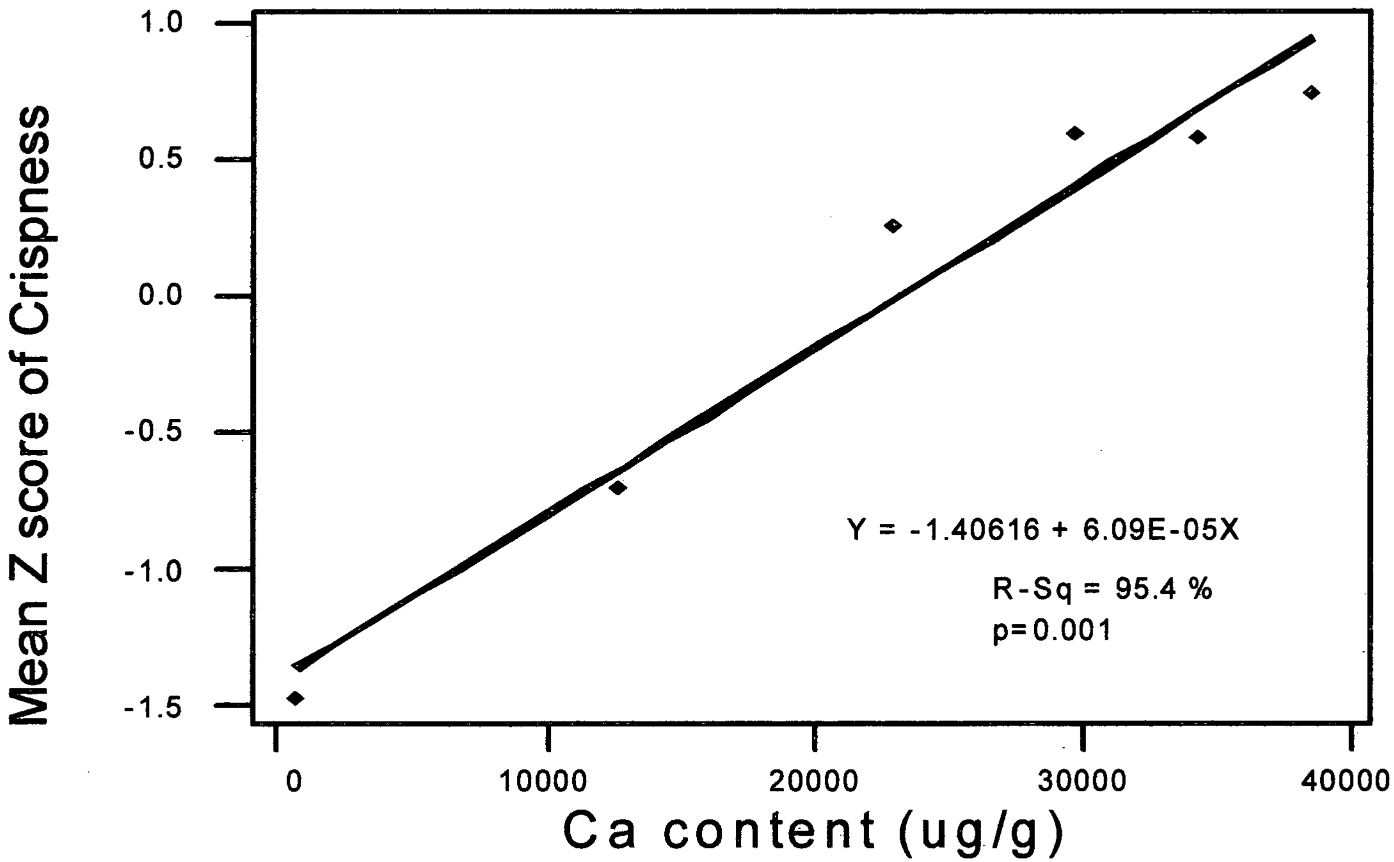

Figure 10. Effect of Ca content on mean crispness z scores of VMD apple chips. n=21.

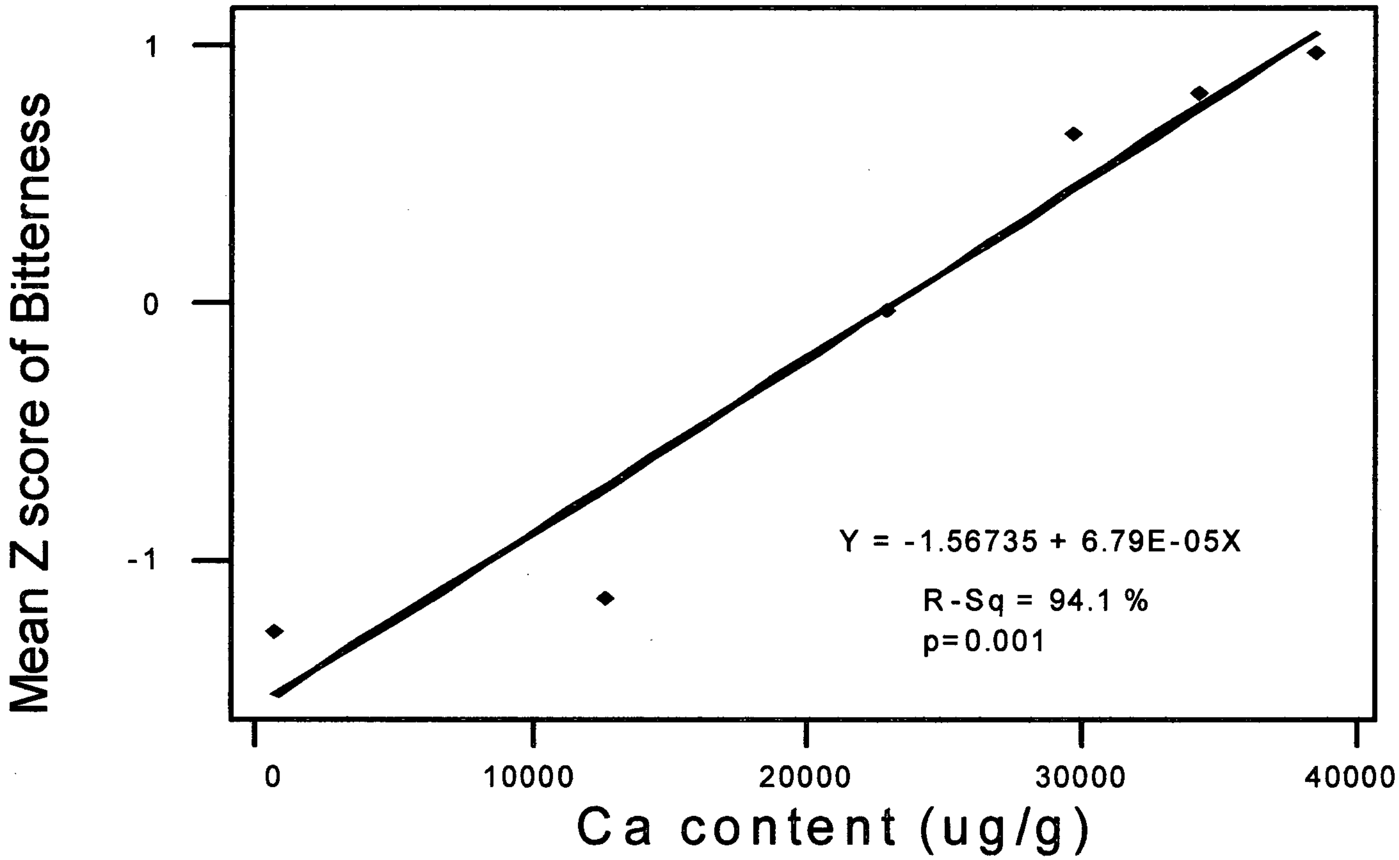

Figure 11. Effect of Ca content on mean bitterness z score of VMD apple chips. n=15.

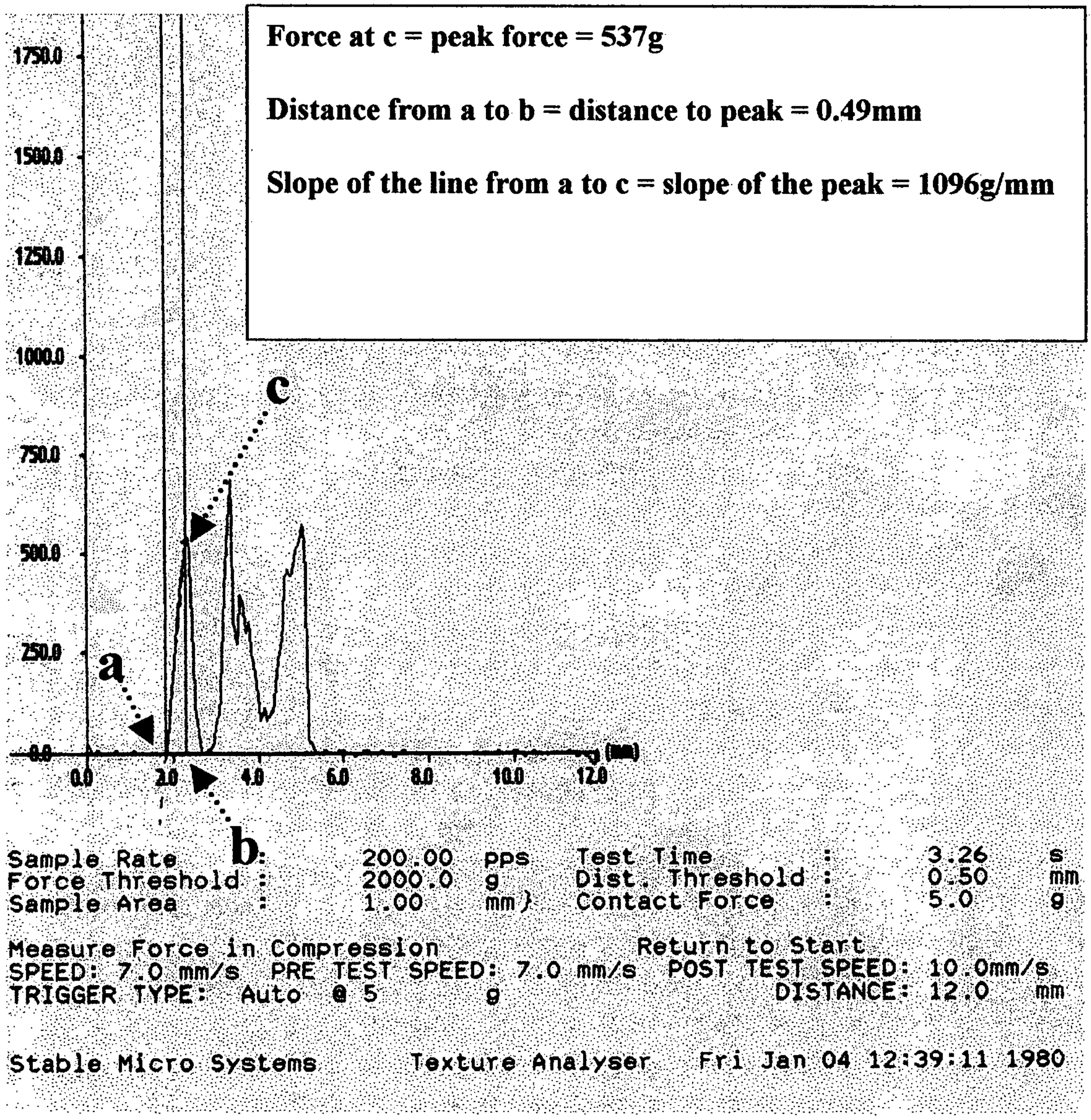

Figure 12. Force vs deformation curve and settings of the texture analyzer in instrumental analysis.

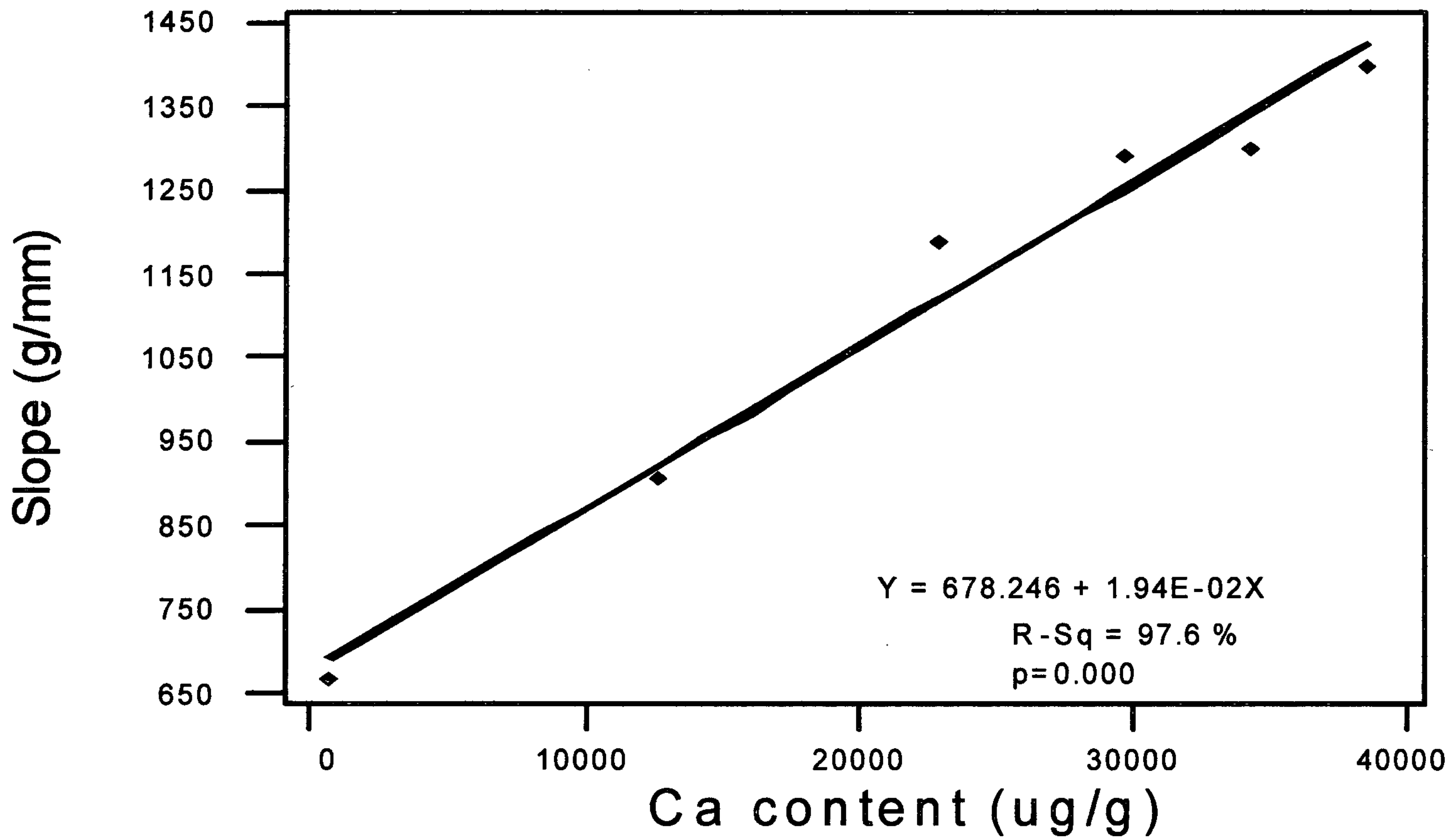

Figure 13. Effect of Ca content on slope of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n=45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

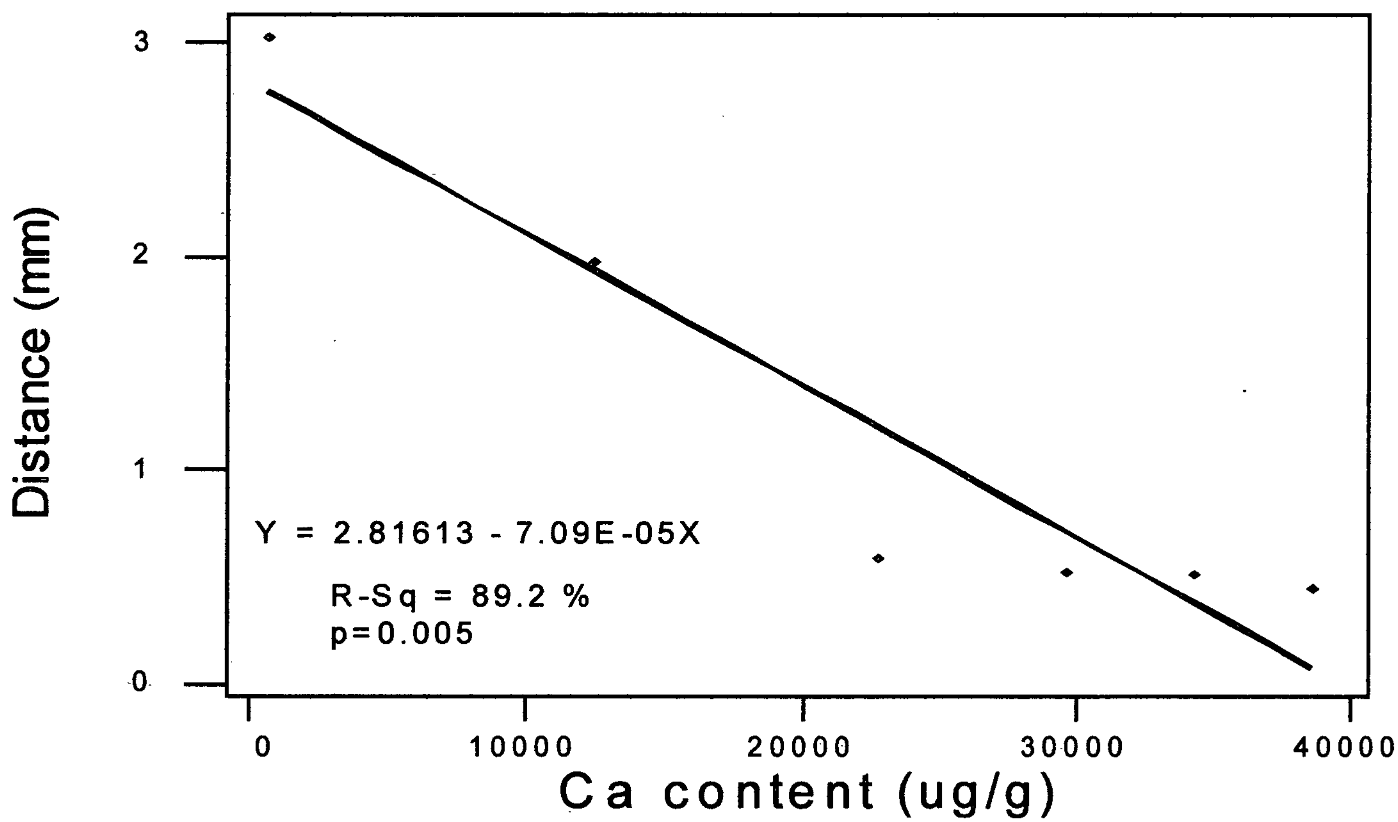

Figure 14. Effect of Ca content on distance to the peak of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n=45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

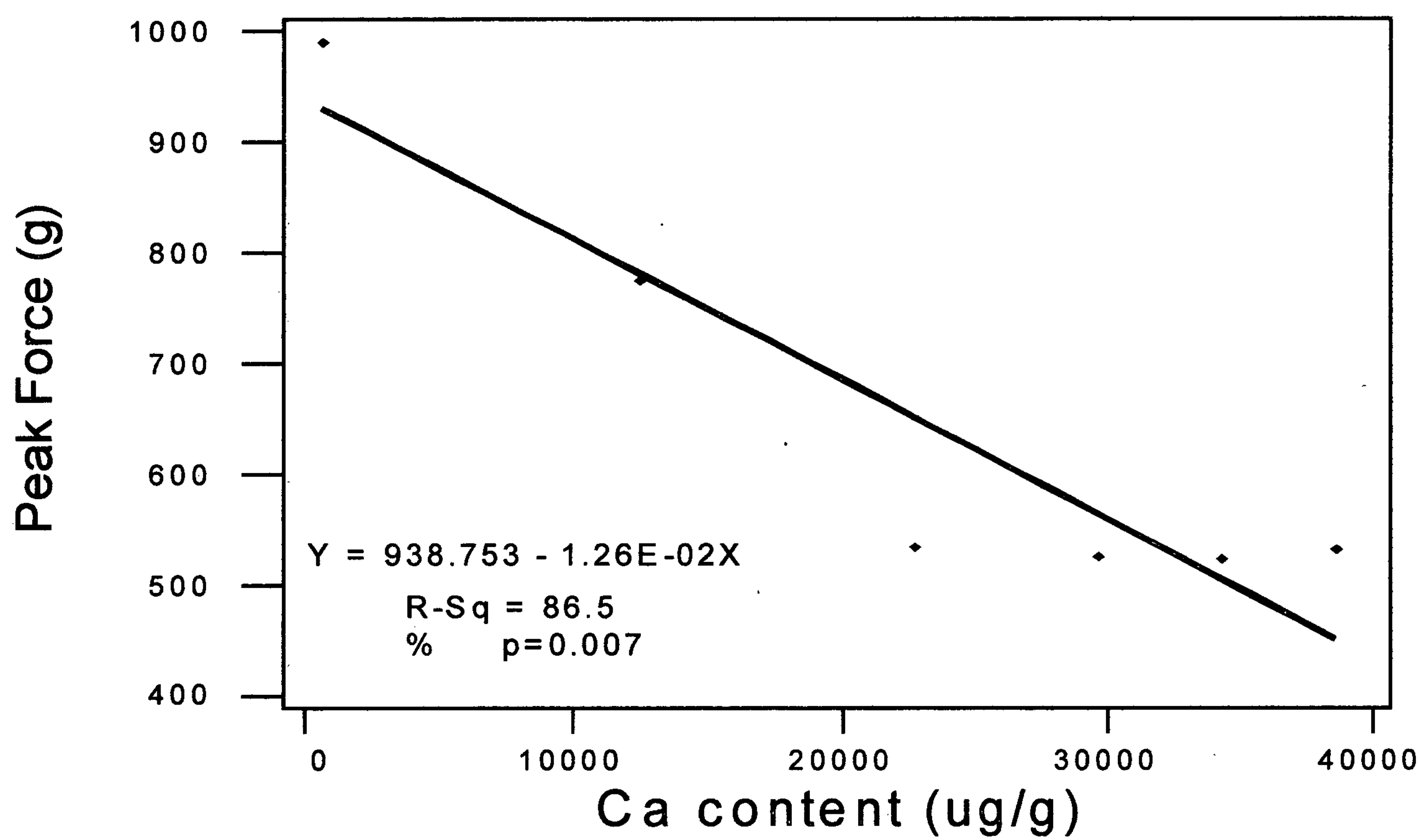

Figure 15. Effect of Ca content on peak force of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n=45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

Ca content of chips. Upon the deposition of Ca in apple tissues, the extensive cross-linking of pectic polymers by Ca may then facilitate the formation of a cell wall network that increased mechanical strength and suppressed the solubilization of cell wall pectins in apples during processing. It appeared that the calcium pretreatment did have a firming effect on apple tissues and thus, produced apple chips with a crispier texture. Since the incorporation of $CaCl_2$ into apples would increase the bitterness of apple chips (Figure 9), the addition of an optimum amount of $CaCl_2$ to the chips that gives a reasonable increase in crispness but without affecting the pleasant taste of the chips would be important. Increasing sample Ca content to much above 22800 μg/g d.b. did not result in an appreciable increase in neither the sensory crispness rating (Figure 8) or the instrumental slopes reading (Figure 16), or the decrease in the instrumental distance or peak force readings (Figure 17 & 18). However, in Figure 9, a sharp increase in sensory bitterness in apple chips was observed when Ca content was incorporated into apple chips at a level over 12500 μg/g db. (i.e. when a calcium pretreatment of > 1%$CaCl_2$ was applied). Therefore, it seemed that the application of a 1% $CaCl_2$ pretreatment to the apple slices would produce apple chips with a significant increase in crispness but without affecting its flavor.

