Abstract

KRINSKY, BERYL. The Development of a Lexicon for Frozen Vegetable Soybeans and Effect of Blanching Time on Sensory and Quality Parameters of Vegetable Soybeans during Frozen Storage (Under the direction of Dr. Timothy H. Sanders)

American vegetable soybean consumption is limited but potential for increased markets based on increased U.S. production is high. Interest in soy foods has risen, fueled by research proving health benefits correlated with soy consumption. The vegetable soybean (Glycine max. (L.) Merrill) is a specialty soybean harvested when the seeds are immature. Due to the narrow window of time available to harvest this crop, freezing is essential for year-round availability of vegetable soybeans. Investigation into vegetable soybean cultivation and processing in the U.S. is ongoing. A flavor lexicon, a set of terms which identify and define the associated aromatic, tastes and feeling factors of a product, for frozen vegetable soybeans was created. This lexicon will provide a standard flavor language for vegetable soybean producers and researchers. A representative sample of commercial frozen vegetable soybean samples was collected. The frozen vegetable soybean lexicon was developed by a 12 member panel of flavor and soybean specialists. Intensity ratings, based on the Sensory Spectrum® scaling method were given to all lexical terms. Food and chemical references, which exemplified the lexicon descriptors were generated and evaluated by the panel. Frozen vegetable soybean flavor was described by 8 aromatics, 3 feeling factors and the basic tastes. In the subsequent months a highly trained descriptive panel validated the lexical language and intensity scores.

Quality concerns related to vegetable soybeans require harvest to be carried out quickly, dictating that the product be frozen for year round availability. Enzyme inactivation by blanching is needed to maintain nutritional and sensory quality of vegetable soybeans during storage. This research objective was to determine the optimal blanching time prior to frozen storage. Vegetable soybeans (Mojo Green var.) were harvested 119 days after planting. Soybean pods were water blanched (100 °C) for 30, 60, 90, 120 and 180 seconds in duplicate and cooled in ice water. One half of each treatment was shelled and the other half remained in-pod. Samples of both types were packed in plastic bags and stored at -24 ° C. Samples were evaluated after 0, 2, 4, 8, 12, 16, 30, 40 and 52 weeks. Analysis consisted of lipoxygenase activity, descriptive sensory analysis, Hunter L-a-b color, texture, and ascorbic acid. Blanching times of 60 seconds or greater were sufficient to inactivate lipoxygenase. Descriptive sensory analysis showed that off-flavor production was enhanced at blanching times less than 60 seconds and that blanching time was directly related to the development of cooked bean and brothy flavor and umami feeling factor. Texture analysis revealed that blanching time was inversely related to bean firmness. Optimal color retention was achieved in 30 to 90 second blanched shelled soybeans and 30 to 120 second blanched soybeans in-pods. The highest ascorbic acid retention was found in shelled soybeans blanched for 60 to 120 seconds, and in-pod soybeans blanched for 60 to 90 seconds. The results indicated that the shortest acceptable blanching time (60 seconds) with respect to lipoxygenase inactivation also yielded acceptable soybean flavor, crisp texture, green color and highest ascorbic acid retention during frozen storage.

The Development of a Lexicon for Frozen Vegetable Soybeans and Effect of Blanching Time on Sensory and Quality Parameters of Vegetable Soybeans during Frozen Storage

By

Beryl Fiana Krinsky

A thesis submitted to the Graduate Faculty of
North Carolina State University
In partial fulfillment of the requirements for the
Degree of Master of Science

Department of Food Science

Raleigh

2005

APPROVED BY:

Dr. T.H. Sanders
Chair of Advisory Committee

Dr. J.C. Allen

Dr. M.A. Drake

Biography

Beryl Fiana Krinsky was born on November 12, 1978 in Miami, Florida to Marsha and Sam Krinsky. Due to Dr. Krinsky's evolving career path, the family moved from Florida to Kentucky to Pennsylvania to West Virginia and back to Pennsylvania, all before Beryl reached the age of 21. The Krinsky family presently resides in Pennsylvania; where Beryl hopes to settle in years to come. Beryl has one younger brother, Gregory Krinsky. The family pet is a Bichon Frise dog, lovingly known as "Mr. Daisy."

The majority of the Krinsky family's verbal history revolves around food and the joy of eating. At age 3 Beryl requested to have her birthday dinner at a Chinese Restaurant in order have her favorite dish, "Moo Shu Chicken." Also at that age Beryl demonstrated the beginning of sensory analysis when declaring a particular quiche, "Good, but not the best I've ever had." At approximately age 10 Beryl determined what her ultimate sign of independence would be. "When I go away to College, you know what I'm going to do?!" Mrs. Krinsky held her breath as Beryl answered. "I'm going to eat all of the Kentucky Fried Chicken® I want!"

The stories continue, but by the time Beryl reached Junior High, her focus had shifted from the taste of food, to food as nutrition. In 1992 she completed an extensive project on the dietary habits of 100 of her fellow eighth graders. In her project she surveyed the current eating knowledge and habits of her fellow students, and then developed recipe alternatives to meet taste and health requirements. This project was enjoyed so much by Beryl that her realization of a future in the field of food and nutrition materialized. Beryl attended Virginia Polytechnic and State University for her undergraduate career, majoring in Human Nutrition, Food, and Exercise. After graduating with her Bachelor of Science degree in 2001, Beryl moved to Raleigh, N.C. to pursue her dietetic internship through Meredith College. Beryl became a registered dietitian in 2002, and began work for a food company. Continuing education was very important to Beryl, and started her graduate work at North Carolina State University in the department of Food Science in 2003. Following graduate school, Beryl plans to pursue an extensive and diverse career in the area of food and nutrition, focusing on developing and presenting healthful food that consumers enjoy.

Acknowledgements

The author would like to express her deepest gratitude to her parents, Sam and Marsha Krinsky, to her brother, Gregory Krinsky, and to her grandmother, Gertie Goldmeier for their unconditional love and support. Miss. Krinsky thanks her amazing boyfriend, Seth Blacksburg for his insight, patience and humor. The author would also like to thank her friends Maggie Cooper, Joe Kleinman, Beth MacIntosh, Jenny Oates, Lauren Fleishman, Eric Bregman and Minoo Mehrotra for always being there.

The author extends her gratitude to her advisor Dr. Timothy Sanders for his guidance and mentorship. She would also like to thank her graduate committee, Dr. MaryAnne Drake and Dr. Jonathan Allen for providing support. A special thanks for Dr. Debra Clare for teaching, assisting and advising. Miss. Krinsky would like to thank the faculty and staff of the Food Science, Statistics and Biological Engineering departments who had provided assistance during her graduate career.

A special and heart felt thank you is extended to Mrs. Lila Chung. Without her vision, none of this would have been possible.

Table of Contents

List of Tables

List of Figures

Chapter One

Literature Review

The Vegetable soybean (Glycine max. (L.) Merrill)

1.1 Introduction

Vegetable soybean (Glycine max. (L.) Merrill) is a member of the Leguminosae family (Norman, 1963; Sheu and Chen, 1991). The vegetable soybean is considered to be a specialty soybean, because unlike the typical harvest of field soybeans, vegetable soybeans are harvested when the seeds are at the immature (R6) stage and have expanded to fill 80 to 90% of the pod width (Lumpkin et al., 1993). The majorities of vegetable soybean varieties have determinate flowering patterns and can be separated into ten representative strains (Chotiyarnwong, 1991; Kokobun, 1991). The botany of vegetable soybeans is similar to field soybeans except for minor morphological and physiological differences (Konovsky et al., 1994). Vegetable soybeans generally have a lighter seed coat, clear hilum, and are higher in protein and lower in oil (Liu, 1997). In general, soybeans can provide the highest yield of protein per unit of land area compared to any plant or animal food source. Consumers across the U.S. concerned with their health are exploring new vegetables that can be incorporated into their diets (Mohamed and Rangappa, 1991). Vegetable soybeans have long been a staple in the Asian consumers' diet, and in recent years have begun to appear as a U.S consumers' vegetable choice.

1.2 History

The definitive origin of the cultivated form of the soybean is unknown (Norman, 1963). The earliest recorded history of vegetable soybean consumption dates back to China in the 3rd century A.D. In the late 1800s two varieties of vegetable soybean seeds were imported into the U.S. and farmers began experimenting with cultivation of the crop. During World War I dried vegetable soybeans were used as an inexpensive source of protein. In the 1930s vegetable soybeans were canned and sold commercially, and during World War II consumption in the US increased. The first recorded significant interest in vegetable soybeans began in 1933, and continued through 1947. After World War II, vegetable soybean production and consumption diminished, but by the late 1970s interest re-emerged, and has continued to increase (Shurtleff and Aoyagi, 1994).

1.3 Anatomy

Vegetable soybeans have slightly larger seeds than field soybeans and the size is adaptable among different varieties (Shurtleff and Aoyagi, 1994). The seed scar is called the hilum, white or gray in color (Konovsky et al., 1994), and descends vertically. The chalaza is a small groove located at the bottom of the hilum. This is the point at which the seed is connected to the pod. The micropyle is located at the top of the hilum, which is a negligible opening in the seed. The primary root of the seedling emerges through this orifice (Markley, 1950).

The soybean seedpod can be compared to other large seeded legumes, such as the pea and garden pea, but is unique in several aspects. The pod is thicker than other legume coats and can range from 16 to 36 microns in thickness. One of the most distinguishable features of the soybean pod is the presence of an endosperm, which is filled with dense protein (Markley, 1950). Soybean pods are covered in a soft white pubescence, and should be completely green when harvested (Carter and Shanmugasundaram, 1993).