The sensory crispness of VMD apple chips was also found to be highly correlated to the instrumental parameters. The correlation coefficients between the sensory crispness and the instrumental parameters were observed to be 0.997 for the slope, -0.990 for the distance and -0.983 for the peak force of the force/deformation curve (Table 3). Crispness is the desired textural characteristics of chips. It has been reported that crispness is characterized by resistance to deformation under load up to the point of sudden fracture,

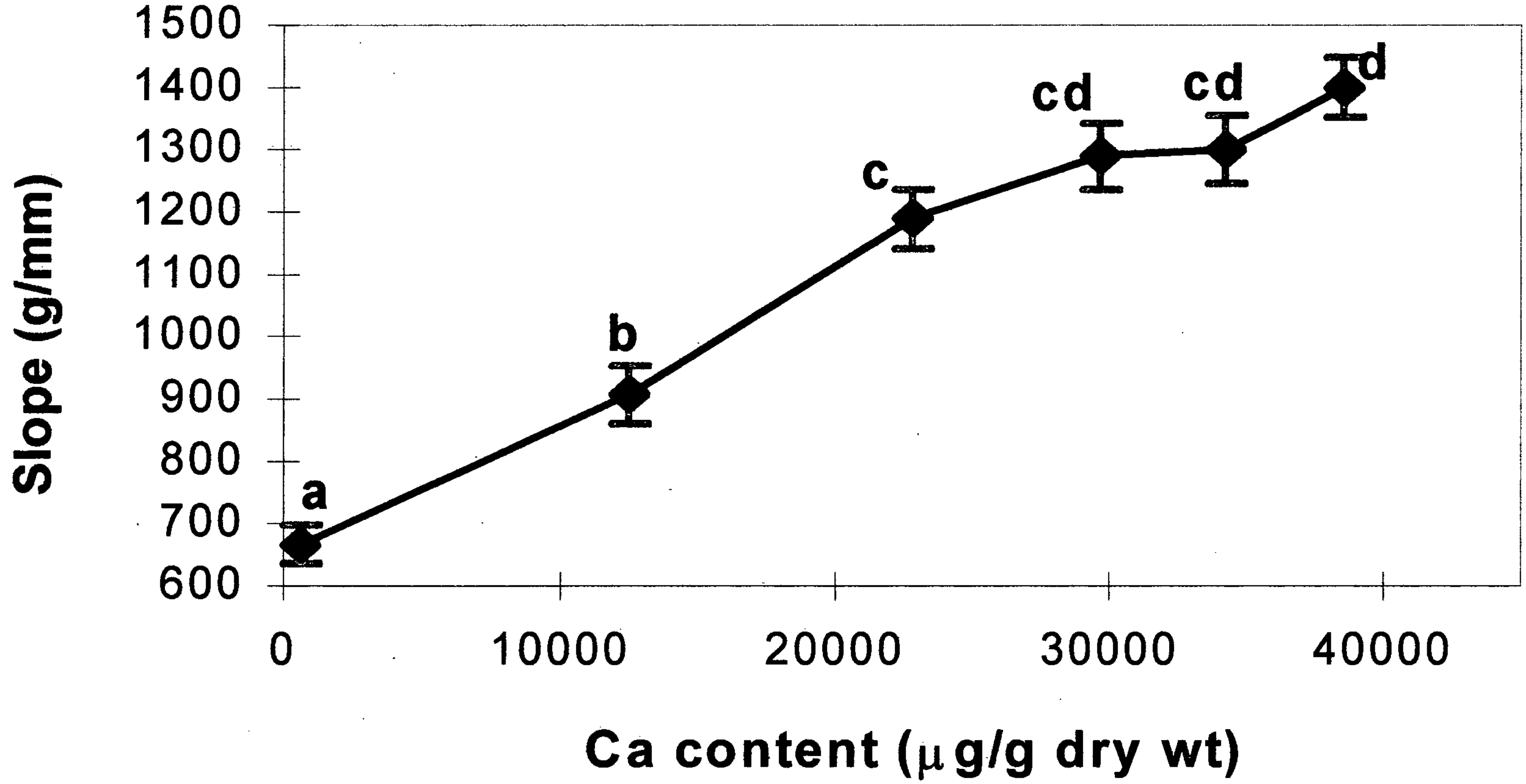

Figure 16. Mean slope of the force/deformation curve of VMD apple chips with different Calcium (Ca) content. The slope of the peak of the force/deformation curve was obtained from VMD apple chips with different Ca content. Experiment was performed in triplicate with 15 measurements obtained from each replicate (n=45). Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean.

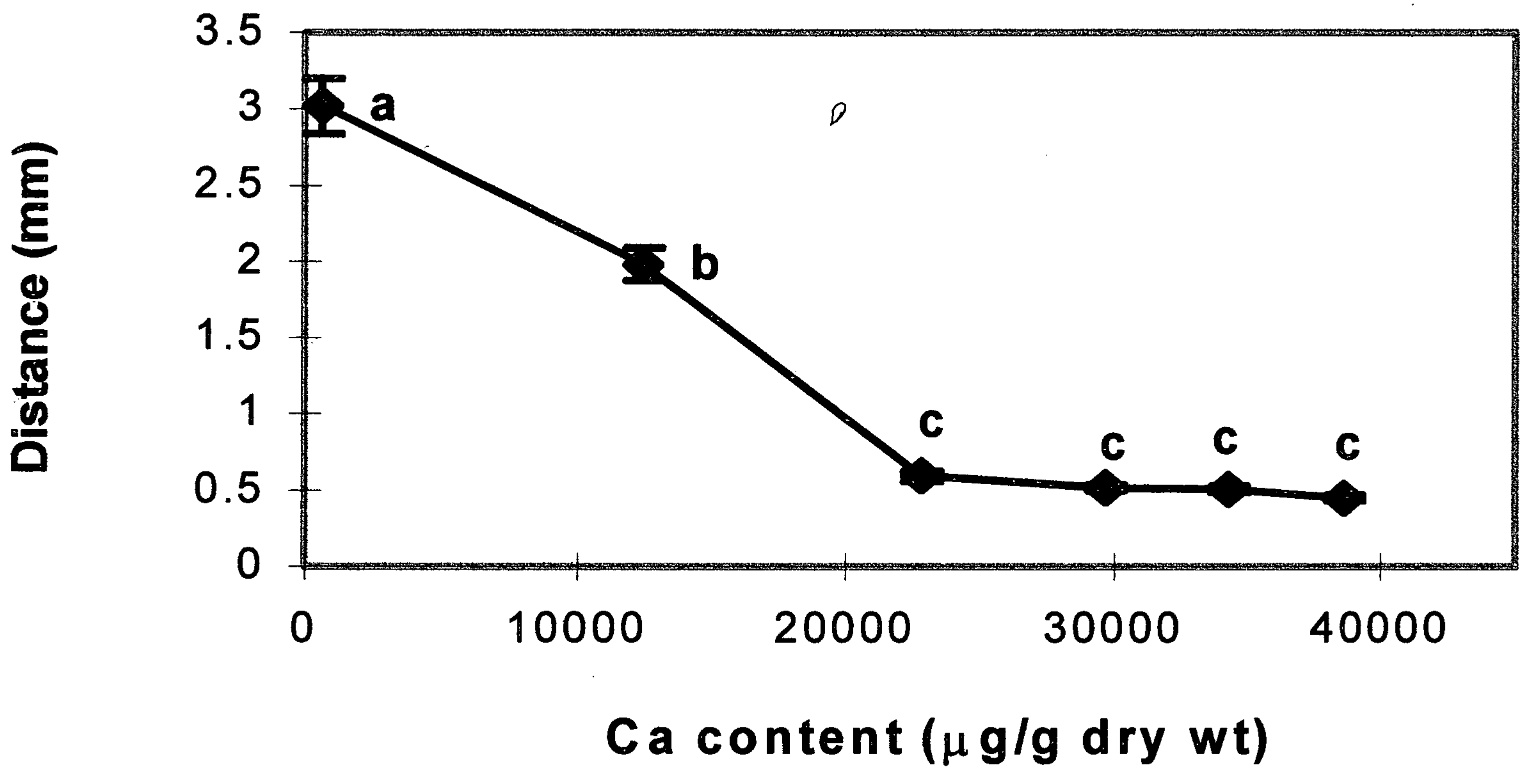

Figure 17. Mean distance of the force/deformation curve of VMD apple chips with different Calcium (Ca) content. The distance to the peak of the force/deformation curve was obtained from VMD apple chips with different Ca content. Experiment was performed in triplicate with 15 measurements obtained from each replicate (n=45). Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean.

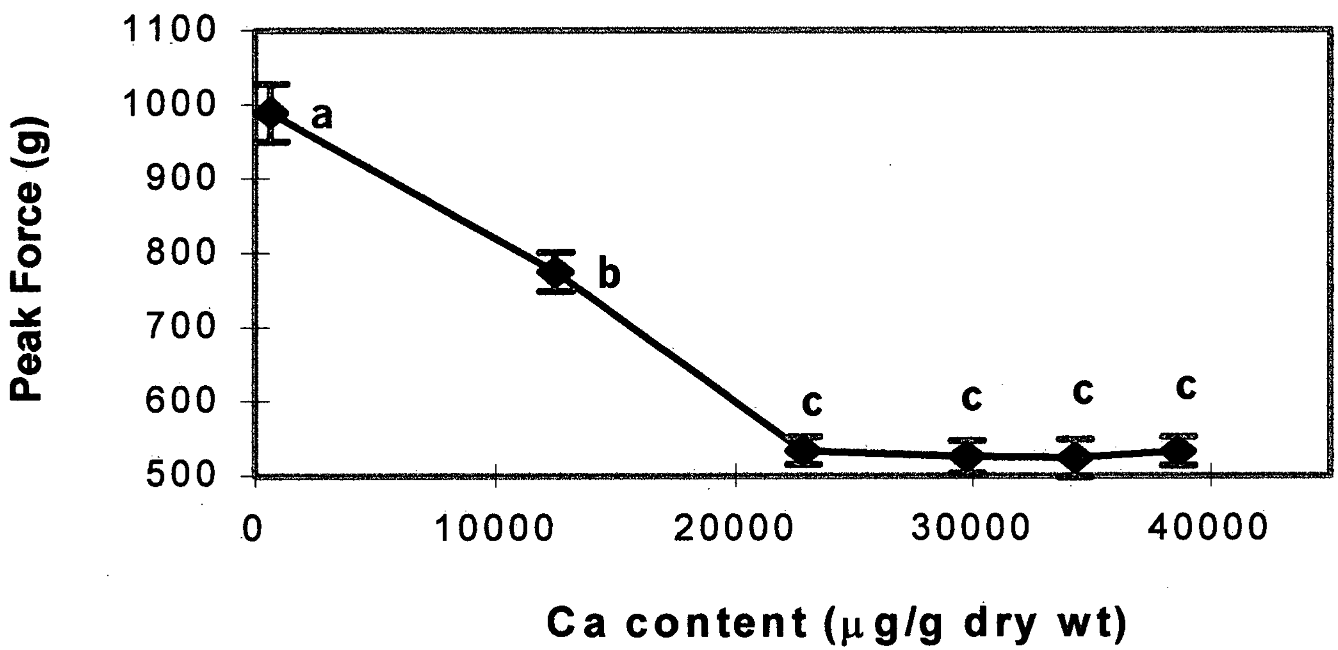

Figure 18. Mean peak force of the force/deformation curve of VMD apple chips with different Calcium (Ca) content. The peak force of the force/deformation curve was obtained from VMD apple chips with different Ca content. Experiment was performed in triplicate with 15 measurements obtained from each replicate (n=45). Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$. Error bars represent the standard error of the mean.

Table 3. Pearson Correlation matrix and associated probabilities between sensory attributes (crispness) and instrumental parameter (slope, distance, and peak force) of VMD apple chips[1]

	crispness	slope	distance
slope[2]	0.997		
	0.000		
distance[2]	-0.990	-0.980	
	0.000	0.001	
peak force[2]	-0.983	-0.969	0.998
	0.000	0.001	0.000

[1] Cell Contents: Correlation
P-Value

[2] The slope, distance and peak force of the peak of the force/deformation curve was obtained from VMD apple chips

and this characteristic can be best measured by the slope of the force/deformation curve (Bourne et al., 1966). Vickers (1980) also stated that among all the instrumental parameters, the slope of the force/deformation curve generally had the highest correlation with the crispness of all foods. This was in agreement with what was observed in this experiment where the instrumental slope of the force/deformation curve was the best representation of the sensory crispness of apple chips. For the peak force and the distance of the force/deformation curve, it has been reported that they generally have the highest correlation with firmness (Vickers, 1980) and elasticity (Bourne et al., 1966) of the product, respectively.

It has been reported that the use of chelating agents to remove Ca from the cell wall of cell suspension cultures results in increased wall loosening and eventually in cell detachment (El Hinnaway, 1974). Clearly, Ca does play a special role in cell-to-cell adhesion and tissue coherence properties in plants (Roux and Slocum, 1982). In fact, calcium has long been known to play an important role in retaining the natural structure and firmness of plant products when they are preserved by canning or freezing (Powers and Esselen, 1946) and prolonging the storage life of the products (Bangerth et al., 1972; Poovaiah and Shekhar, 1978). It was reported that the addition of calcium to canned fruits and vegetables often gives a firmer product (Kertesz et al., 1940). Also, calcium chloride is used commercially in pickling solutions to maintain the desired firm and crunchy texture of pickles (Schur, 1987). Calcium infiltration to maintain fruit structure is well-documented (Poovaiah, 1986; Stow, 1989; Glenn and Poovaiah, 1990). In previous studies, it had been found that increasing Ca content of apple fruit through Ca pretreatments resulted in the reduction of softening rate (Mason, 1976; Betts and

Bramlage, 1977; Scott and Wills, 1977; Johnson, 1979) and the decreasing of pectin solubilization (Sams and Conways, 1984). The effect of calcium chloride pretreatment on qualities and storage life of apple slices was studied by Ponting et al. (1971 & 1972). Their results showed that calcium pretreatment of unsulfited apples have a firming effect in both acid and alkaline solutions and was effective in preserving the color, flavor and firmness of the refrigerated apple slices over an extended storage period.

The effect of Ca on apple chip structure was observed under the scanning electron microscope. The untreated (0% $CaCl_2$) apple chip tissue had a honeycomb structure constructed of closely connected cells (Figure 19). In contrast to the thin and smooth cell wall structure observed in the untreated apple chip tissue, that of the Ca-pretreated tissues was thicker and more irregular, and thus, might result in a stronger texture (Figure 20 & 21). Instead of a net-like pattern, more severe cell wall breakage resulting in large open structures in the Ca-pretreated tissues and thus, gave a crisper texture to the chips. In the Ca-pretreated apple tissues, the rigidity of cell wall structure confered by the crosslinking of Ca ions to pectin might result in an increase in the strength and a decrease in the flexibility of cell walls. Therefore, with the same amount of expansion force provided by VMD, a greater loss of the original apple structure was observed in the Ca-pretreated apple chips. Also, the increase in cell wall rigidity might also prevent the collapse of sample structures during further dehydration. These results of structural analysis supported those of instrumental and sensory textural analyze, again suggesting that Ca-pretreatment seems to give VMD apple chips puffier appearance and crisper texture.

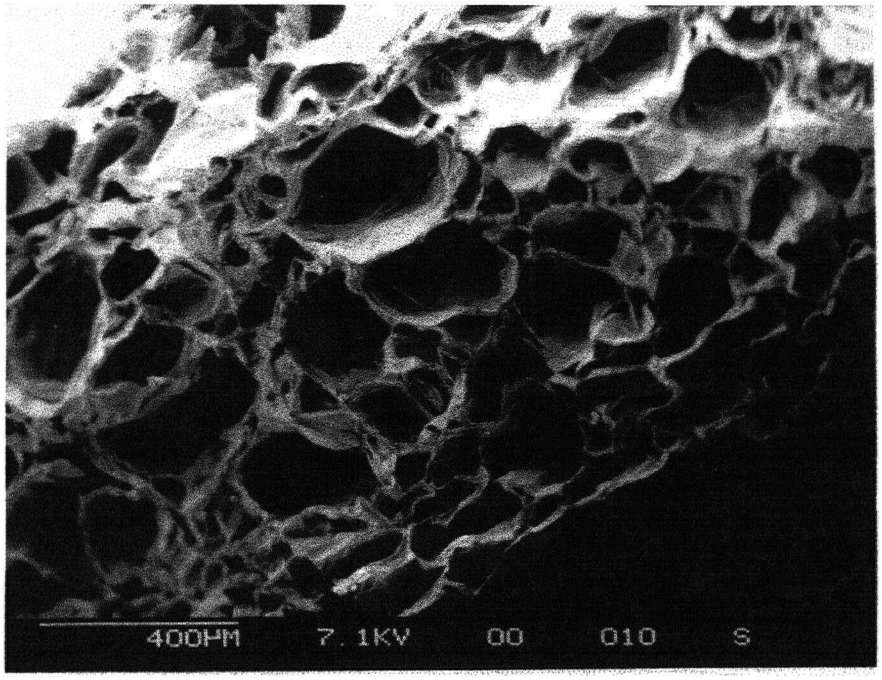

Figure 19. Scanning electron micrograph (200x) of Golden Delicious VMD Apple Chips with 0%$CaCl_2$ Pretreatment.

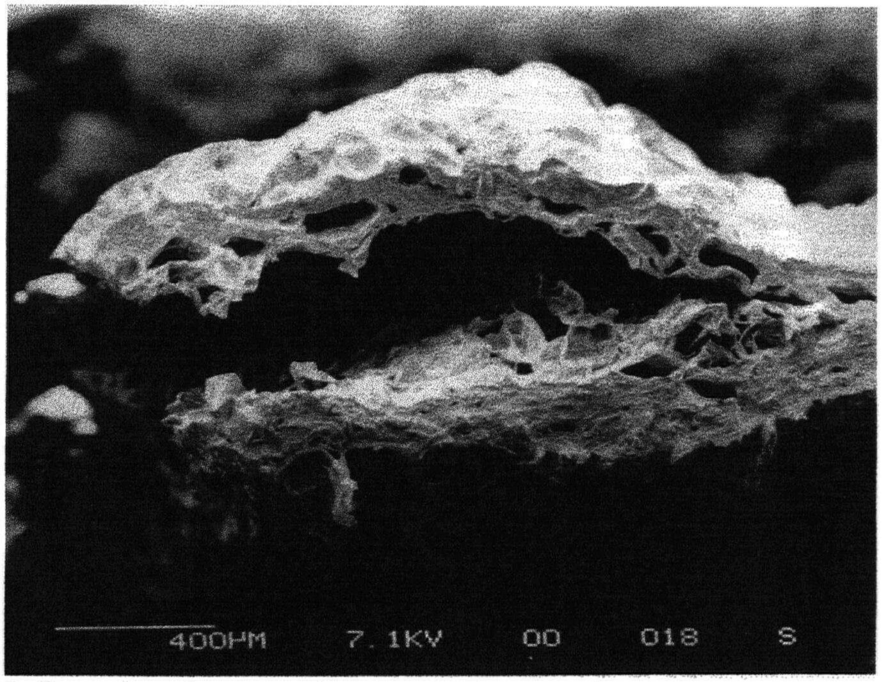

Figure 20. Scanning electron micrograph (200x) of Golden Delicious VMD Apple Chips with 1%$CaCl_2$ Pretreatment.

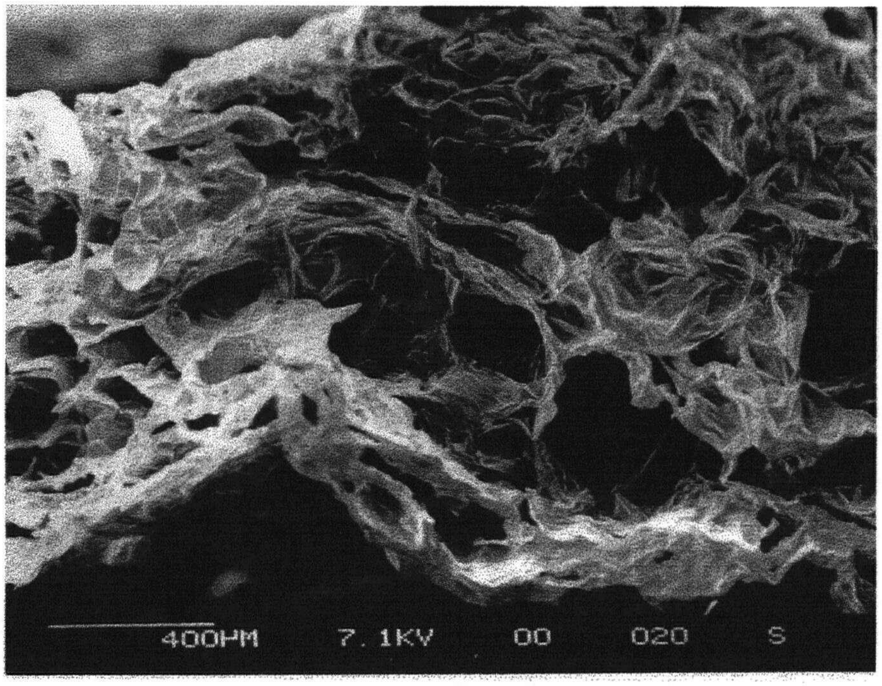

Figure 21. Scanning electron micrograph (200x) of Golden Delicious VMD Apple Chips with 5%$CaCl_2$ Pretreatment.

4.2 The Effects of Vacuum Levels and Drying Techniques on Texture of Apple Chips

After equilibration for 14 days, the water activity of the VMD Golden Delicious apple chips given the calcium pretreatment was found to be 0.25 at 25^0C.

A negative and significant linear relationship (r^2 = 0.83) was found when apple chip's density was regressed against vacuum level (Figure 22). This result indicates that when a higher vacuum level was employed during vacuum microwave drying, a larger puffing effect was obtained, thus leading to a less dense apple chip product. Previous studies demonstrated that the structure of carrot (Lin et al., 1998) and potato (Durance and Liu, 1996) slices could be puffed and expanded by vacuum microwave drying. During vacuum microwave heating, the absorption of microwave energy by water molecules in the interior of the apple chips results in rapid generation of heat within the chips and thus, evaporating the water within the chips at a higher rate than it could diffuse to the surface. As a result, a large vapor pressure differential between the center and surface of products was obtained. Under the low chamber pressure provided by the vacuum during the VMD process, this high internal vapor pressure would result in an outward force causing the apple chips to expand and puff up. Vickers and Bourne (1976) demonstrated that a dry crisp food will probably consist of cells or cavities which are usually filled with air and a structural phase or cell walls that are formed by a brittle matrix, and will produce characteristic crisp sounds arise from collective breaking of individual cells. Therefore, it seems that puffing is essential if a crispy texture is desired in a dried food product (Torreggiani et al., 1995). Durance and Liu (1996) and Durance (1997) also reported that the level of vacuum employed affected the extent of puffing. A

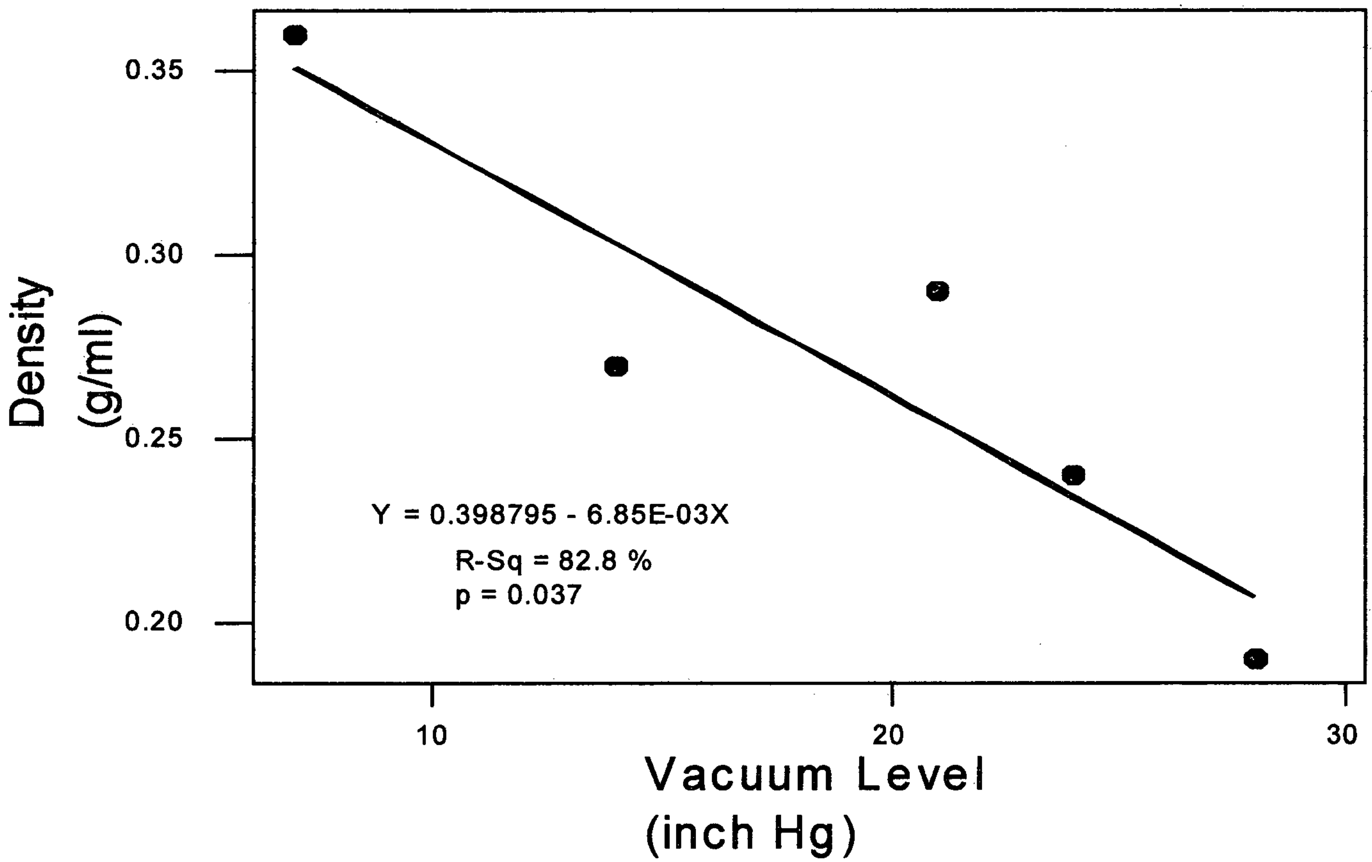

Figure 22. Effect of 5 levels of applied vacuum on density of VMD apple chips. The density of apple chips was measured by immersing a 10g sample in a 500 ml graduated cylinder with 200 ml of flaxseed. All measurements were recorded as mean. n= 3 for all observations.

second advantage of the application of vacuum is that when food is heated in a vacuum chamber, the moisture of the food can be removed at a lower temperature than without a vacuum. Alternatively, for a given temperature, the rate of water removal from the food will be greater when vacuum is applied. The suction force provided by the vacuum allows the water vapor to pump out quickly from the inside of the food and thus, results in a rapid mass transfer rate. In the case of heat-sensitive foods, such as apple chips or other fruit products, lower drying temperature and shorter drying times are very important for the production of high quality products which have better retention in texture, flavor, color and nutritional values.

A positive and significant linear relationship was found between the slope of the force/deformation curve and the vacuum level employed during VMD (r^2 = 0.83) (Figure 23). Further, significant linear relationships were observed between the distance (r^2 = 0.73) (Figure 24) and peak force (r^2 = 0.81) (Figure 25) of the force/deformation curve and the vacuum level. This indicates that crispier and firmer textures that were less elastic were obtained when higher levels of vacuum were employed. Also, the slope of the force/deformation curve obtained by apple chips was found to be highly related to the chips' densities; a correlation of -0.986 was obtained (Table 4). The correlation coefficients between the densities and the other two instrumental parameters were observed to be -0.957 for the peak force and 0.924 for the distance (Table 4). Hence, with the application of higher vacuum levels, crispier apple chips with less elasticity and higher firmness were obtained as a result of a greater degree of puffing.

In the study of the effect of drying techniques on texture of apple chips, for practical purposes, only chips produced from the highest level of vacuum (28inch Hg)

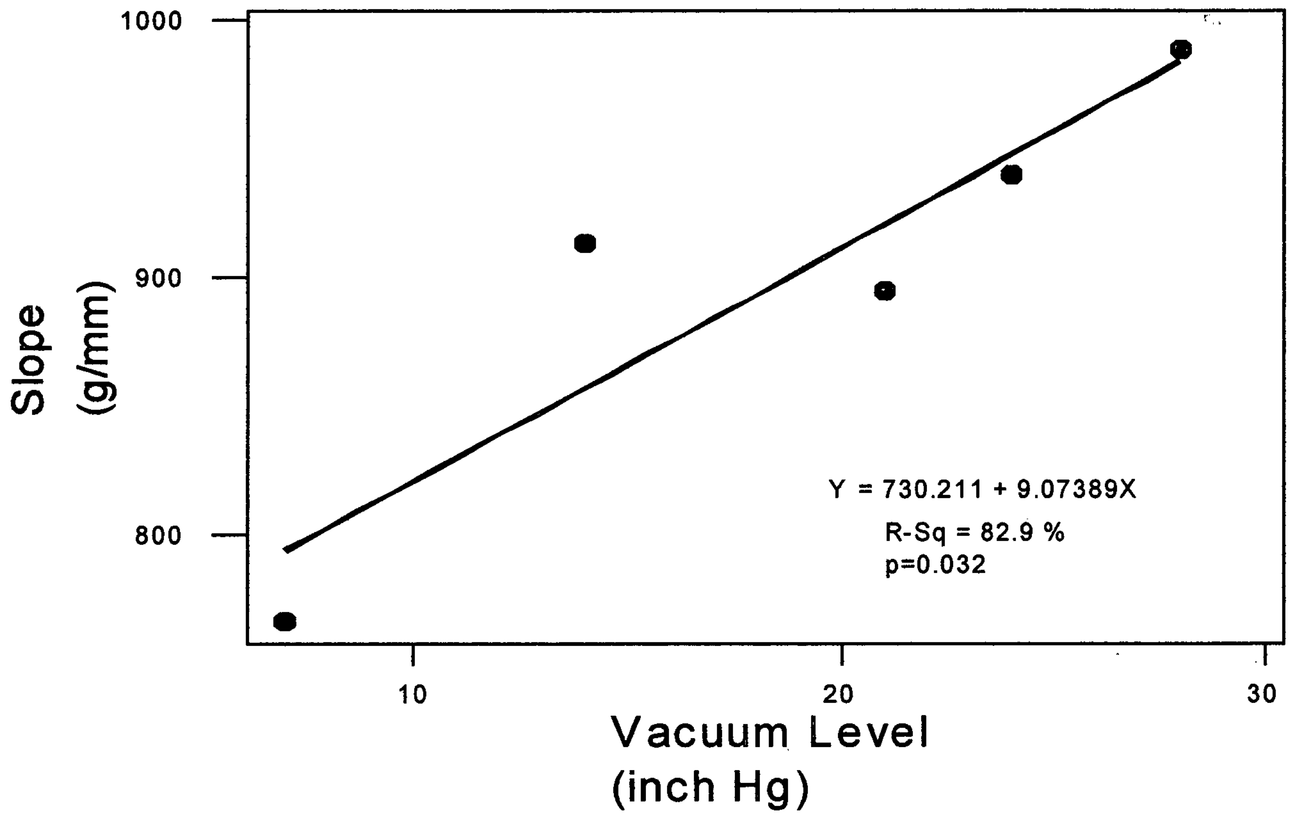

Figure 23. Effect of 5 levels of applied vacuum on slope of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n = 45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

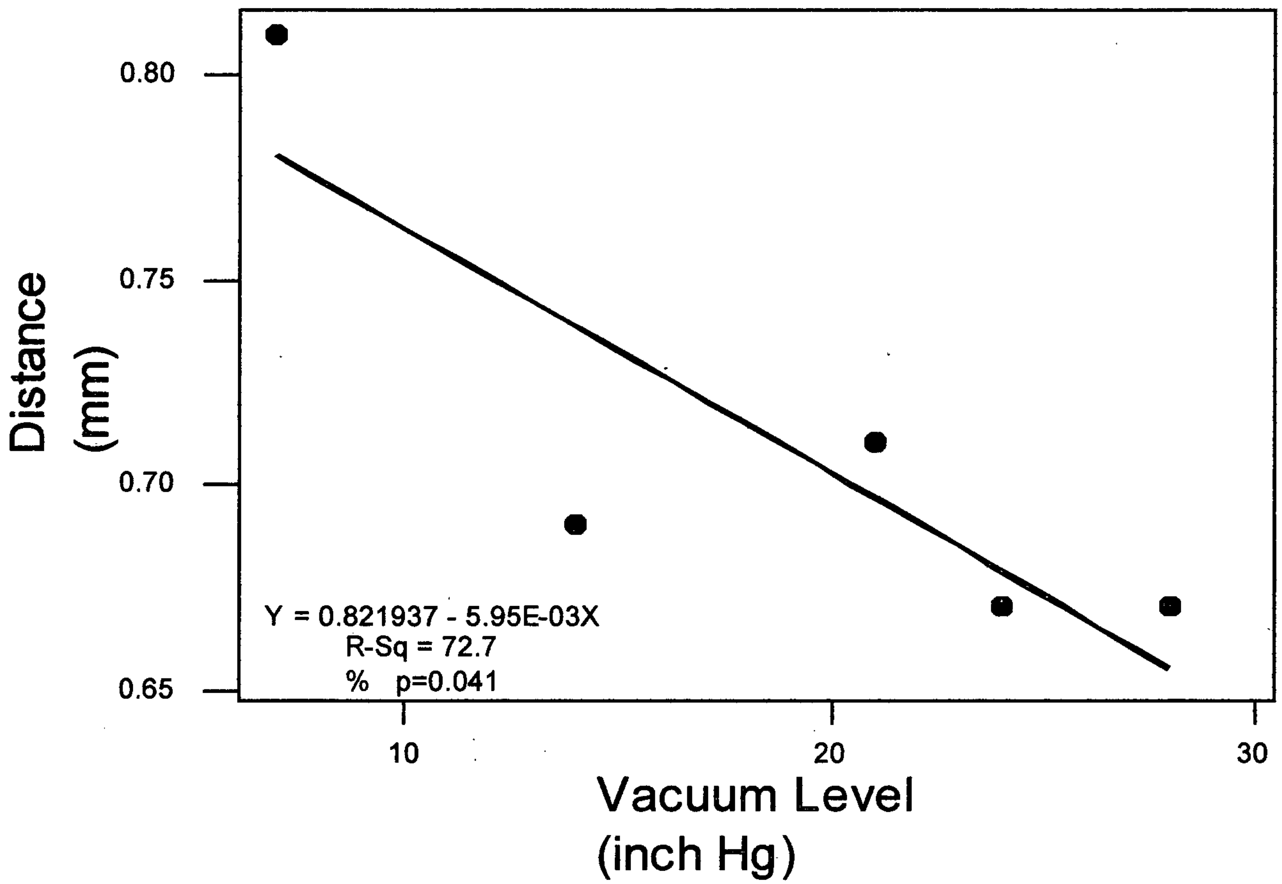

Figure 24. Effect of 5 levels of applied vacuum on distance to the peak of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n = 45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

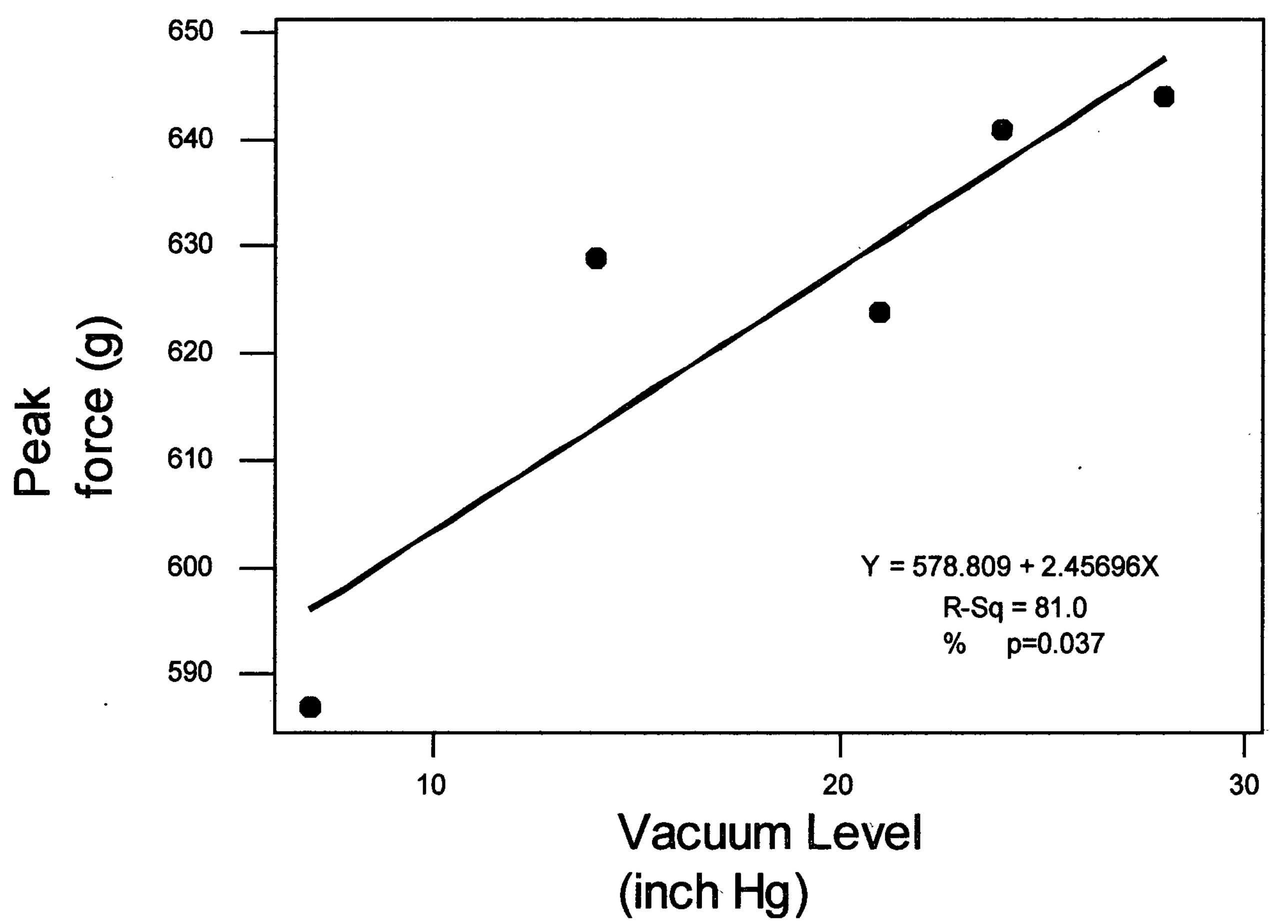

Figure 25. Effect of 5 levels of applied vacuum on peak force of the force vs deformation curve obtained by VMD apple chips on the instrumental test. All measurements were recorded as mean. n = 45 for all observations. Experiments were done in triplicate on 15 samples obtained from each trial.