1.4 Growing and Harvesting

Cultivation practices for production of vegetable soybeans are similar to those for production of field soybeans. However, vegetable soybeans have distinct appearance characteristic requirements, which demand special attention during growing. Enhanced care during cultivation includes; irrigating the field prior to planting, inoculating new fields with Rhizobium, maintaining proper soil moisture during growing, and controlling weeds (Kokobun, 1991). Soybeans are susceptible to various diseases and pests throughout the growing season. Approximately one hundred bacterial, fungal, viral, and nematode pathogens are known to attack soybeans (Liu, 1997). Rotation of crops, spraying fungicides and insecticides, and choosing resistant varieties created through genetic breeding, are the major tools used by farmers to control diseases and pests (Liu, 1997). Adopting specialty varieties and specific cultural practices are necessary in producing high quality vegetable soybeans (Kokobun, 1991).

Vegetable soybeans are highly photosensitive. Sufficient exposure to sunlight, accompanied with adequate moisture levels and supplemental fertilizer, will yield a visually acceptable pod (Konovsky et al., 1994). Researchers at the Asian Vegetable Research and Development Center (AVRDC) removed leaves from vegetable soybean stems to determine how pod color was affected. When leaves were removed at two-thirds of the plants' mature height, the pods darkened significantly compared to the control. Additional sunlight was directly responsible for the superior darker green color. Excessive sunlight and insufficient moisture levels will negatively affect the pod color, and result in sunburn (Konovsky et al., 1994).

Most vegetable soybean varieties are produced in China, Taiwan or Japan. There are many vegetable soybean varieties, which have been developed for use in specific climatic conditions (Carter and Shanmugasundaram, 1993). The majority of vegetable soybeans is temperature dependent and can only be grown in the warmest months. Soybeans are harvested immature 75-100 days after planting (DAP) (Kono, 1986). Some vegetable soybean plants are photoperiod sensitive, and can only be grown during the time of year with longer nights (Liu, 1997). This type of soybean is not harvested until a minimum of 105 DAP (Kono, 1986). Planting latitude is a major consideration in acclimating soybeans to various geographic regions. In areas of the world with short growing seasons (latitudes greater than 36 degrees), only one crop of soybeans is produced per year. In areas with longer growing seasons (latitudes between 27 and 36 degrees) up to three different crops may be produced. Vegetable soybeans grown in Japan can be produced in early, normal or late cropping systems; utilizing three different crop rotations. In the winter months, vegetable soybeans are grown in heated greenhouses and transplanted to unheated vinyl tunnels in the early spring. This enables the crop to be harvested out of the customary season, and when sold fresh commands a higher price (Kokobun, 1991). In Chinese soybean varieties, regional differences in seed composition are large. Northern China's soybeans are comparably higher in seed oil content, while southern varieties are higher in protein. Three major cropping systems exist in central and southern China, and are identified by the time of planting (spring, summer, and fall). Varieties adapted to these contrasting cropping systems differ in seed composition. Spring planted soybean varieties have relatively low protein content; fall planted soybeans have contrastingly high protein (Cui, 1999).

Vegetable soybeans are harvested when the pods are approximately 80% mature, which normally occurs 28 – 30 days following flowering (Lumpkin et al., 1993). At this stage the pods are bright green, and have not yellowed or become dehydrated. According to previous research, vegetable soybeans should be harvested between the R6 and R7 growth stages (Fehr et al., 1971). Timing of harvest is critical for high quality vegetable soybeans. If the soybeans are harvested before or after the optimum harvest date the pods and seeds will lose the desired sensory and quality characteristics. Quality characteristics may vary according to genotype, time of harvest, crop growth at stage of harvest, and environmental conditions (Mbuvi and Litchfield, 1995). Premature harvest will yield pods with small and underdeveloped seeds, and seeds with lower sweetness flavor (Carter and Shanmugasundaram, 1993). Late harvesting may result in yellowing and dehydration of the pods, a degradation of free amino acids in the seeds (Carter and Shanmugasundaram, 1993), and a decline in ascorbic acid content in the seeds (Konovsky et al., 1994).