Table 4. Pearson Correlation matrix and associated probabilities between density and instrumental measurement of VMD apple chips[1]

	Density	Slope	Peak force
Slope[2]	-0.986 0.002		
Peak force[2]	-0.957 0.010	0.987 0.002	
Distance[2]	0.924 0.025	-0.971 0.006	-0.993 0.001

[1]Cell Contents: Correlation
P-Value

[2] The slope, peak force and distance of the peak of the force/deformation curve was obtained from VMD apple chips

(i.e. VMD chips with highest crispness) were used for comparison to the air and freeze dried ones. Due to the puffing effect provided by vacuum microwave drying at 28inch Hg, the density of vacuum microwave dried (VMD) apple chips (0.19g/ml) was significantly lower than that of air dried (AD) apple chips (0.43g/ml) (Figure 26). Freeze dried (FD) apple chips had the lowest mean density (0.14g/ml) among the dried samples, but not significantly different from VMD. During air drying, as the total water content is reduced, the liquid interface passes through the surface and creates very high surface tension forces that caused progressive contraction of the samples, eventually resulting in the shrinkage of tissue structures (Stanley and Tung, 1976). However, during freeze drying, the frozen apple slices remain rigid and moisture is sublimed directly from a solid state to a vapor state. This rigidity to a large extent prevents the collapse of the solid matrix after drying (Liapis, 1987) and leaving numerous voids within the structure. FD apple chips, due to their porous structure, were spongy but not crispy. The smallest slope (367g/mm) (Figure 27) and the largest distance (4.16mm) (Figure 28) and peak force (922g) (Figure 29) among the dried samples were obtained by the FD chip samples in the instrumental test. Although no significant differences was observed in the peak force and the distance between the AD and VMD apple chips, the peak slope obtained by VMD apple chips (989g/mm) was significantly higher than that of AD apple chips (824g/mm). It appears that the " puffed" VMD apple chips were crispier than the AD apple chip; the later's structure became severely collapsed as a result of lengthy, intensive hot air drying. Apart from tissue shrinkage, the diffusion of solutes during air drying may also have a effect on the texture of apple chips. In the early stages of drying as moisture is removed from the surface of the sample, it is replaced by the migrating liquid water from the

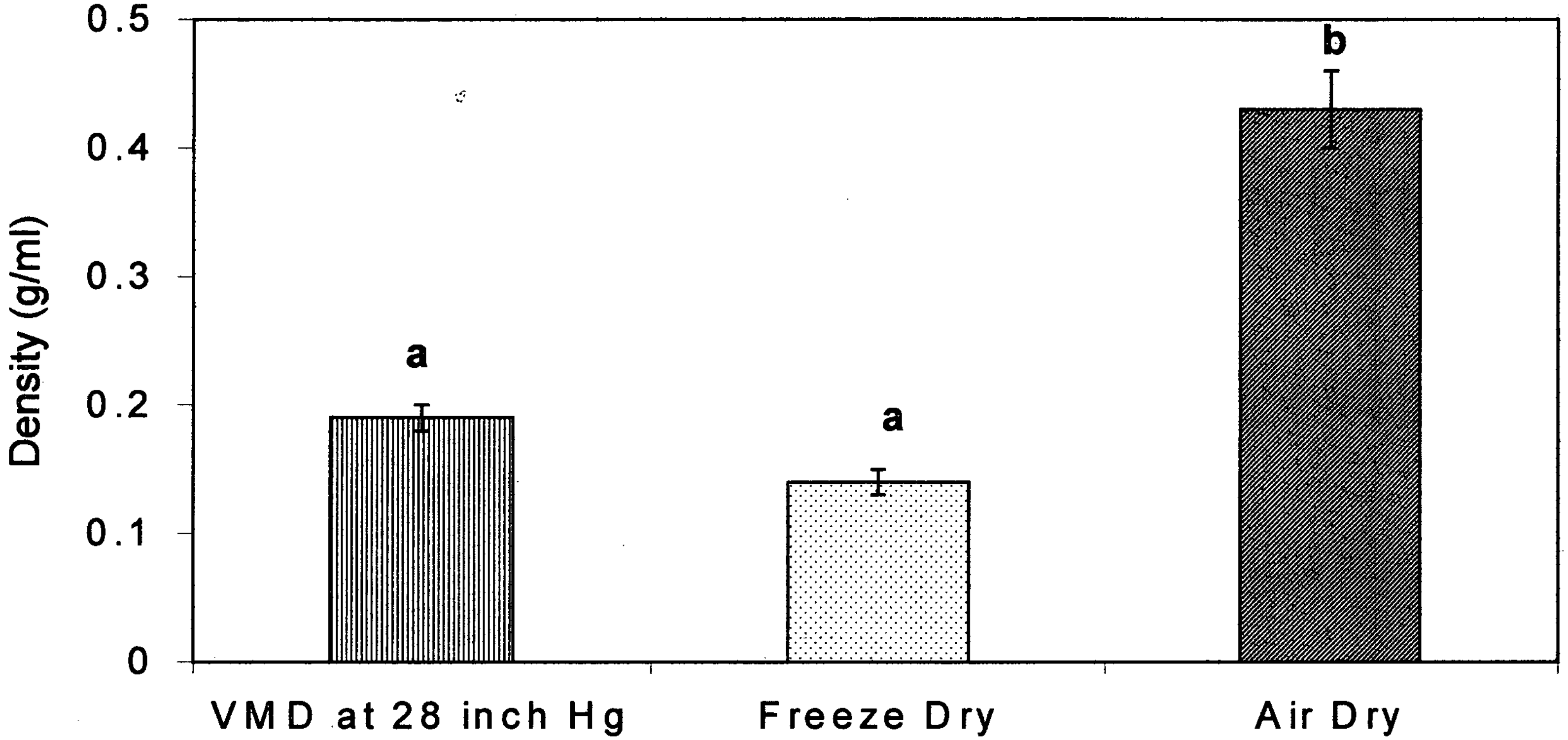

Figure 26. Density (g/ml) of apple chips from different drying techniques. The density of apple chips was measured by immersing 10g of samples in a 500 ml graduated cylinder pre-filled with 200 ml of flaxseed. All measurements were recorded as mean (standard error of mean). n= 3 for all observations. Experiments were done in triplicate and 10g of samples were obtained from each trial and used for density measurement. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$.

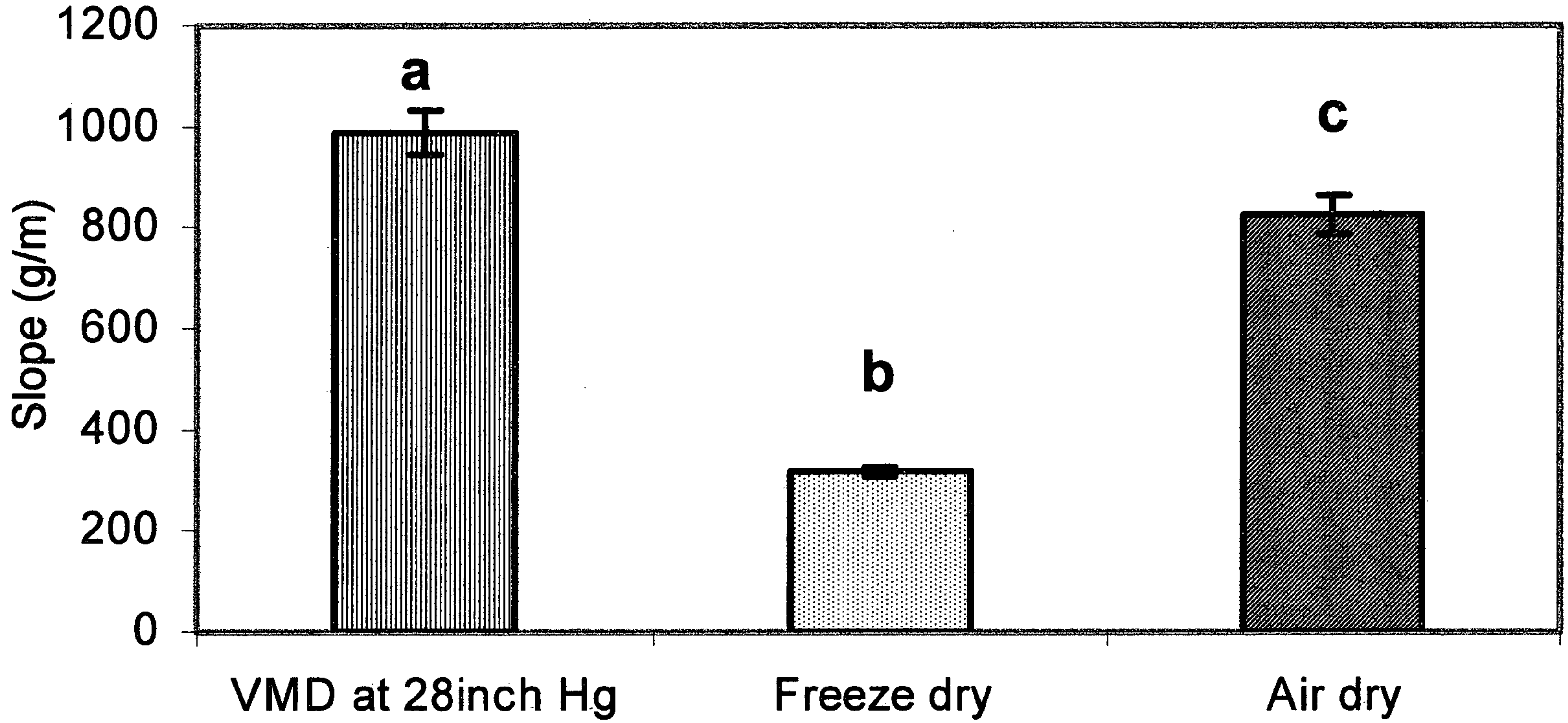

Figure 27. Slope (g/mm) of apple chips from different drying techniques. The slope of the peak of the force vs deformation curve was obtained from apple chips produced by different drying techniques. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$.

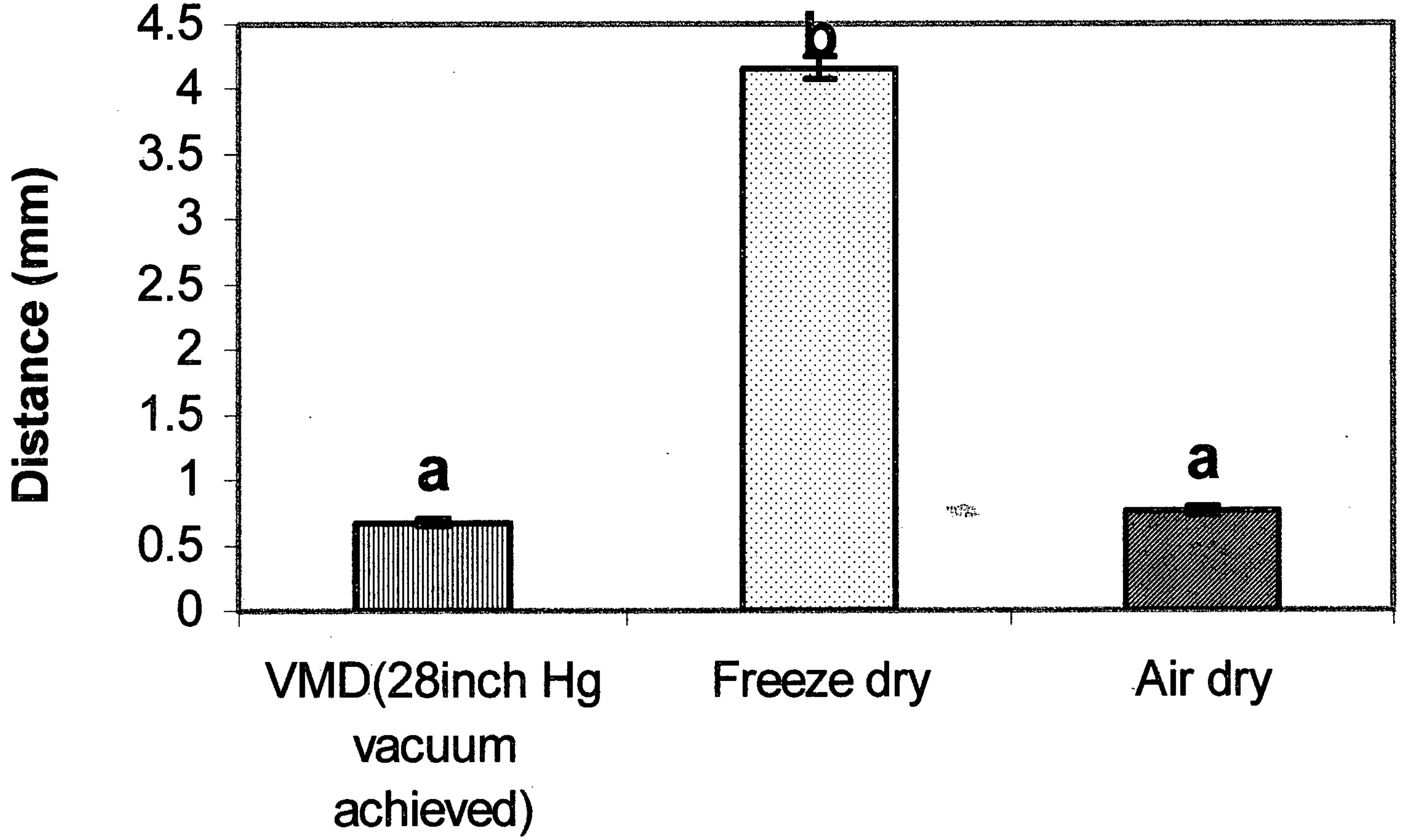

Figure 28. Distance (mm) of apple chips from different drying techniques. The distance to the peak of the force vs deformation curve was obtained from apple chips produced by different drying techniques. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$.

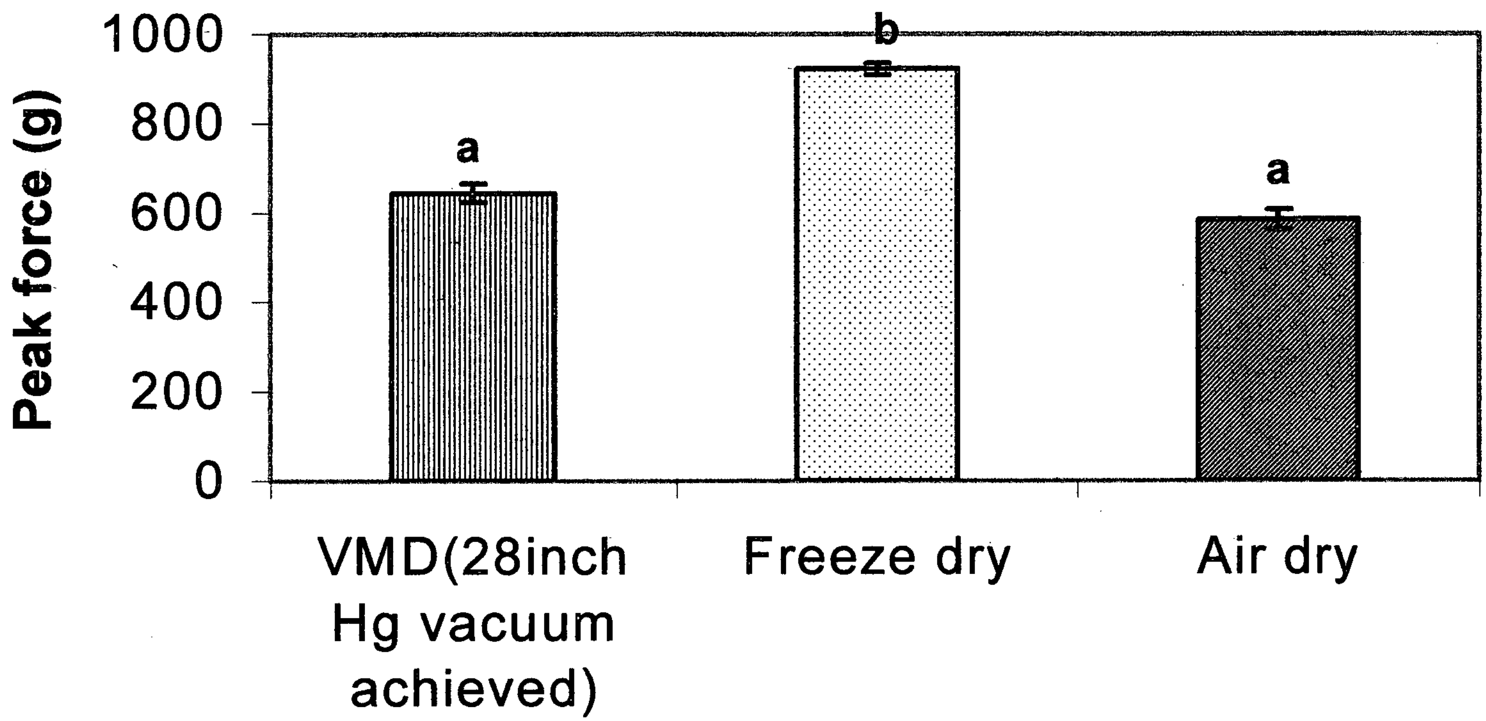

Figure 29. Peak force (g) of apple chips from different drying techniques. The peak force of the force vs deformation curve was obtained from apple chips produced by different drying techniques. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Treatment differences were determined by Tukey's multiple comparison test. Any 2 values not followed by the same letter were significantly different at $P \leq 0.05$.

interior of the sample. A layer of soluble solids is then left and builds up on or near the external surface of the product. This would then increase the resistance to further escape of water from the product's interior and eventually causes the formation of a tough and leathery skin described as 'case hardening' (Hanson, 1976).

Effects of different drying methods and vacuum levels on apple chip structure were also observed under the scanning electron microscope. After air drying, apple chips exhibited severe tissue shrinkage, and severely collapse with almost no open structures (Figure 30). The structure of the VMD apple chips at 7mmHg vacuum level was similar to that of the air dried ones, except that a small amount of open structure could still be observed (Figure 31), The less severe shrinkage in the VMD (7mmHg) apple tissue compared to that of the AD sample may be due to the shorter drying time and lower drying temperature, not exceeding 60^0C, obtained by microwave heating. However, in the absence of vacuum, an open structure was not observed. In contrast, with the application of full vacuum, the VMD (28mmHg) apple chip tissue was less affected by the drying process as judged from the extent of shrinkage (Figure 19); a honeycomb network structure which formed by closely connected, and puffy looking cells were again observed. A similar honeycomb network was observed in the freeze-dried sample with the least amount of tissue shrinkage or cell collapse among all the tested samples (Figure 32). However, the cell walls of freeze dried samples looked comparatively smoother and thinner than those of the VMD samples; the cell wall did not look rough, explaining the non-crispy and spongy texture obtained by the freeze-dried apple chips.

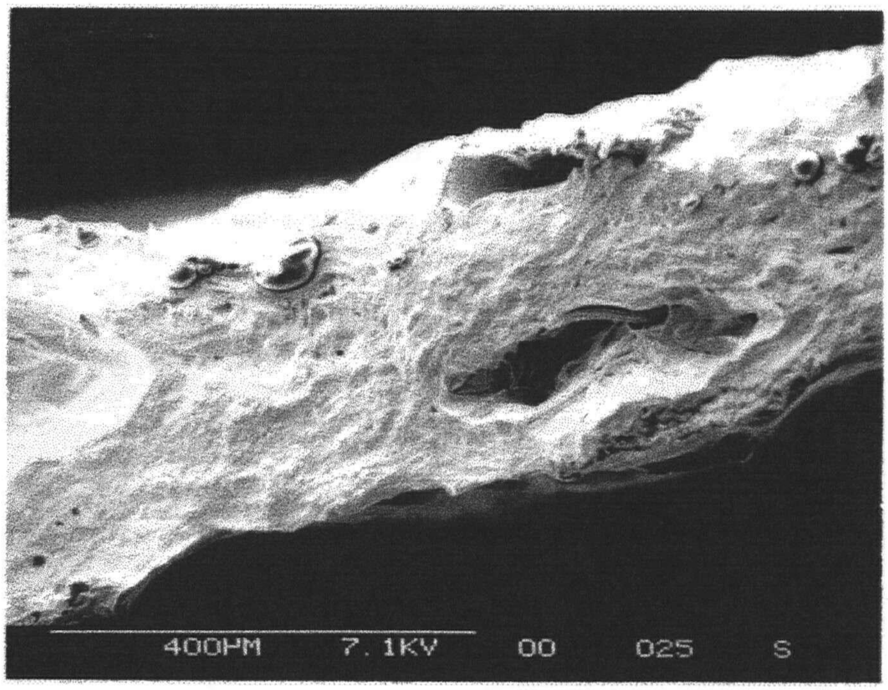

Figure 30. Scanning electron micrograph (200x) of Air Dried Golden Delicious Apple Chips.

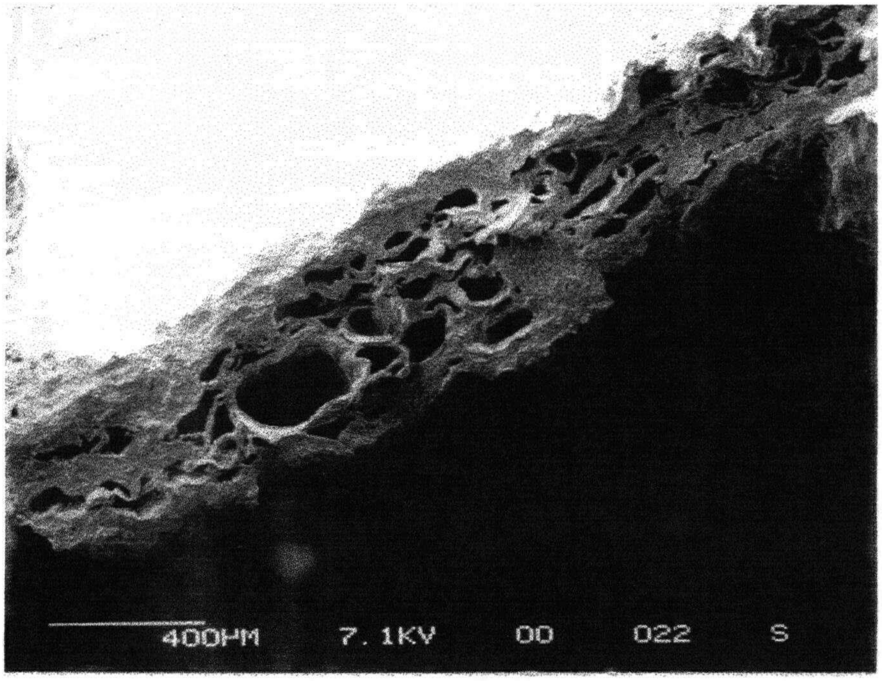

Figure 31. Scanning electron micrograph (200x) of VMD (7mmHg) Golden Delicious Apple Chips.

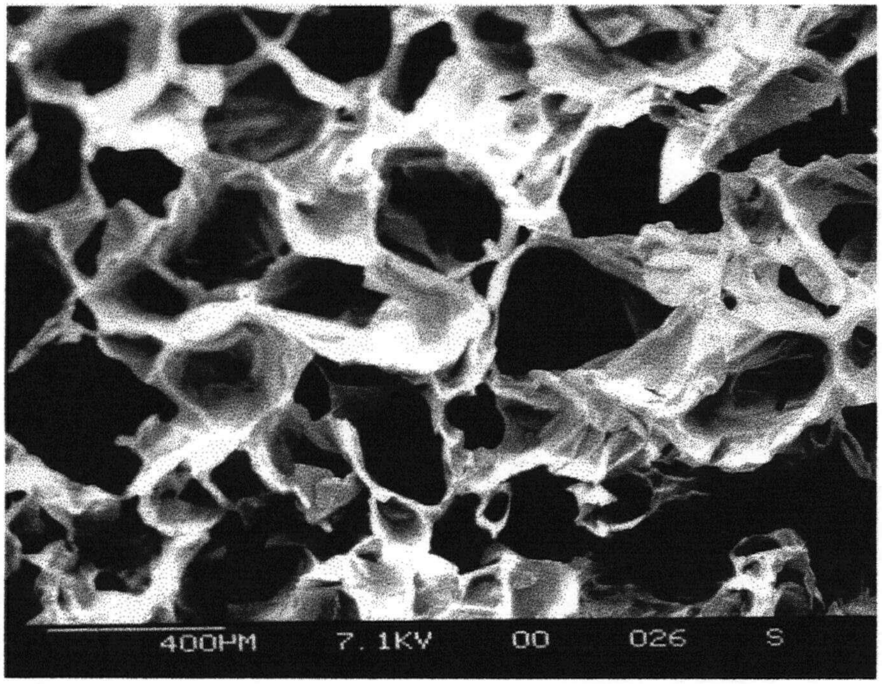

Figure 32. Scanning electron micrograph (200x) of Freeze Dried Golden Delicious Apple Chips.

4.2.1 Moisture Sorption Isotherms (MSIs) of Apple Chips Dehydrated with Different Drying Techniques

The isothermal equilibrium relationship between moisture content and water activity of food represented by the moisture sorption isotherm (MSI) is of great importance for the design and optimization of unit operations such as drying, storing, packaging, and mixing. The MSI of a food provides us with information on the microbial or physicochemical stability of foods and is important for the prediction of storage life and the optimal storage conditions for dehydrated foods (Iglesias and Chirife, 1982). In drying operations, it is the desorption of water and the effect of drying on the products that concern us. The desorption isotherms at 25^0C of apple chips (Golden Delicious) that were air dried (AD), air dried in combination with VMD dried (AD-VMD) and those that were freeze dried (FD) are shown in Figure 33, 34 and 35, respectively. All three desorption isotherms were similar in shape to those reported in the published literature (Iglesias and Chirife, 1982). These desorption isotherms of apple chips (AD, AD+VMD, and FD) were sigmoid-shaped isotherms typical of many foods and had the characteristic shape of the isotherm of the high-sugar fruit materials (i.e. hygroscopic materials) (Tsami et al., 1990). At low or moderate water activity, water is typically absorbed only to the surface -OH sites of crystalline sugar and thus, low equilibrium moisture content was obtained, while at higher a_w (above 0.65), dissolution of sugar occurs and crystalline sugar is converted into amorphous sugar (Saltmarhc and Labuza, 1980). This would then increase the number of adsorption sites upon breakage of crystalline structure of sugar and resulted in a sharp increase in moisture content. Further, the pectin content was probably another factor affecting the water binding capacity of apple. At higher a_w

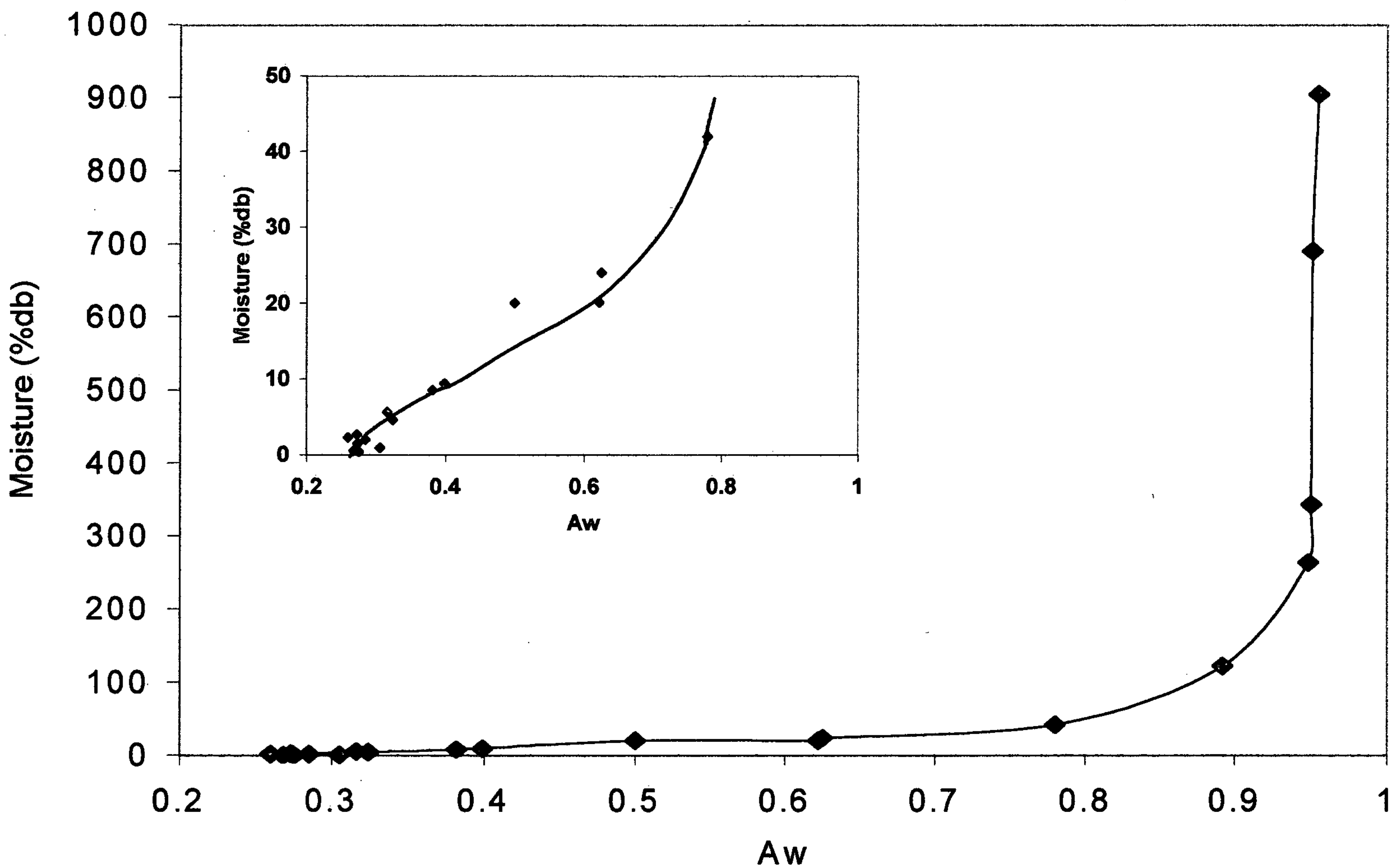

Figure 33. Moisture sorption isotherm (desorption curve) of air dried (AD) apple chips at 25^{0}C.

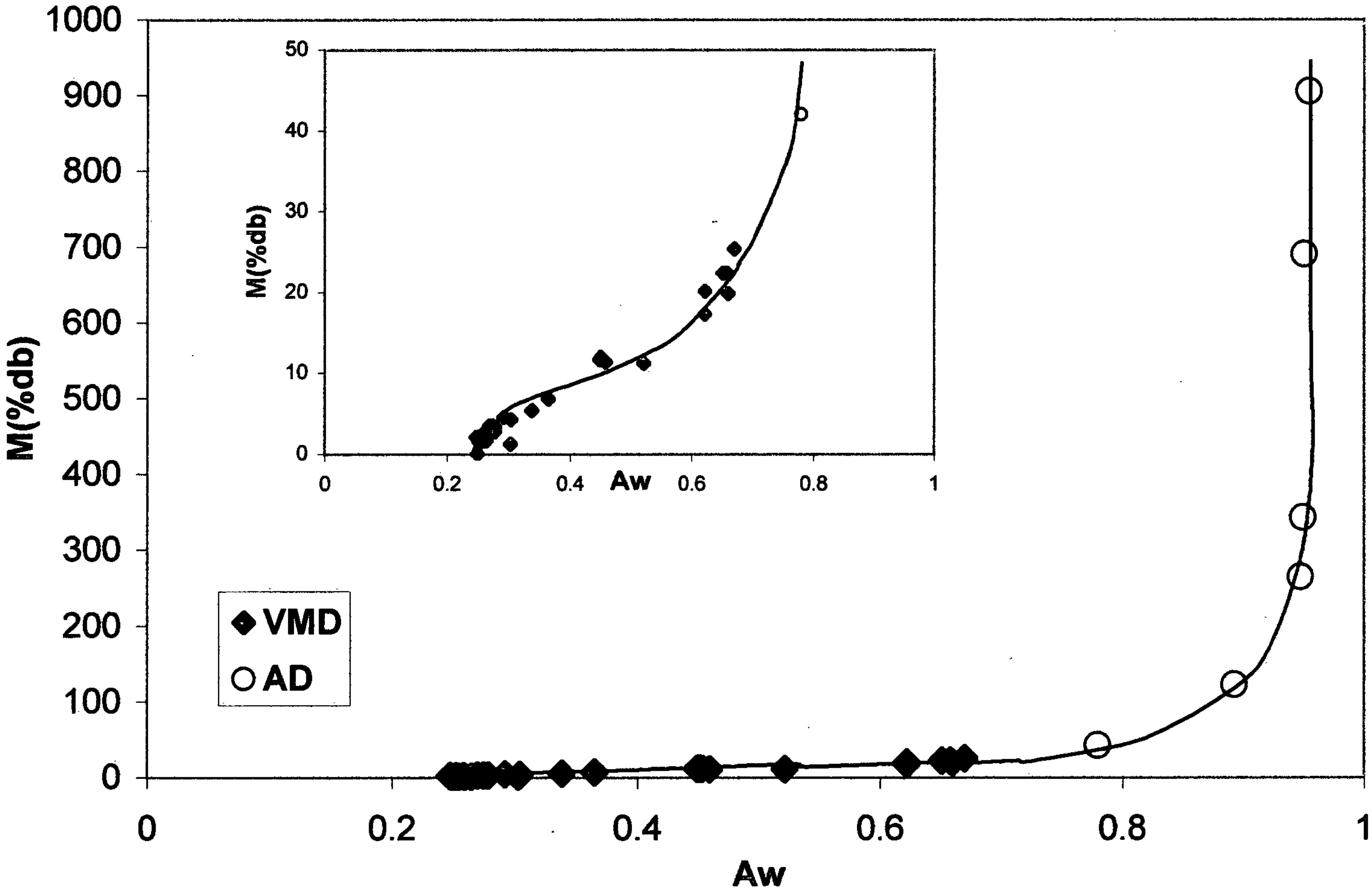

Figure 34. Moisture sorption isotherm (desorption curve) of air dry in combination with VMD apple chips at 25^{0}C.

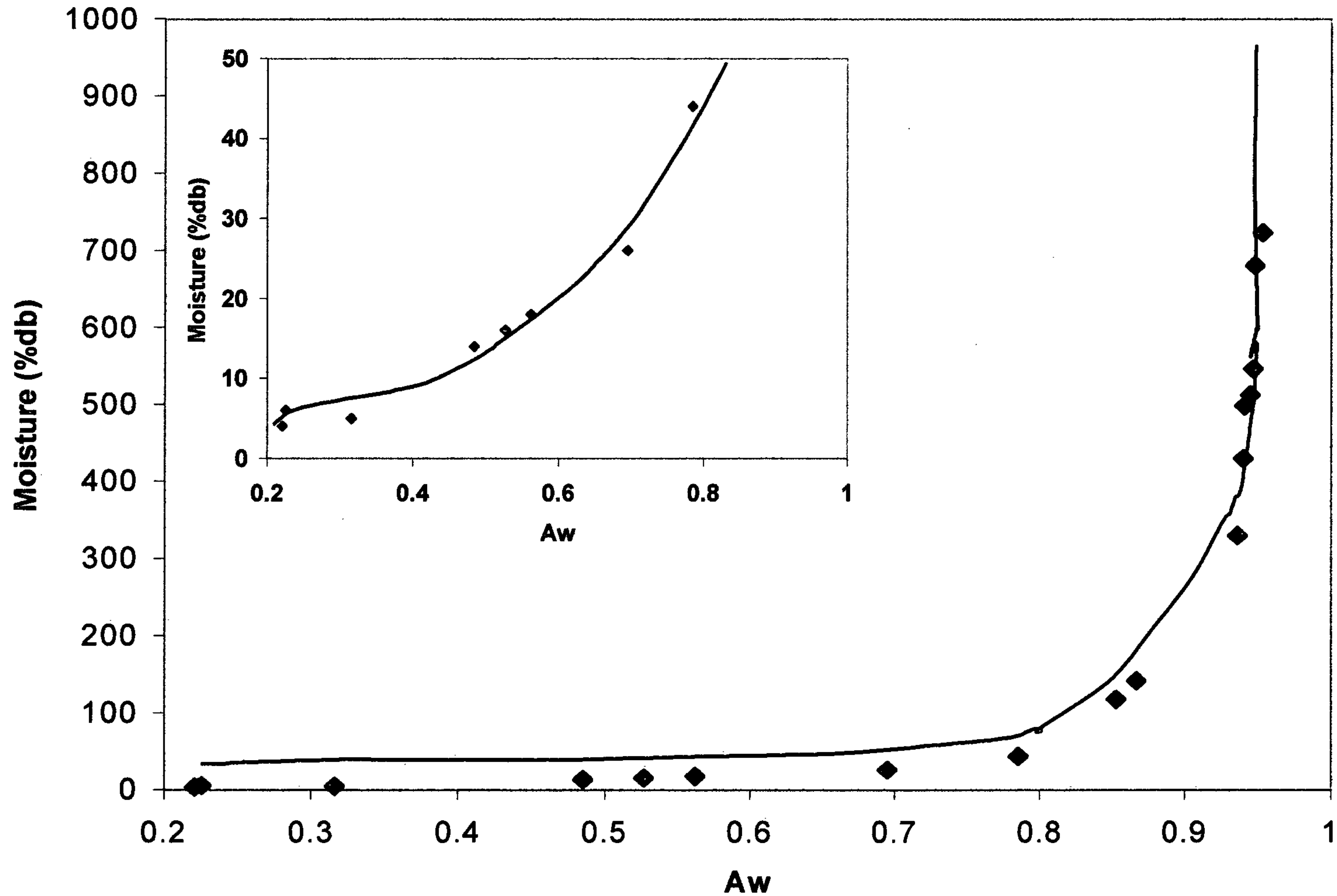

Figure 35. Moisture sorption isotherm (desorption curve) of freeze dried (FD) apple chips at 25^0C.

(above 0.65), the pectin content will swell as water is taken up and thereby, result in higher water binding capacity. It has been stated that the fiber source will act like a bundle of glass capillaries which during hydration will wet and swell taking up more water (Chen et al., 1984). Comparison of the desorption curves of the AD, AD-VMD and FD apple chips can be made by overlapping the three curves. As illustrated in Figure 36, FD apple chips had a much higher water binding capacity at higher a_w (above 0.8) than the AD and the AD-VMD products. It seems that the porous network in the structure of the FD apple chip sample, with the least amount of tissue shrinkage or cell collapse among the three, allowed the FD sample to adsorb more water. At lower a_w (below 0.4), all three isotherms tended to coincide.

The experimental desorption data were fitted into the GAB model and the estimated empirical constants of the model were presented in Table 5. While similar monolayer moisture contents (MM) were obtained by the AD (4.542%db) and the AD-VMD (4.554%db) apple chips, the FD samples gave a much higher value of the GAB monolayer moisture content (15.874%db). As has been mentioned above, the higher MM value of FD apple chips may be caused by the highly porous structure of the samples such that more surface area is available to bind water than in the AD and AD-VMD materials. The calculated values of the monolayer moisture content (MM) for apple chips were in agreement with those of dehydrated apple slices reported in the literature (Lazarides et al., 1995; Lomauro et al., 1985; Roman et al., 1982) which has a monolayer moisture content around 4-7 %db. Also, both C and K are related to the temperature effect. C is the Guggenheim constant related to heat of sorption of first layer of moisture. In fact, the GAB equation is an extension of the two parameter BET model which takes

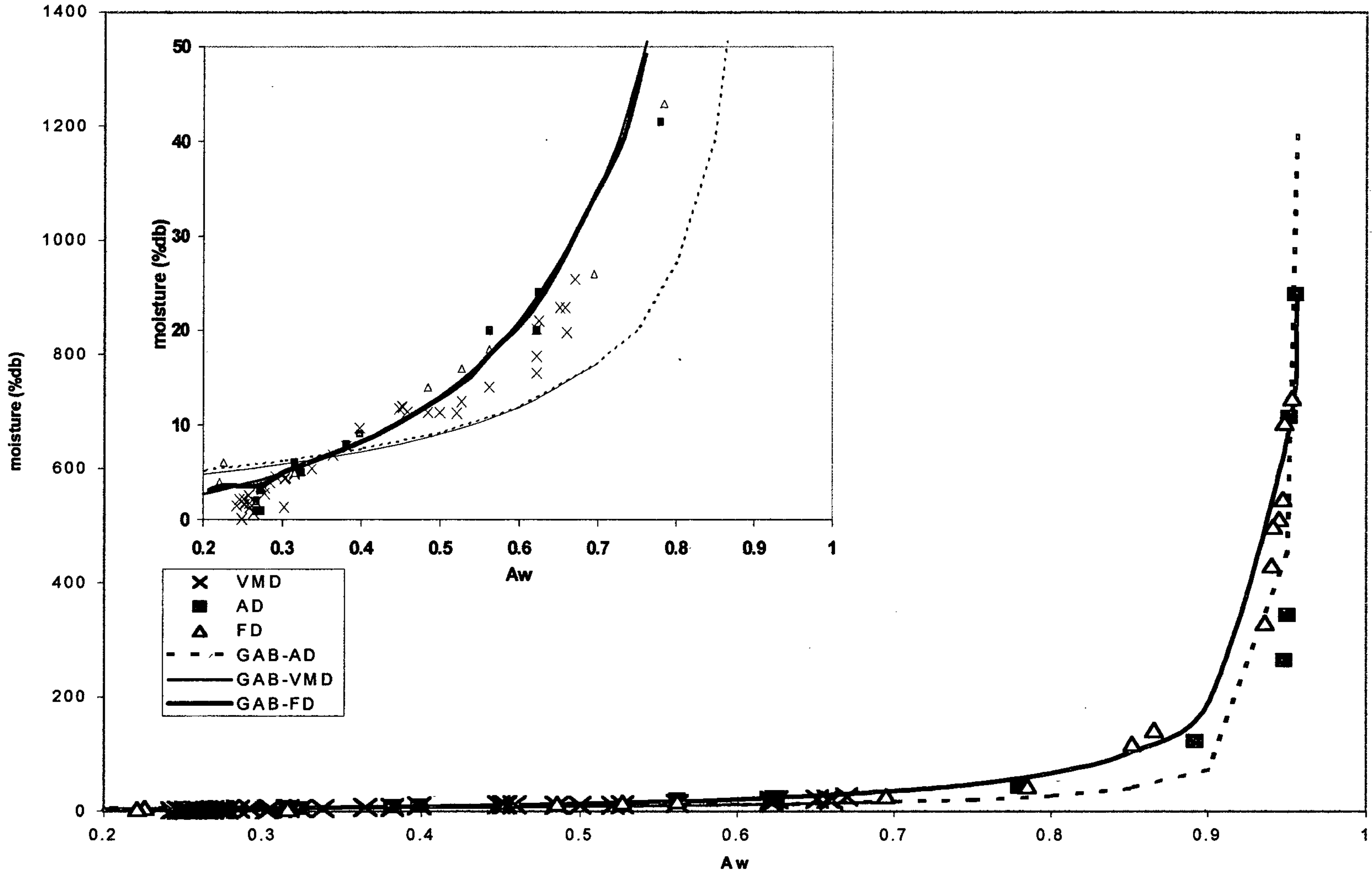

Figure 36. Moisture Sorption Isotherms (desorption curve) of Air Dried (AD), VMD and Freeze Dried (FD) Apples at 25^{0}C.

Table 5. GAB constants and regression parameters for desorption isotherms of Air dried (AD), Air dried-VMD (AD-VMD), and Freeze Dried (FD) apple chips.

Parameter[1]	AD	AD-VMD	FD
MM (%db.)	4.542	4.554	15.874
C	35.651	18.076	0.627
K	1.042	1.042	1.028
r^2	0.963	0.952	0.986

[1] MM is the monolayer moisture content of the sample, C is the Guggenheim constant related to heat of sorption of the first layer of water, k is a factor related to the total heat of sorption of multilayers of water, and r^2 is the regression coefficient.

into account the modified properties of the sorbate in the multilayer region and bulk liquid properties through the introduction of a third parameter K which is a factor related to the total heat of sorption of multilayer. When K=1, the GAB equation reduces to the BET equation (Rahman, 1995). As illustrated in Table 5, the K values obtained for apple chips were all close to 1. For apples, K values around 0.9-1.2 have been reported in literature (Lomauro et al., 1985). Further, as illustrated in Table 5, the values of r^2 obtained by all three drying methods were quite high and this indicates that the fit of the experimental desorption data to the GAB equation was quite satisfactory. For the AD sample, its severely collapsed structure might result in a decrease in available surface area, with a relatively higher salt concentration compared to that of the AD-VMD and the FD samples. Although its monolayer moisture content was the lowest among the three treatments, this monolayer water, may be interacting predominantly with the ionic salts. This may explain why the monolayer water was more tightly bound in the AD samples than in the AD-VMD and the FD samples, as evidenced by a much higher C value for the AD chips (35.651) than that of the AD-VMD (18.076) and the FD chips (0.627).