1.5 Appearance

Acceptance of vegetable soybeans by Asian consumers is governed by appearance, sweetness, overall flavor, aroma and texture (Carter and Shanmugasundaram, 1993). The Taiwan grading system for vegetable soybean pods is based on appearance. Standards are established by pod size, number of seeds per pod, pod color, and degree of pest damage (Tsou and Hong, 1991). A partial listing of ideal characteristics of vegetable soybeans may be found attached (Table 1). Number of seeds per pod is an important quality factor, dictating that each vegetable soybean pod contain two to three seeds. Acceptable pod length is five centimeters. Total mass can range from two and a half to three grams (Konovsky et al., 1994). Vegetable soybeans have been assigned grades by the Iwate Prefecture (Masuda, 1991; Sitatani; 1991). Grade A vegetable soybeans must contain 90% or more pods with two to three seeds (per selling container) and the pods may not exhibit deterioration caused by insect damage (malformed, injured or spotted). Grade B vegetable soybeans also should have 90% or more pods with two to three seeds. These pods may be a lighter green color, caused by later harvesting. Grade B vegetable soybeans also may show a small extent of insect damage. Seeds can be smaller, and less uniform. In both grades, pods are not acceptable if they are very light green or yellow, severely insect damaged, one seeded, or have split open (Konovsky et al., 1994).

1.6 Maturation

Vegetable soybeans differ from field soybeans at time of harvest, with higher seed contents of fat, protein, and fiber, and lower percentages of nitrogen free extract, and ash (Markley, 1950). There is a slow increase in the dry weight of young soybeans one to two weeks after flower fertilization, and a faster increase during two to five weeks after flowering. The percentage of oil content increases quickly to about 5% after the seed achieves a mass of approximately 30 milligrams, and will reach its final value of 20% when the seed is about half of its final weight (Liu, 1997). Protein accumulation is very rapid during development, and reaches a maximum percentage of 34%, 36 days after flowering, corresponding to wet seed weight. Changes in seed moisture are dependant on soybean variety. Approximately 25 days following flowering there is a decrease in seed moisture, and an increase in dry seed weight. The seed moisture at this stage is approximately 83%, and weight can range from 5 to 22 milligrams per seed. Moisture declines until approximately day 75, ranging from 15.9 % to 40.2%. Dry seed weight can reach 240 to 312 milligrams per seed (Liu, 1997).

1.7 Varieties

The center for domestication of soybeans is believed to be central or southern China. As soy-foods became popular in the diet, farmers practiced genetic selection as they cultivated the crop by saving seed from desirable plants and sowing them in the following year (Qiu et al., 1999). The development of improved soybean varieties for food offers potential expansion in domestic and international markets. Research on development and improvement of vegetable soybean varieties has been ongoing since the early 1900s (Shurtleff and Aoyagi, 1994). The first variety from hybridization, Man Cang Jin, was developed in 1935 and released in 1941. Man Cang Jin became an important parent in subsequent Chinese and Japanese breeding. By 1995, modern breeding efforts led to the release of over 600 varieties in China (Cui et al., 1999). Vegetable soybeans have been specially bred, typically under contracts between foreign soy-food manufacturers and U.S. seed companies (Liu, 1997). The soy-food industry demands soybean varieties based on optimum physical seed traits, chemical constituents, and processing quality (Carter and Shanmugasundaram, 1993). The development of new varieties involves breeding types that have characteristics of high economic yield, tolerance or resistance to biotic and antibiotic stress, traits that add value to the end product, and stability of the traits in target environments (Rao et al., 2002). Varieties are also breed based on various qualities like consumer acceptance and resistance to disease (Takahashi, 1991). For the fresh-frozen market, uniformity of seed maturity, a thicker soybean pod wall to reduce freezing damage and planting specifications for mechanized harvest, in addition to the quality traits of the fresh product are required (Shanmugasundarum et al., 1992). Traditionally, varieties with genetically controlled "stay green" seed coat and cotyledon have been preferred by growers due to extended harvest period, and lower degree of yellowing associated with maturity. The Japanese variety, Tanbaguro, has become a popular vegetable soybean variety due to its exceptionally smooth texture, high sugar content, large seed size, and good flavor (Kokobun, 1991). The Asian soybean varieties have been developed to possess a maximum number of desirable traits (Rao et al., 2002). Prior research has focused on genetically removing lipoxygenase to help lessen the degree of beany flavor in the soybean (Konovsky et al., 1994).

The AVRDC have been conducting vegetable soybean variety trials since the mid 1900s, and have identified approximately 100 successful vegetable soybean varieties

(Masuda, 1991). In the mid 1980s the Chiang Mai Field Crop Research Center initiated a vegetable soybean breeding program through hybridization, selection, and introduction of germplasm (Sitatani, 1991). Research in vegetable soybean variety identification and development is conducted in the United States by Universities and Federal researchers. There is currently a narrow base of genetic diversity for vegetable soybean varieties in the U.S., which creates a need for introduction and evaluation of exotic vegetable soybean germplasm from Asian countries (Carter and Shanmugasundaram, 1993). Basic agronomic research on vegetable soybeans was initiated at Cornell University and through this research several popular vegetable soybean cultivars were developed (Kline, 1980). Washington State University (WSU) has participated in extensive vegetable soybean variety identification and development. In 2002 WSU selected five AVRDC breeding lines for advancement in variety development. Washington state vegetable soybean growers and seed producers will have access to any newly developed varieties. Virginia State University is currently conducting vegetable soybean breeding. The objective of that breeding program is to develop vegetable soybean varieties that possess both nutritional value and desirable agronomic traits, in order to gain the greatest consumer acceptance as a commercial frozen vegetable (Mebrahtu et al., 1991).