4.2.2 Drying Curves

According to the drying curves shown in Figure 37, VMD was a much faster drying process than either air or freeze drying. The apple slices having an initial moisture content of 1000% on a dry basis (db.) were first partially air dried and then VMD to a final moisture content of around 10% db. within 1 hour. By comparison, similar samples required around 3 hours and more than 10 hours to reach the same final moisture content during air drying and freeze drying, respectively.

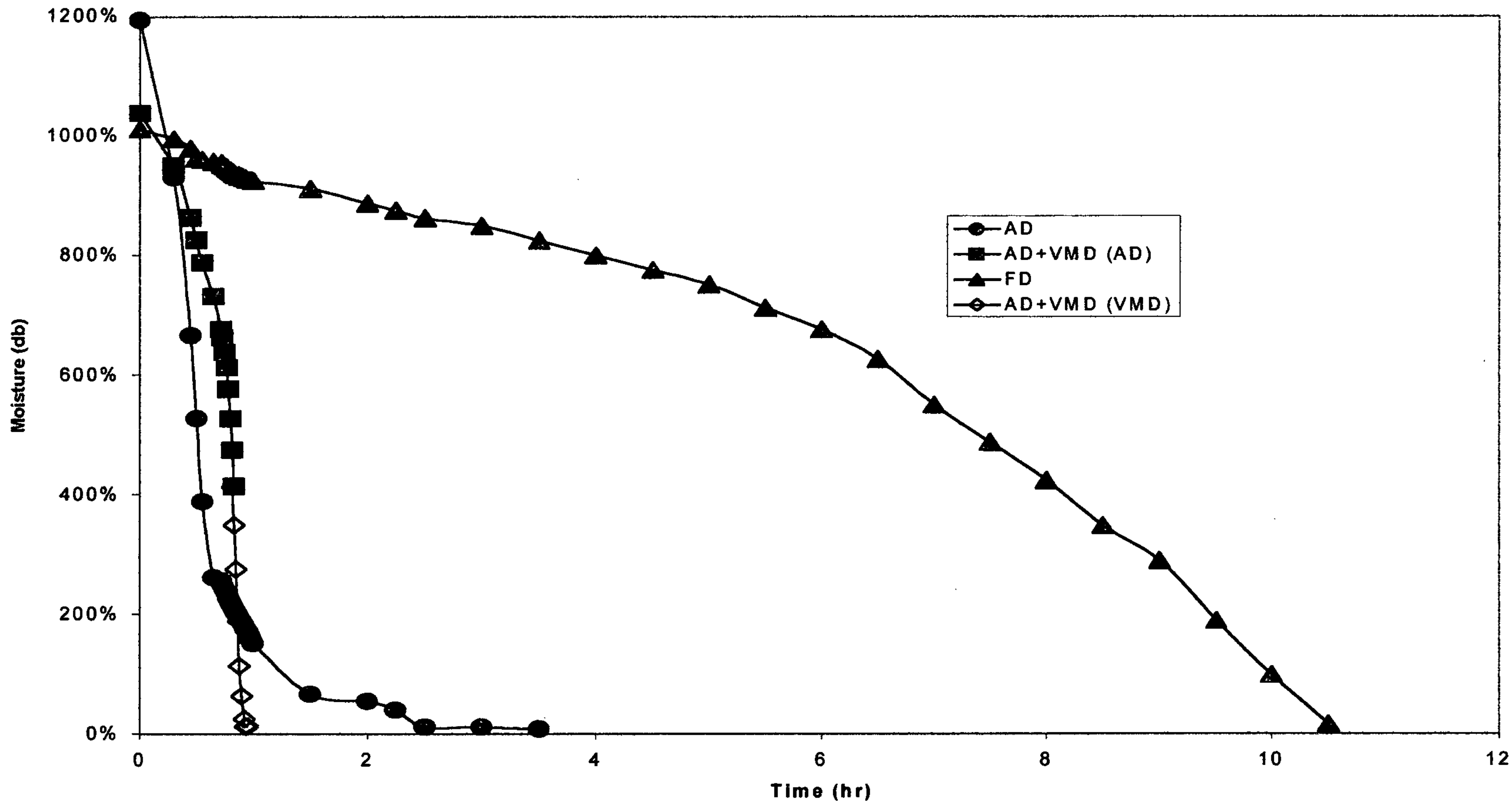

Figure 37. Drying Curve of Air Dried (AD), Air Dried+Vacuum Microwave Dried (AD+VMD) & Freeze Dried (FD) Apple Chips.

During vacuum microwave drying, the microwave energy was directly absorbed by the water molecules within the apple slices, thus accelerating the evaporation of the water molecules and causing a large vapor pressure within the fruit pieces (Lin et. al., 1998; Drouzas et al., 1999). The low chamber pressure provided by the vacuum together with this high vapor pressure produced by the microwave heating created a porous and puffed structure, and thus facilitated the transport of the water molecules. In addition, the vacuum within the chamber maintained the porous structure of the apple slices, and thus sharply reduced the required drying time.

As illustrated in Figure 37, the drying curve of the conventional air-dried apples slices shows two main periods: the constant rate period and the falling rate period. During the constant rate period, the water molecules migrated from the interior of the apple slices by capillary action and thus evaporated freely from the surface of the fruit pieces while still maintaining a uniform wetted surface. During the falling rate period, the moisture is no longer drawn to the surface fast enough to maintain a completely wetted surface and is depleted in the sub-surface water reservoirs (Ozilgen et al., 1995; Uretir et al., 1996). This would result in shrinkage and collapse of the apple slices which then leads to reduction in matrix porosity and thus, result in low transport rate of water and prolonged drying time (Drouzas et al., 1999). In this study, the VMD process was applied before the onset of the falling rate period, which is the least efficient portion of the conventional air drying system, and therefore drying time could be considerably reduced. This was in agreement with what had been found by Kiranoudis and his group (Kiranoudis et al., 1997). In the case of freeze drying, frozen apple slices were dried by sublimation of ice. The rate of freeze drying is limited by the difficulty of transferring heat to the ice phase in the product and of transporting water vapor from the ice core in the center through the dried exterior portion of the sample, and finally, towards the condenser. During freeze drying, when heat is applied by conduction to the frozen product in a vacuum chamber, the surface layer of the product dries rapidly and leaves an increasingly thick layer of insulating dry material surrounding the decreasing ice core. This insulating material then increasingly interferes with the complete removal of the moisture from the ice core within the product (Gutterson, 1971). Therefore, freeze drying is the most time consuming drying process among the three.

4.3 The Effect of Apple Varieties on Texture of VMD Apple Chips

It was stated in previous studies (Lee et al., 1967) that size of cells, intercellular spaces, and physiological conditions of cell turgor in the fresh tissues can affect texture in processed tissue. Apples of different varieties are different in textural characteristics and processing qualities as a result of different structural features (Summers, 1994). Both sensory and instrumental tests were carried out for the textural analysis of VMD apple chips of Golden Delicious, Red delicious and Fuji apple varieties. Calcium treatments (0 & 1% $CaCl_2$) were applied to each variety of apples in order to investigate the effects of calcium on the texture of apple chips of different varieties. The 1% $CaCl_2$ treatment was chosen because it had been demonstrated in section 4.1 that this level of $CaCl_2$ would give a significant increase in crispness without a significant increase in bitterness of the apple chips.

For the sensory analysis, ANOVA of raw sensory scores indicated that panelist effects were significant for all four sensory attributes (crispness, apple flavor, sweetness, and off flavor) tested, the Ca pretreatment by panelist interaction was significant for three attributes (crispness, sweetness and off flavor), the variety by panelist interaction was significant for sweetness and the replicate by panelist interaction was significant for crispness (Table 6). Therefore, standardization of sensory scores was again performed as in section 4.1 for all sensory attributes tested. Although for all four sensory attributes, results for main effects of varieties, Ca pretreatments and replicates from both the ANOVA and the Tukey's multiple comparison tests of standardized scores (i.e. z scores) (Figure 38, 39, 40 & 41) remained the same as that carried out using raw sensory scores (Figure 42, 43, 44 & 45), ANOVA of z scores resulted in a slight increase in the power of

Table 6. Analysis of variance of raw sensory scores of VMD apple chips of different apple varieties and Ca pretreatment .

		Crispness	Apple Flavor	Sweetness	Off flavor
Variety	**F-ratio**	8.26	15.59	14.75	7.14
	P-value	0.001	0.000	0.000	0.002
Ca pretreatment	**F-ratio**	43.75	29.43	56.02	20.90
	P-value	0.000	0.000	0.000	0.000
Panelist	**F-ratio**	7.67	15.87	16.67	4.75
	P-value	0.000	0.000	0.000	0.002
Replicate	**F-ratio**	0.05	1.27	0.93	0.33
	P-value	0.948	0.287	0.400	0.723
Replicate x Panelist	**F-ratio**	2.20	1.12	0.59	0.21
	P-value	0.040	0.361	0.785	0.987
Variety x Panelist	**F-ratio**	0.53	1.54	3.06	0.79
	P-value	0.833	0.163	0.006	0.613
Ca pretreatment x Panelist	**F-ratio**	3.31	1.56	3.60	3.73
	P-value	0.016	0.197	0.011	0.009

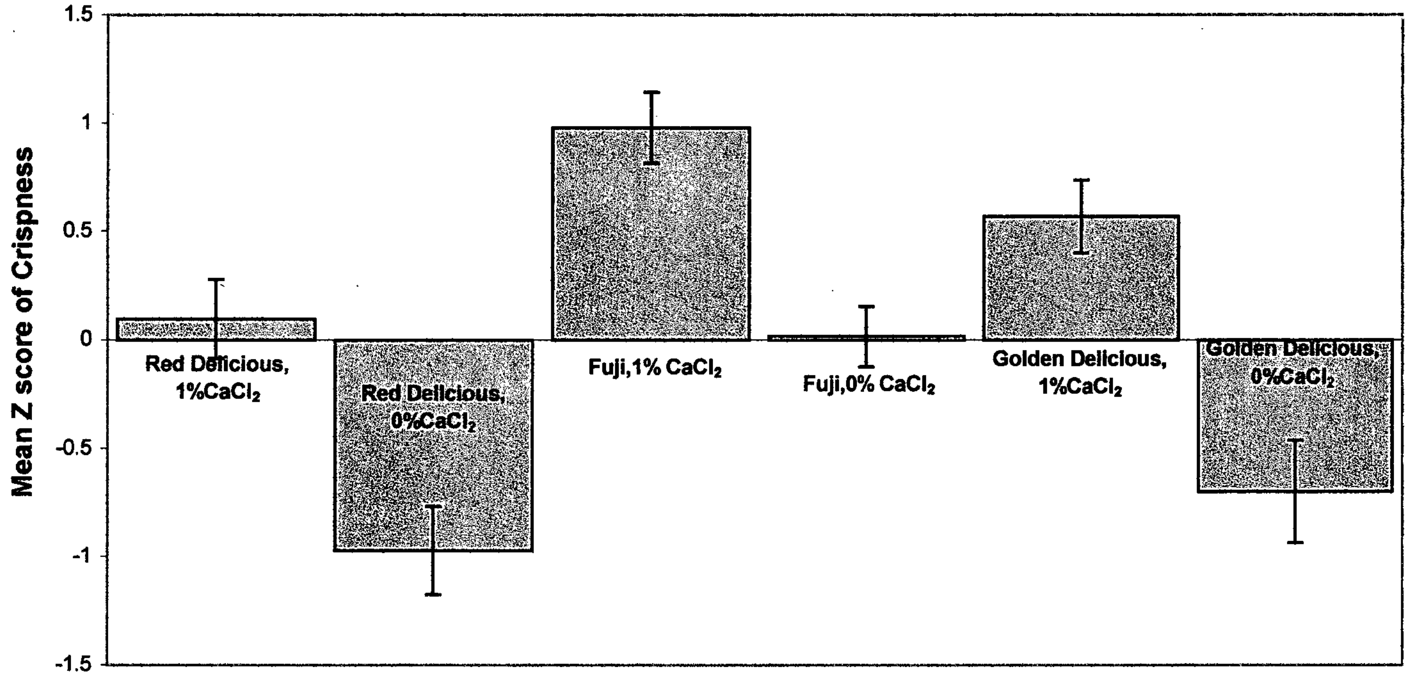

Figure 38. Mean Crispness z scores of different varieties and $CaCl_2$ treatment of VMD apple chips. z score = (score - mean)/ std. dev. n= 15 for crispness. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in crispness. Fuji apples was significantly crispier ($p<0.05$) than the other two apple varieties.

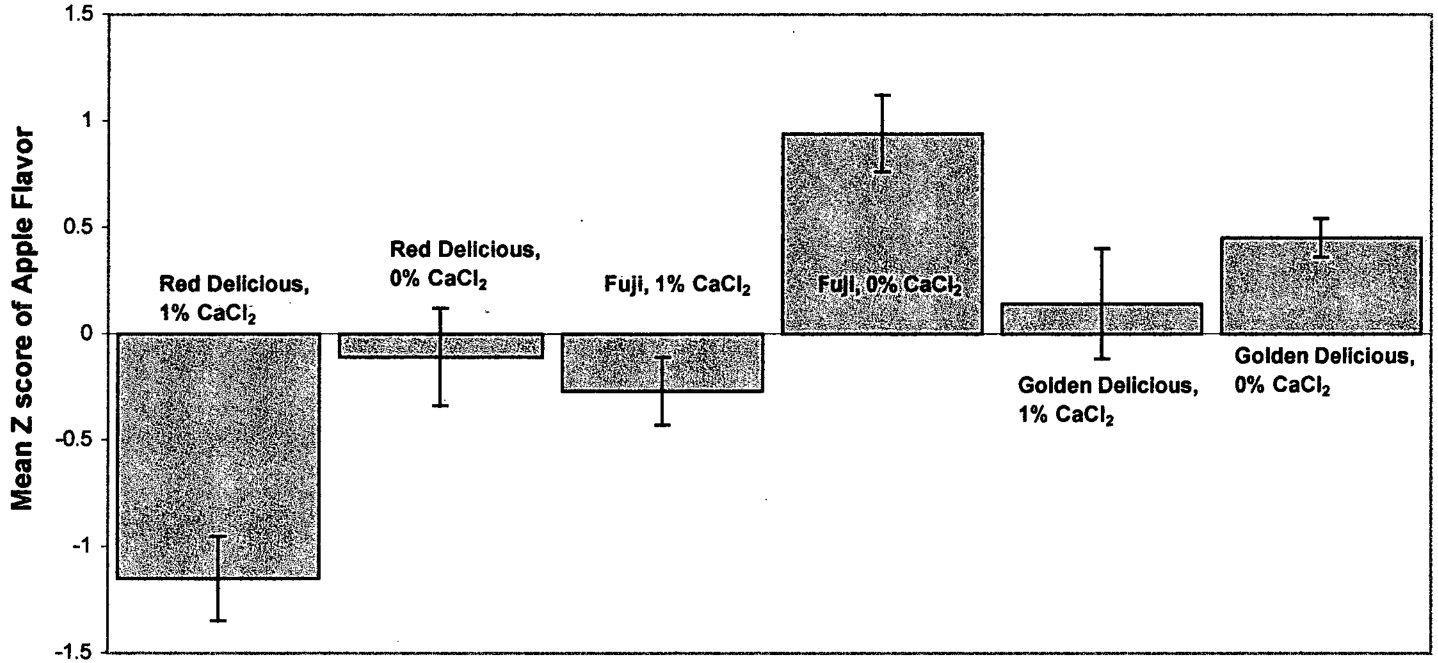

Figure39. Mean Apple Flavor z scores of different varieties and $CaCl_2$ treatment of VMD apple chips. z score = (score - mean)/ std. dev. n= 15 apple flavor. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) decrease in apple flavor. Fuji and Golden Delicious apples had significantly higher apple flavor ($p<0.05$) than Red Delicious apples.

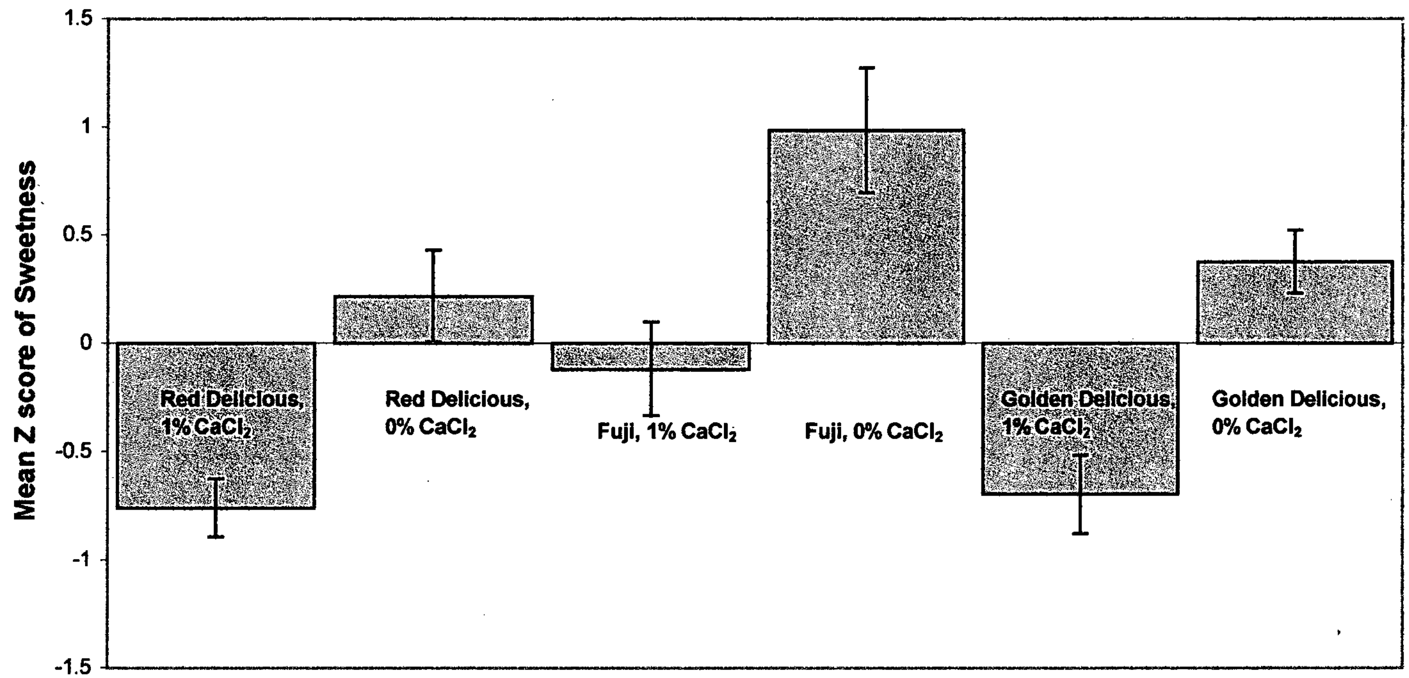

Figure 40. Mean Sweetness z scores of different varieties and $CaCl_2$ treatment of VMD apple chips. z score =(score - mean)/std.dev. n = 15 for sweetness. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) decrease in sweetness. Fuji apples was significantly sweeter ($p<0.05$) than the other two apple varieties.

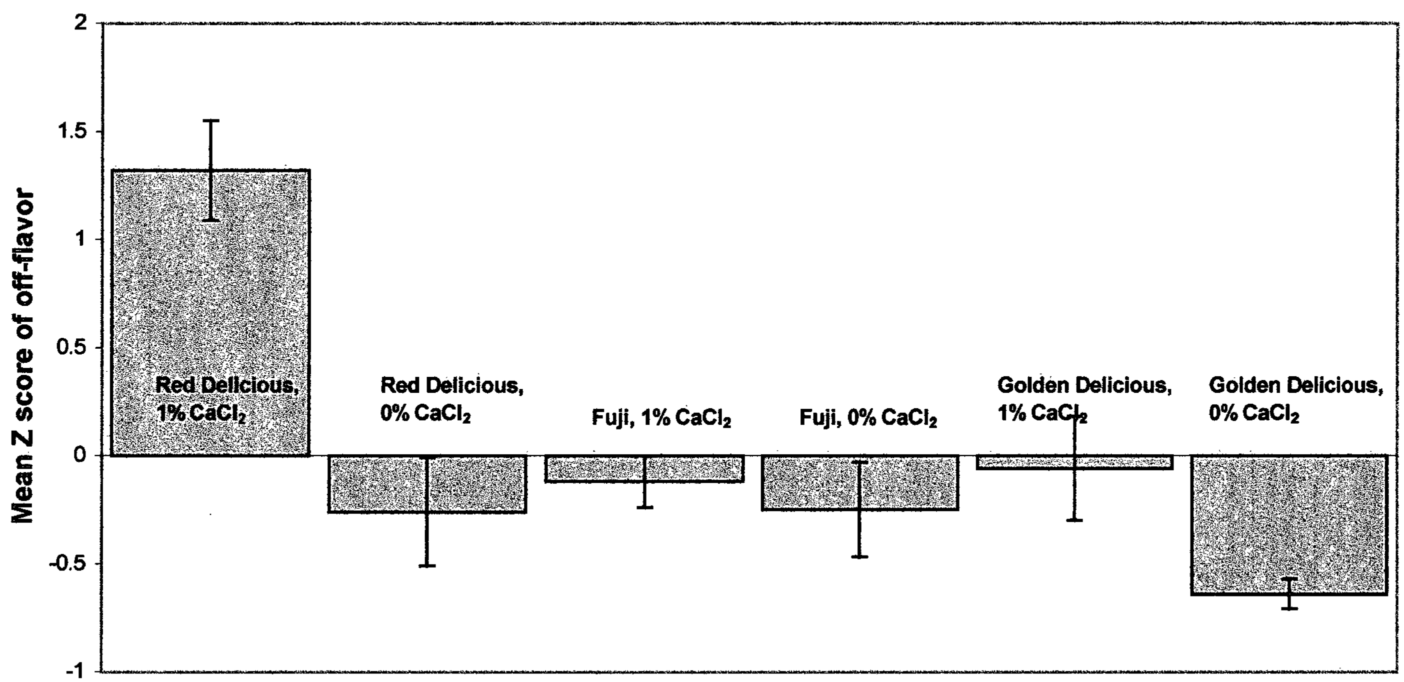

Figure 41. Mean Off Flavor z scores of different varieties and $CaCl_2$ treatment of VMD apple chips. z score =(score - mean)/std.dev. n = 15 for off-flavor. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in off-flavor. Red Delicious apple had a significantly higher off flavor ($p<0.05$) than the other two apple varieties.

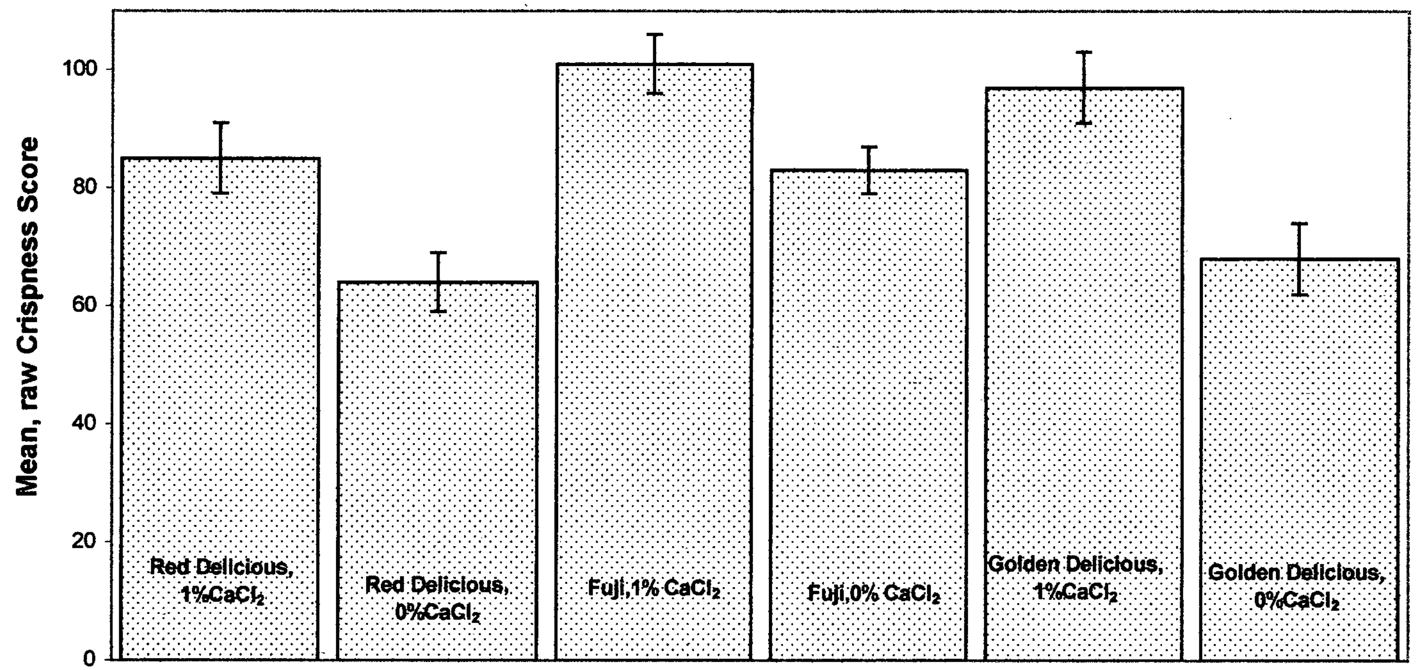

Figure 42. Mean, raw sensory crispness scores of different varieties and $CaCl_2$ treatment of VMD apple chips. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. n= 15 for crispness. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in crispness. Fuji apples was significantly crispier ($p<0.05$) than the other two apple varieties.

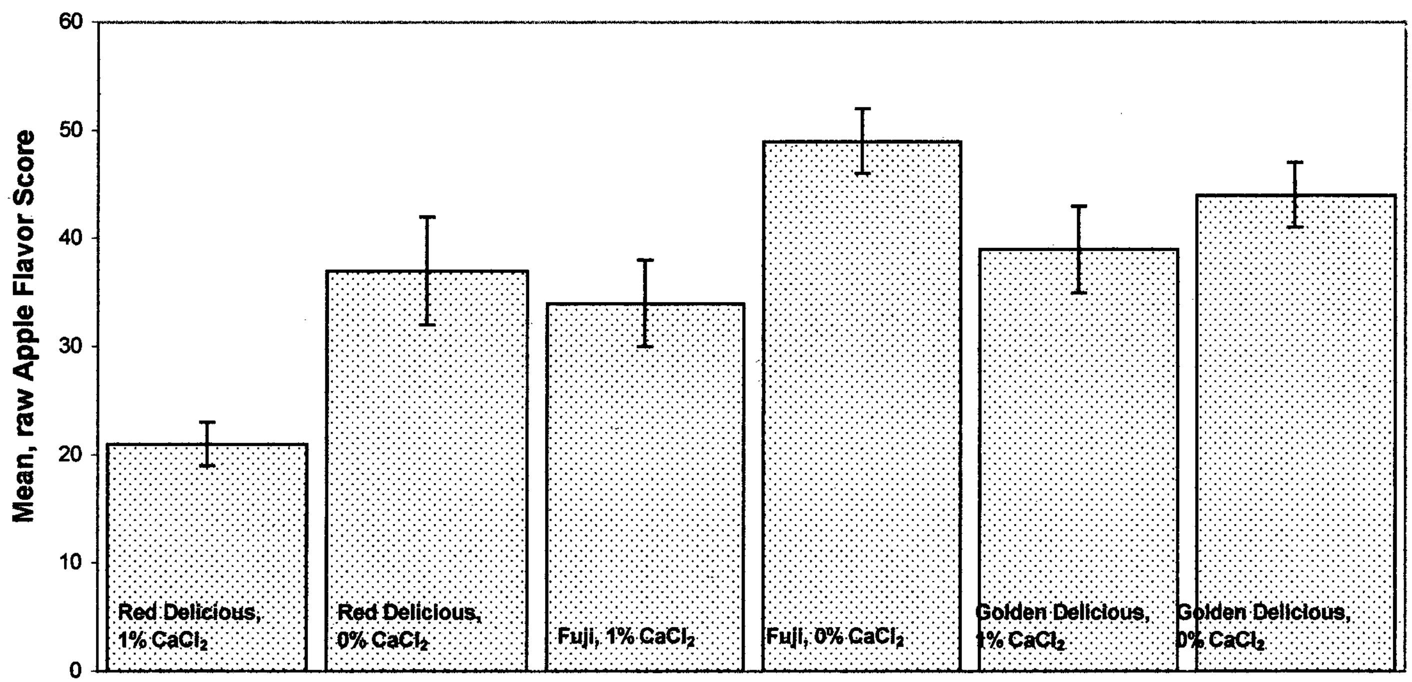

Figure 43. Mean, raw sensory apple flavor scores of different varieties and $CaCl_2$ treatment of VMD apple chips. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. n= 15 for apple flavor. For all varieties, calcium pretreatment caused a significant ($p<0.05$) decrease in apple flavor. Fuji and Golden Delicious apples had significantly higher apple flavor ($p<0.05$) than Red Delicious apples.

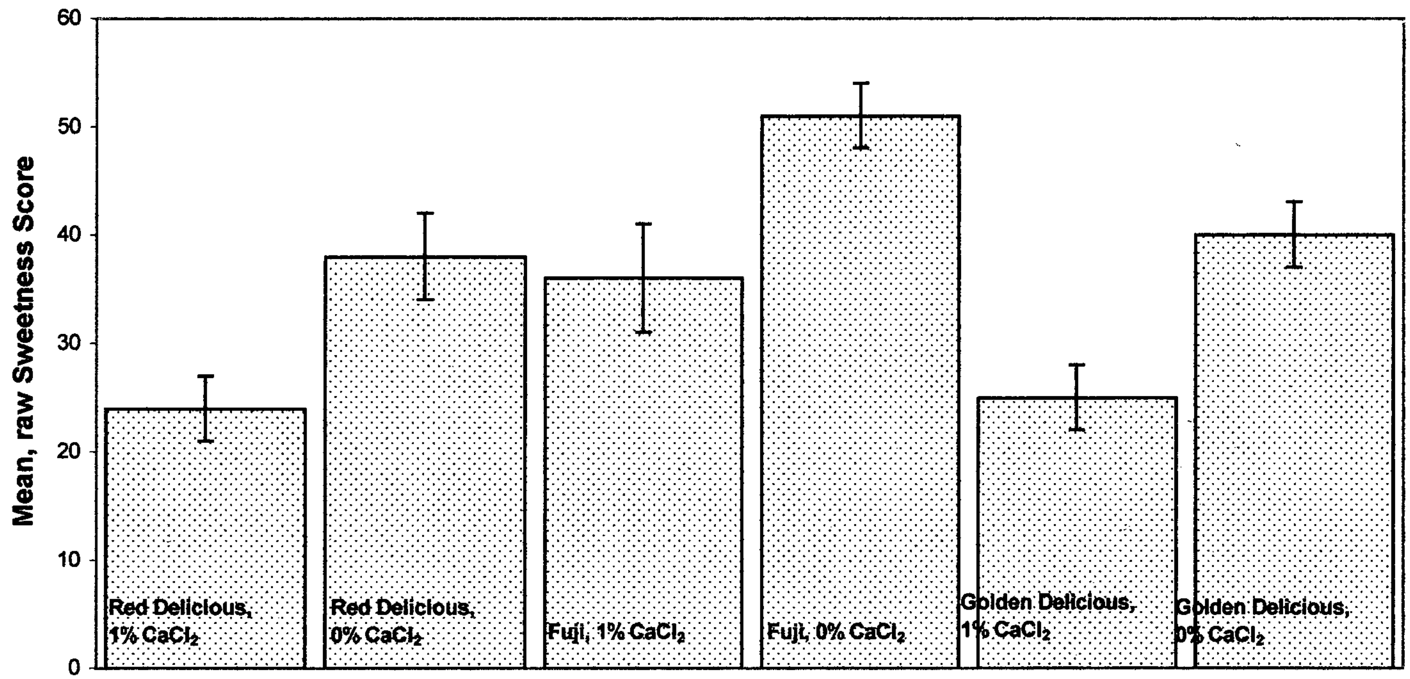

Figure 44. Mean, raw sensory sweetness scores of different varieties and $CaCl_2$ treatment of VMD apple chips. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. n = 15 for sweetness. For all varieties, calcium pretreatment caused a significant ($p<0.05$) decrease in sweetness. Fuji apples was significantly sweeter ($p<0.05$) than the other two apple varieties.

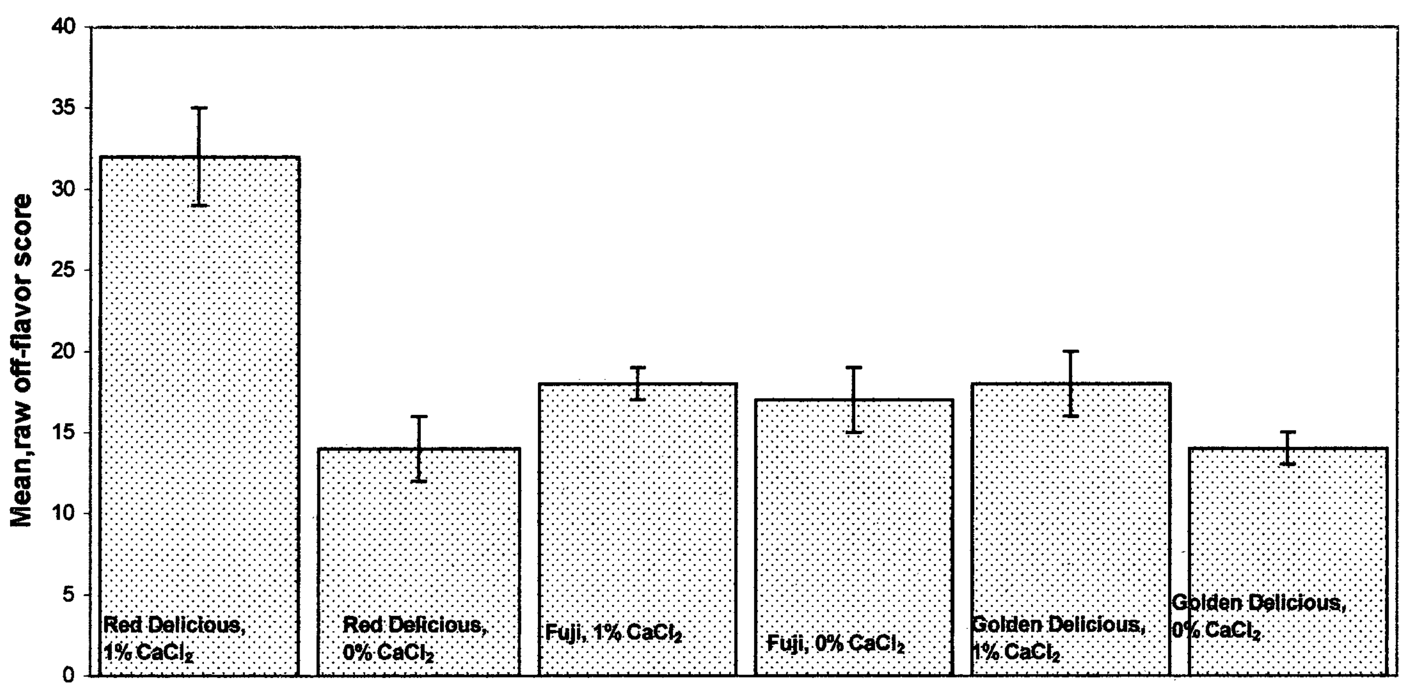

Figure 45. Mean, raw sensory off flavor scores of different varieties and $CaCl_2$ treatment of VMD apple chips. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. n = 15 for off-flavor. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in off-flavor. Red Delicious apple had a significantly higher off flavor ($p<0.05$) than the other two apple varieties.

analysis and the P values of variety effects were reduced in two of the sensory attributes tested (crispness and off flavor). Standardization removed the panelist effect by calculations. Although the Ca pretreatment by panelist interaction was still significant for sweetness when ANOVA were carried out using z scores, both the variety by panelist interaction and the replicate by panelist interaction was nonsignificant for all four sensory attributes tested (Table 7). Further, by comparing the data presentation in Figure 38-41 to that in Figure 42-45, it showed that a more substantial benefit of standardization of scores was perhaps the improved clarity of data presentation that more obvious and clearer trends were observed from the Figures.

Results of both the sensory test (Figure 38) and the instrumental test (Figure 46, 47 and 48) showed that Ca-pretreated (1% $CaCl_2$) apple chips of all apple varieties obtained a significantly higher rating in sensory crispness and a significantly higher instrumental slope, smaller distance and smaller peak force than their non Ca-pretreated (0% $CaCl_2$) ones. This is consistent with results presented in section 4.1 and again suggested that calcium did have an effect in firming the tissues of apple slices and thus, crisper chips were obtained after dehydration when calcium pretreatment was performed. When different varieties of apples were used for VMD apple chips production, significant differences in the instrumental slope and distance was observed (Figure 46 & 47). For both Ca-pretreated and non-treated apple chip samples, the Fuji apple yielded chips with significantly higher slope and smaller distance than the Golden Delicious and the Red Delicious apples. Also, there was a trend for Fuji apple chips to have a slightly smaller peak force than that of the other two apple varieties. In fact, more replications of instrumental measurement of peak force may be needed to get a significant difference

Table 7. Analysis of variance of standardized[1] sensory scores (z score) of VMD apple chips of different apple varieties and Ca pretreatment .

		Crispness	Apple Flavor	Sweetness	Off flavor
Variety	**F-ratio**	13.58	15.24	7.78	8.88
	P-value	0.000	0.000	0.001	0.000
Ca pretreatment	**F-ratio**	55.00	28.36	44.83	17.51
	P-value	0.000	0.000	0.000	0.000
Panelist	**F-ratio**	0.00	0.00	0.00	0.00
	P-value	1.000	1.000	1.000	1.000
Replicate	**F-ratio**	0.57	1.27	2.58	0.94
	P-value	0.570	0.288	0.084	0.398
Replicate x Panelist	**F-ratio**	2.03	1.35	1.16	0.69
	P-value	0.057	0.239	0.339	0.699
Variety x Panelist	**F-ratio**	0.94	1.36	1.83	0.96
	P-value	0.488	0.233	0.088	0.476
Ca pretreatment x Panelist	**F-ratio**	0.71	0.69	1.05	1.01
	P-value	0.585	0.601	0.388	0.411

[1] Scores of individual attributes were standardized within each panelist and z score =(score -mean)/std.dev.

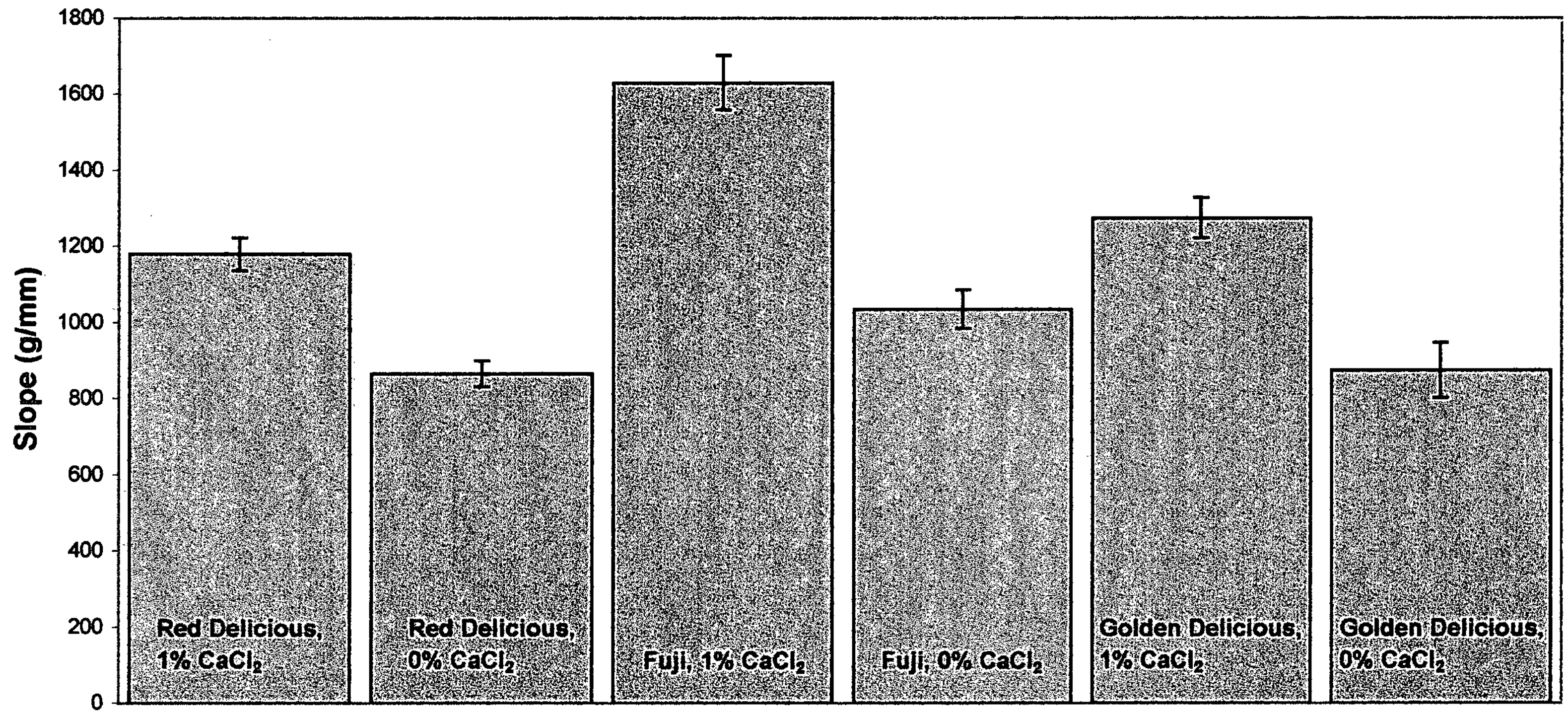

Figure 46. Mean Slope of different varieties of VMD apple chips. The slope of the peak of the force/deformation curve was obtained from VMD apple chips of different varieties and Ca content. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in slope. Slope of the Fuji apple chips were significantly steeper ($p<0.05$) than other varieties.