1.8 Vegetable soybean in sustainable agriculture

New crops offer U.S. agriculture many potential benefits for producers, rural communities, and industry. Field soybeans have contributed more than $500 billion to the U.S. economy from 1925 through 1985 (Liu, 1997). The vegetable soybean has many agricultural advantages, which makes it a high value crop (Shanmugasundaram et al., 1992). Benefits of vegetable soybean cultivation include; atmospheric nitrogen fixation in the root nodules by Rhizobium bacteria, a short duration crop, easily included into preexisting cropping systems, a higher income potential compared with the field soybean, and stems, leaves, roots, and shells of soybeans can be used as fertilizer, to greatly benefit organic farms (Shanmugasundaram et al., 1992). Cultivation of the vegetable soybean can increase farmers' incomes, enhance employment opportunities, and enrich the soil with organic matter and nutrients; all are which form a part of sustainable agriculture (Mentreddy et al., 2002). In the U.S., the demand for vegetable soybeans results in a farm value close to $600 per ton greater than the field soybean (Mentreddy et al., 2002).

1.9 Chemical composition

A listing of the components found in vegetable soybeans is displayed in Table 2. Compared to field soybeans, vegetable soybeans have higher protein and lower oil content (Markley, 1950). They are higher in ascorbic acid, β - carotene, and contain lower amounts of trypsin inhibitors, phytates, and oligosaccharides (Liu, 1997). Vegetable soybeans contain approximately 16% protein, 13% carbohydrate, 5% lipid, and 65% moisture. Vegetable soybeans are high in fiber, and provide significant amounts of iron, potassium, magnesium and Vitamin C (Song et al., 2003). Vegetable soybeans are also one of the few natural sources of isoflavones, containing a range of 78 to 220 microgram per gram (Mohammed and Rangappa, 1991). The isoflavones found in soybeans are primarily genistin and daidzein (Markley, 1950). Tocopherols are also present in vegetable soybeans, and the concentration ranges from 84 to 128 microgram per gram (Mohammed and Rangappa, 1991).

1.10 Protein

The principal components of soybean protein are 2S (trypsin inhibitor and cytochrome C), 7S (β -conglycinin), 11S (glycinin) and 15S (a polymer of glycinin). The S stands for Svedberg units. The numerical coefficient is the characteristic sedimentation constant in water at 20^{o} C. The concentration and ratio of the protein components is dependent on the variety (Liu, 1997), and cultivation practices for the soybean (Staswick and Nielson, 1983). A supply and balance of nitrogen and sulfur nutrients effect total soybean protein, and may influence patterns of 11S and 7S protein accumulation in developing seeds (Staswick and Nielson, 1983). When sulfur is limiting, seeds typically contain lower levels of glycinin, and greater amounts of the β subunit of β - conglycinin (Naito et al., 1994). There is also a pronounced decline in methionine and cysteine, which could be due to a decline in the 2S protein fraction (Staswick, 1983). A similar effect is seen in nitrogen deficient soybeans, with a subsequent elevation of both 7S and 11S proteins following application of nitrate (Davies et al., 1985).

Soybeans contain all of the essential amino acids required for human and animal nutrition; isoleucine, leucine, lysine, methionine, cysteine, phenalyanine, tyrosine, threonine, tryptohpan, valine, and histidine (Carter and Shanmugasundaram, 1993). Among all of the vegetable protein sources, soybeans provide the most complete amino acid balance for human and animal food (Cui et al., 1999) (Table 3). Net protein utilization (NPU) is the ratio of amino acids converted to protein in the body, based on the total quantity of amino acids in the food consumed. This data has been obtained from studies conducted on rats. The NPU value can be calculated by determining dietary protein intake, and measuring nitrogen excretion. The NPU score ranges from 40 (vegetables) to 94 (meat). In experimental rat trials, soy protein originally received a low NPU score. It was later recognized that methionine, low in soy protein, is a limiting amino acid for the rat. Rats require approximately 50% more methionine than humans. The World Health Organization (WHO) and the Food and Drug Administration (FDA) adopted a corrected protein digestibility corrected amino acid score (PDCAAS) as the official assay for evaluating protein quality. After correcting for digestibility, proteins that provide amino acids equal to or in excess of human requirements receive a PDCAAS of 1.0. Soy protein has a PDCAAS of 1.0 and meets protein needs of human adults, when consumed as a sole source of protein at the rate of 0.6 gram per kilogram of body weight (Young, 1991).

1.11 Lipoxygenase

Lipoxygenase (LOX) catalyzes the oxidation of polyunsaturated fatty acids and produces conjugated fatty acid hydroperoxide derivatives (Liu, 1997). LOX is active in both production of volatile flavor and aromatic compounds in plant products, as well as formation of free radicals that degrade essential constituents, like vitamins, color, phenolics, and protein (Robinson et al., 1995). LOX is an anti-nutritional factor prevalent in soybeans, relating to the destruction of desirable vitamins and protein (Mohammed and Rangappa, 1991). LOX has been found in many sources such as plants, and fungi; however soybeans have the highest concentration of this enzyme (Liu, 1997). Flavor and aromatic compounds produced by LOX are desirable is some foods, conversely the enzyme produces off flavors in several commodities including vegetable soybeans. Interest in soybean LOX is generally based on the production of volatile compounds associated with grassy, beany, and rancid off flavors (Robinson et al., 1995).

Various mechanisms have been proposed for LOX production of hydroperoxides. Two different pathways involving aerobic and anaerobic reactions have been suggested. In both pathways there are three steps in the formation of hydroperoxides; the activation of the native enzyme, removal of a proton from the activated methylene group of the substrate, and insertion of oxygen into the substrate molecule with formation of the hydroperoxide (Robinson et al., 1995).

L-1, L-2, L-3a, and L-3b are isozymes of lipoxygenase that have been identified in soybeans, and have been categorized. The L-1 isozyme is characterized by a high optimum pH of 9.0 and formation of large amounts of 13-hydroperoxides. L-2, L-3a and L-3b have an optimum pH of 7.0 and form equal amounts of 9-hydroperoxides and 13-hydroperoxides (Kumar et al., 2003). The soybean isozymes have a molecular weight of approximately 100,000 and contain one atom of iron per mole of protein (Robinson et al., 1995).

At least three detrimental effects caused by lipoxygenase occur in food (Eskin et al., 1977). LOX may interact with the essential fatty acids linoleic, linolenic, and arachindonic acid. Further degradation of the hydroperoxides results in the formation of volatile compounds such as aldehydes, ketones, and alcohols (Robinson et al., 1995). Many of these compounds have low flavor thresholds and objectionable odor or uncharacteristic flavors (Liu, 1997). LOX related off flavors are more predominant in vegetable soybeans which have been stored in frozen conditions and are un-blanched or insufficiently blanched (Ludikhuyze et al., 1998). The LOX reaction continues at frozen temperatures if the LOX was not sufficiently inactivated prior to storage (Ludikhuyze et al., 1998).

Soybean varieties lacking components or the complete LOX isozymes should theoretically be less susceptible to LOX mediated oxidation (Robinson et al., 1995). Naturally occurring soybean varieties deficient in more than one isozyme have not yet been identified. Genetically modified soybeans that exist without isozymes L-1 and L-3, or isozymes L-2 and L-3 have been developed (Robinson et al., 1995). Research is underway at AVRDC to completely eliminate soybean LOX enzymes, in order to reduce off flavors (Tsou and Hong, 1991). The agronomic performance of these plants is expected to be equal to plants that contain all naturally occurring LOX isozymes (Robinson et al., 1995).

1.12 Lipid

The lipid component in soybeans is primarily made up of triacylglycerides (TAG) (Liu, 1997). TAG are neutral lipids consisting of three fatty acids attached to one glycerol molecule (Groff and Gropper, 2000). Similar to many other plant oils, the majority of fatty acids in soybeans are unsaturated. The most abundant fatty acid in soybeans is linoleic acid, followed in descending order by oleic, palmitic, linolenic, and stearic acid (Liu, 1997). Consumption of monounsaturated (oleic) and polyunsaturated (linoleic and linolenic) fatty acids is negatively correlated with risk of cardiovascular disease. This reduced risk is commonly attributed to a decrease in total cholesterol and improved cholesterol lipoprotein ratios related to consumption of these fatty acids (Groff and Gropper, 2000).

1.13 Carbohydrate

The soluble carbohydrates found in soybeans are primarily disaccharides and oligosaccharides; sucrose, raffinose, and stachyose (Liu, 1997). Typical carbohydrate concentration ranges are 41-67% sucrose, 5-16% raffinose, and 12-35% stachyose, as a percentage of total soluble carbohydrates (USDA, 2004). Humans do not have the ability to digest oligosaccharides in the duodenal or small intestinal mucosa (Groff and Gropper, 2000). Consumption of raffinose and stachyose may result in significant amounts of these sugars passing unabsorbed into the colon (Mahan et al., 2000) where they are then metabolized by bacteria and result in gas production (Groff and Gropper, 2000).