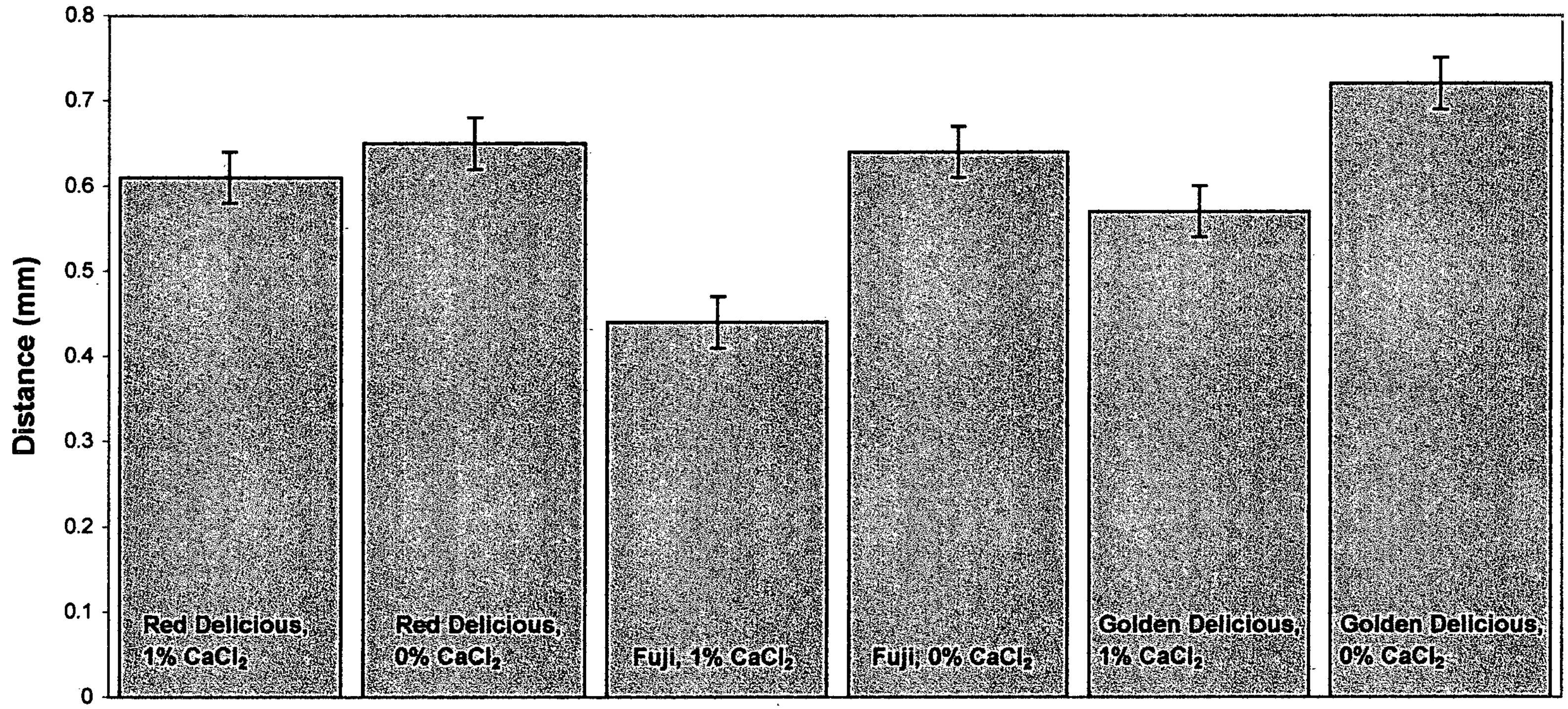

Figure 47. Mean Distance of different varieties of VMD apple chips. The compression slope to the peak of the force/deformation curve was obtained from VMD apple chips of different varieties and Ca content. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in distance. Distance of the Fuji apple chips were significantly smaller ($p<0.05$) than other varieties.

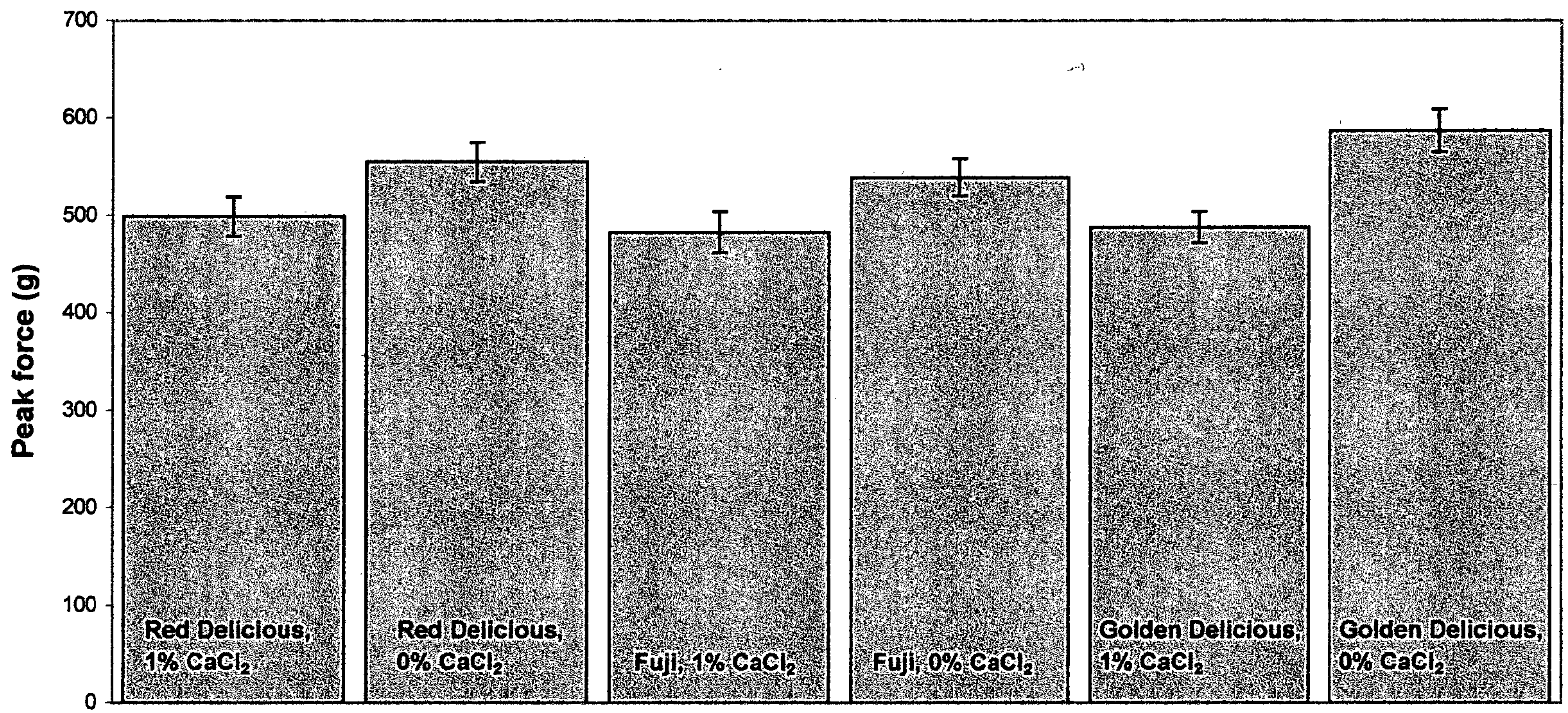

Figure 48. Mean Peak Force of different varieties of VMD apple chips. The peak force of the force/deformation curve was obtained from VMD apple chips of different varieties and Ca content. Experiments were performed in triplicate. n = 45 for all observations and 15 measurements were obtained from each replicate. Data were analyzed using ANOVA. Differences among mean values were established using Tukey's multiple comparison test. For all varieties, calcium pretreatment caused a significant ($p<0.05$) increase in peak force. Varieties were not significantly different from each other.

between samples from statistical analysis. Results from sensory analysis also demonstrated that Fuji apple chips were significantly crispier than both the Golden Delicious and Red Delicious apple chips (Figure 38). Further, the calcium content of the Fuji apple chip was also found to be slightly higher than that of the Golden Delicious, followed by the Red Delicious (Table 8). Since the calcium content was found to be highly correlated to the sensory crispness (correlation = 0.854), the instrumental slope (correlation = 0.857), distance (correlation = 0.768) and peak force (correlation = 0.971) of the chips (Table 9), calcium may indeed have a firming effect on apple tissue. Therefore, a crispier chip sample was produced from apple tissue with a higher calcium content. Also, as had been observed earlier in section 4.1 (Table 3), the sensory crispness was again found to be highly correlated to the instrumental parameters (Table 9). Therefore, results from the sensory analysis of the texture of apple chips supported those of the instrumental ones.

According to Figure 39, 40 & 41, Ca-pretreated apple chips possess a significantly lower apple flavor and sweetness, and a significantly higher off flavor than untreated chips. The mechanism of how calcium chloride can affect the flavor of apple has not been reported in the literature. One possibility is that the bitterness of calcium chloride might distract panelists during sensory evaluation of the flavors and thus, affect the intensity of apple flavors that could be detected by the panelists. Furthermore, both Fuji and Golden Delicious apple chips were shown to have significantly higher apple flavor (Figure 39) and lower off flavor (Figure 41) than the Red Delicious apple chips. Also, as illustrated in Figure 40, the Fuji apple chips obtained a significantly higher sweetness score than the other two apple varieties.

Table 8. Ca content of apple chips of different apple varieties

Treatment (variety, %$CaCl_2$ dip)[1]	**Ca content** (μg/g)[2,3,4]
Red Delicious, 1%	11900(50)
Red Delicious, 0%	540(6)
Fuji, 1%	13100(80)
Fuji, 0%	690(4)
Golden Delicious, 1%	12500(70)
Golden Delicious, 0%	620(4)

[1] Apple slices were dipped in various % of $CaCl_2$ solution for 1min immediately after blanching. Experiments were performed in triplicate.

[2] All measurements were expressed as dry weight of apple chips

[3] n=3 for all observations and 1 measurement was obtained from each replicate.

[4] All measurements were recorded as mean (standard error mean). Each mean value was obtained from the average of three samples.

Table 9. Pearson Correlation matrix and associated probabilities between the Ca content, sensory attribute (crispness) and the instrumental parameter (slope, distance and peak force) of VMD apple chips' texture of different apple varieties[1]

	Ca content	Crispness	Slope	Distance
Crispness	0.854 0.030			
Slope[2]	0.857 0.029	0.929 0.007		
Distance[3]	0.768 0.074	-0.899 0.015	-0.964 0.002	
Peak Force[4]	0.971 0.010	-0.869 0.025	-0.868 0.025	0.854 0.031

[1] Cell Contents: Correlation
P-Value

[2] The slope of the peak of the force vs deformation curve was obtained from VMD apple chips

The microstructures of the chips of different apple varieties were also studied. As found in section 4.1, the Ca-pretreated (1%$CaCl_2$) chip samples (Figure 20, 50 & 51) were found to have thicker cell walls and larger empty regions than the non-treated ones (Figure 19, 52 & 53) in the three apple varieties. Also, a more obvious puffing effect was observed in the Ca-pretreated samples. Among the three varieties, similar structures were obtained for Fuji and Golden Delicious apple chips, while Red Delicious apple looked comparatively less puffy than the other two. A slightly greater amount of cell collapse was observed in both the Ca-pretreated and the non-treated chips made from Red Delicious apples.

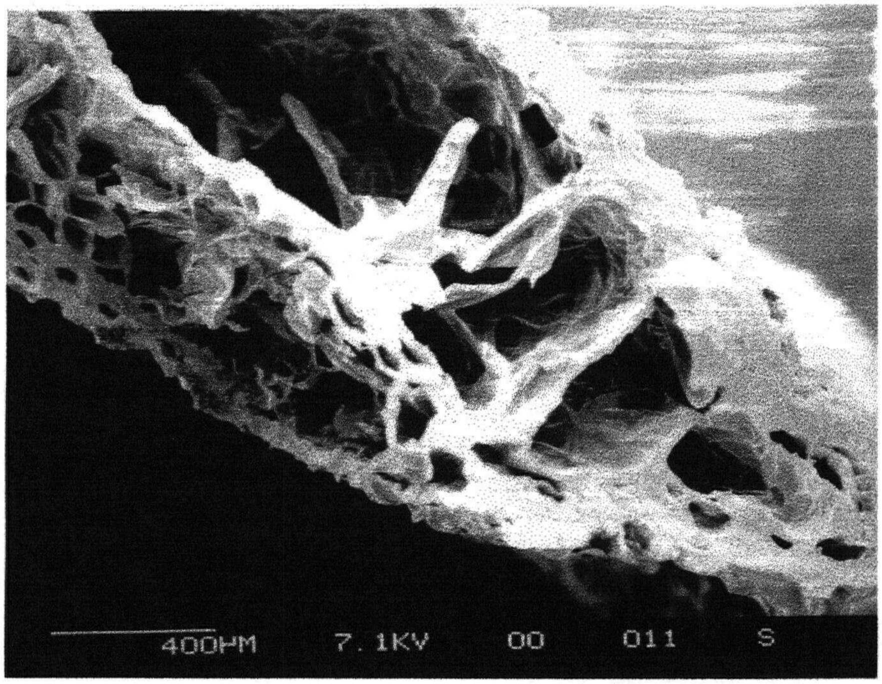

Figure 50. Scanning electron micrograph (200x) of Fuji VMD Apple Chips with 1%$CaCl_2$ Pretreatment

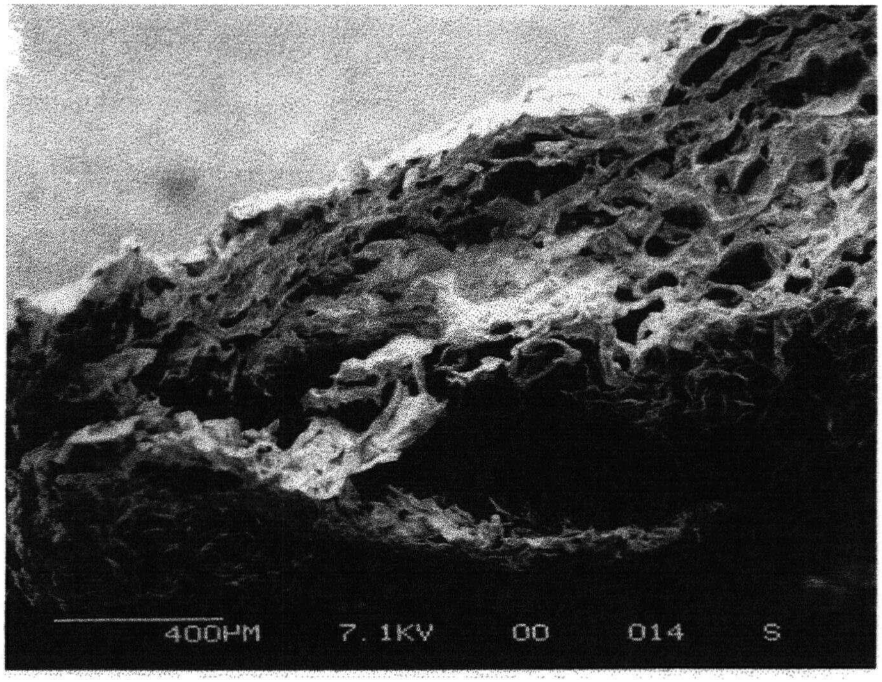

Figure 51. Scanning electron micrograph (200x) of Red Delicious VMD Apple Chips with 1%$CaCl_2$ Pretreatment.

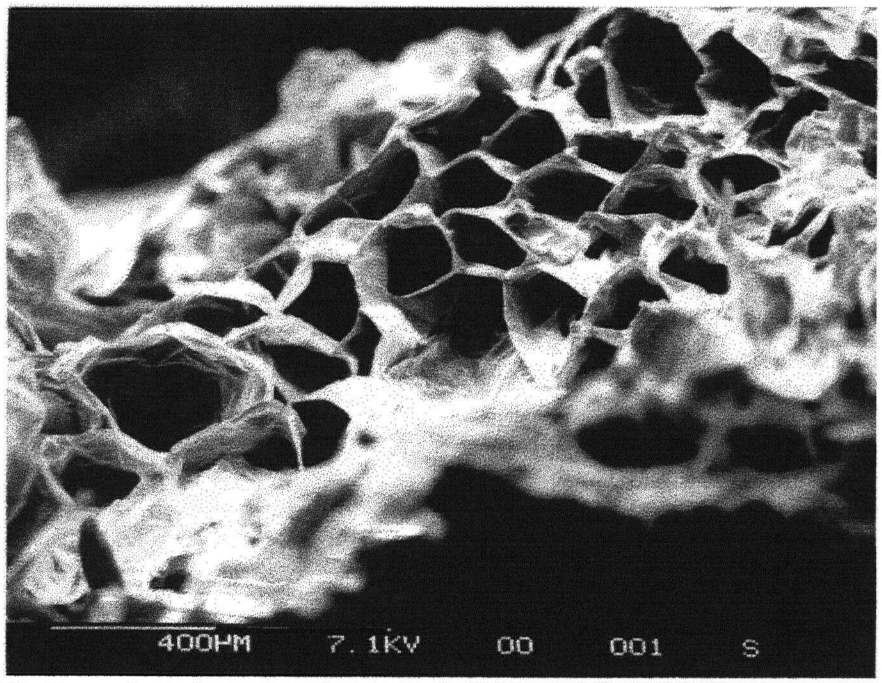

Figure 52. Scanning electron micrograph (200x) of Fuji VMD Apple Chips with 0%$CaCl_2$ Pretreatment.

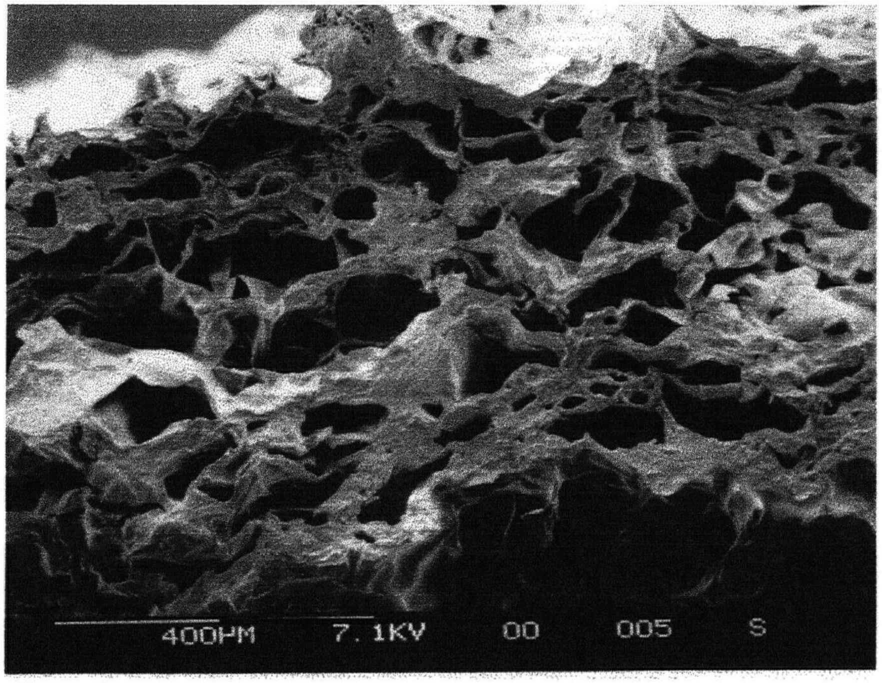

Figure 53. Scanning electron micrograph (200x) of Red Delicious VMD Apple Chips with 0%$CaCl_2$ Pretreatment.

5. Conclusions

Ca-pretreatment of apple slices before vacuum microwave dehydration was shown to enhance the crispness of apple chip products. The application of a 1% $CaCl_2$ pretreatment to the apple slices produced apple chips with a significant increase in crispness but not in bitterness.

Instrumental analysis showed that the textural properties of vacuum microwave dehydrated (VMD) samples (28mmHg) were superior to air-dried samples and freeze-dried samples. Also, the levels of vacuum employed were shown to have an effect on the textural properties of VMD samples; a greater puffing effect and lower density was obtained when a higher level of vacuum was applied and crispier apple chips were obtained.

The desorption isotherms of apple chips dehydrated by different drying techniques (AD, AD-VMD, and FD) were all observed to have a characteristic shape of the isotherms of the high-sugar fruit materials. While low equilibrium moisture content was obtained at low or moderate water activity, a sharp increase in moisture content was observed at higher water activity (above 0.65). By fitting the experimental desorption data into the GAB model, a much higher value of the GAB monolayer moisture content was obtained by the FD apple chips (15.874%) than that of the AD (4.542%db) and the AD-VMD (4.554%db) apple chips. Also, results from the drying curves of apple chips demonstrated that VMD was a much faster drying process than either air or freeze drying.

Furthermore, both the instrumental analysis and the sensory analysis of the texture of apple chips showed that Fuji apple chips have a significantly crispier texture than that of Red Delicious and Golden Delicious apple chips. Also, Ca-pretreated

($1\%CaCl_2$) apple chips possessed a significantly lower apple flavor and sweetness, and a significantly higher off flavor than that of the untreated ones. Both Fuji and Golden Delicious apple chips were observed to have a significantly higher apple flavor and lower off flavor than that of Red Delicious apple chips. Fuji apple chips was found to be the sweetest among the three.

For sensory analysis, standardization within panelists was an effective means of dealing with the tendency of different panelists to use different portions of the line scale for scoring identical samples. Further, standardization improved the clarity of data presentation and in some cases, increased the power of ANOVA to distinguish between samples with small but real differences.

Vacuum microwave dehydration, which allows food to dry rapidly without exposure to high temperature, may be used in the production of high quality apple chips that are crispy but fat free.

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