There is a natural variation in complex sugar composition in soybean varieties. This suggests a mutation in the gene that encodes the enzymes associated with the oligosaccharide sugars (Geater and Fehr, 2000). Recessive alleles have been identified that may reduce these enzymes. In the occurrence of these natural gene mutations, there can be up to a 97% reduction of raffinose and stachyose in the soybean seed (Main et al., 1983). Researchers have examined processes to remove these oligosaccharides. Removal can be achieved through fermentation or enzymatic hydrolysis (Liu, 1997). The optimal alternative involves complete elimination of the problematic carbohydrates. Research in soybean plant breeding is examining reduction or elimination of the oligosaccharides (Masuda, 1991).

Vegetable soybeans contain insoluble carbohydrates; cellulose, hemicellulose, pectin, and trace quantities of starch (Liu, 1997). Consumption of insoluble carbohydrates is recommended for humans, due to an increase in fecal weight, a delay in the digestion of starch, and a slower absorption of glucose in the blood stream (Groff and Gropper, 2000). Both the soluble and insoluble carbohydrates in soybeans fall under the category of dietary fiber (Liu, 1997). Vegetable soybeans contain approximately 4.2 grams of fiber per 100 gram total wet weight (USDA, 2004). Fiber consumption has been linked to optimum health and aiding in resistance to diseases. Soluble fiber has been proven to lower the low density lipoprotein component of total serum cholesterol, while insoluble fibers exert an overall protective effect and reduce cancer risk (Mahan et al., 2000). American consumers do not typically eat the recommended daily allowance of dietary fiber (Kritchevsky, 1997).

1.14 Vitamin C

Vitamin C, including ascorbic acid and dehydroascorbic acid, is an important nutritional component in many horticulture crops. Vitamin C has functionality in cellular mechanisms including collagen formation, aiding in absorption, enhancement of immunity, and antioxidant capabilities (Mahan et al., 2000). More than 90% of the vitamin C in human diets is supplied by fruits and vegetables (Lee and Kader, 2000). There is approximately 27 milligrams per 100 grams of vitamin C present in vegetable soybeans (Kokobun, 1991). Vitamin C retention in produce is directly related to post harvest processing. During processing, distributing, and storage of frozen vegetables, ascorbic acid oxidizes to dehydroascorbic acid, which is irreversibly hydrolyzed and possesses no vitamin C activity (Giannakourou and Taoukis, 2003). The oxidation of ascorbic acid is favorable in the presence of oxygen, heavy metal ions (copper and iron), alkaline pH and high temperature (Lee and Kader, 2000). Vitamin C losses are enhanced in vegetable products, with extended storage at elevated temperature, low relative humidity, physical damage, and chilling injury (Lee and Kader, 2000). Degradation of the vitamin can be considerable during processing and cooking (Song et al., 2003). Blanching may reduce the vitamin C content during processing, but successfully reduces further decline during the frozen storage of the vegetable product (Lee and Kader, 2000).

1.15 Isoflavones

Isoflavones, which are phytochemicals, are found in large quantities in soybeans. These compounds are currently under investigation for their role in prevention and reduction in severity of certain chronic diseases. The primary soybean isoflavones are genistein, and daidzein (Watanabe et al., 2002). Approximately 1.5 – 2.0 milligram per kilogram body weight of soy isoflavones are needed every day to provide an anti-carcinogenic effect in adults (Wang et al., 1994). Vegetable soybeans are rich sources of isoflavones, and contain an average of 1354 microgram per gram (Wang et al., 1994).

Recent increases in the interest in soy are due primarily to the presence of isoflavones and the reported health benefits of these compounds (Mohammed and

Rangappa, 1991). In various experimental models, isoflavones such as genistein and daidzein have been shown to inhibit the growth of cancer cells, lower cholesterol, and reduce bone resorption (Liu, 1997). Coronary heart disease and all types of cancer account for more than half of all deaths attributed to chronic diseases in the U.S. (CDC, 2004). The scientific community has established a correlation between poor diet and risk of chronic diseases, such as heart disease and cancer (Mahan and Escott-Stump, 2000). The incidence of chronic disease in Asian consumers was practically nonexistent for many years, while these consumers ate a traditional diet high in soy (Liu, 1997). Japanese women traditionally consume approximately 100 grams of soy, and soy products daily, which will include an average of 30 milligrams of isoflavones (Watanabe et al., 2002). In recent years, there has been a marked increase in chronic diseases in the Asian populations, in both U.S. and Asian countries. Researchers believe this was due to altering the Asian diet to the westernized diet, which decreased overall soy food consumption (Liu, 1997).

In 1999 the Food and Drug Administration (FDA) authorized the use of health claims on labels of foods containing soy protein. This statement is based on research conducted by the FDA (Federal Register, 1999) showing that foods containing soy protein, which are included in a diet low in saturated fat and cholesterol, may reduce the risk of coronary heart disease by lowering blood cholesterol levels. Research indicated that 25 grams of soy protein daily was needed in the diet to produce a significant cholesterol lowering effect. Soy foods that qualify for this health claim must contain a minimum of 6.25 grams of soy protein (per serving), and must be low in fat, saturated fat, and cholesterol (Federal Register, 1999). One serving of vegetable soybeans (1/2 cup) provides approximately 13 grams of soy protein, which is more than half of the recommended daily intake for soy protein (Liu, 1997).

1.16 U.S. production

Production of vegetable soybeans in the U.S. is low, and in its beginning stage despite considerable research throughout this century on the crop. Therefore, most frozen vegetable soybeans sold in the U.S. have been imported (Konovsky et al., 1994). Vegetable soybeans are increasing in popularity among West Coast and Midwest consumers, and are sold as a frozen vegetable in grocery stores and oriental food markets (Lin, 2001). Approximately 13,000 acres of vegetable soybeans are required to meet the demand for fresh and frozen markets in the U.S. (Johnson et al., 1999). Frozen vegetable imports into the U.S. increased from 300 to 500 tons per year in the 1980s. In 2000, over 10,000 tons of vegetable soybeans were consumed by Americans (Lin, 2001). An estimated 26 million Americans consume soy foods (Liu, 1997). Out of this total, less than 10% of the soybeans were produced in the U.S. It is estimated that by the year 2010 U.S. imports could total 25,000 tons of vegetable soybeans per year (Lin, 2001). Many food brokers identify fresh vegetable soybeans as the one of the highest in demand vegetable products due to a limited growing season (Chang, 2001).

U.S. farmers are beginning to cultivate vegetable soybeans in response to developing niche markets. Harvested seasonally, freezing is required for year-round availability of vegetable soybeans. In order to achieve success in large scale production of vegetable soybeans in the U.S., optimization of the processing regimen to produce a frozen product was needed. The objective of this research was to determine the most favorable blanching time prior to frozen storage to maintain optimum sensory and quality parameters of vegetable soybeans. This objective required the development of a descriptive lexicon and intensity references for vegetable soybean flavor.

1.17 Frozen vegetable soybean lexicon

In order to evaluate the flavor of frozen vegetable soybeans during shelf life, a frozen vegetable soybean flavor lexicon was created. Using language to express a flavor experience is synonymous with descriptive sensory analysis. Lexicons are tools used in this type of analysis. A flavor lexicon can be defined as: a set of words to describe the flavor of a product or commodity, and can be applied or practiced using descriptive sensory analysis techniques (Drake and Civille, 2003).

Descriptive sensory analysis involves compiling an appropriate collection of terms to describe the flavor characteristics for a given product or product category. In a flavor lexicon, the language used to describe a particular product is chosen and remains constant for all products within a category (Lawless and Heyman, 1999). Effective flavor lexicons are used to identify differences in the product for which it was developed, and do not use multiple terms to describe the same flavor (Drake and Civille, 2003). Lexicons are widely used in industry for comparing and monitoring products, and for profiling new or competitive products. In the past, descriptive analysis lexicons have been used for products such as: beef (Berry et. al, 1980), peanuts (Johnson et. al, 1987), chicken (Lyon, 1987), apples (Dalliant-Spinnler et. al, 1996), cheddar cheese (Drake et. al, 2001), and more (Drake and Civille, 2003).

Flavor lexicon development involves collecting a product frame of reference. The frame of reference consists of an extensive sample set that covers the widest array of flavor characteristics associated with the product being evaluated (Drake and Civille, 2003). Including samples with both on and off notes is crucial (Munoz and Civille, 1998).

An “on note” means that the note is typically associated with the sample. An “off note” may occur in a product as the result of aging, or improper processing or storage conditions. Using the words "on" note and "off” note to identify descriptors is usually preferable to using "good" or "bad." This terminology helps to avoid generating negative impressions in communicating because some traditional off-notes may be critical to the flavor profile of certain products (Drake and Civille, 2003).

A group of highly trained descriptive sensory experts, and experts in the product under evaluation, will review the frame of reference and generate terminology. During tasting evaluation, group participants will vocalize the flavor adjectives to describe each flavor in the product that they taste. An extensive list should be formulated to characterize the aromatics, basic tastes, and feeling factors found in the sample (Johnson et al., 1987). The terms can be grouped according to flavor types or categories (Drake and Civille, 2003).

Following generation of the preliminary language, a descriptive panel is needed to refine the developed language and identity references (Drake et al., 2001). References can be qualitative and, or quantitative. In lexicon development, qualitative references are critical for every term (Drake and Civille, 2003). References are either food or chemical samples of each specified flavor. The importance of definitions and references is related to lexical language reproducibility at different places or times. Possessing established references will enable an uncomplicated universal interpretation and reproduction of results (Drake and Civille, 2003). After the lexical language has been refined, and references identified, a final language should be validated by additional evaluation of specified samples (Drake et al., 2001).

1.18 Vegetable soybean flavor

The flavor of vegetable soybeans is commonly described as nutty and sweet, with a low degree of beany flavor for a soy product (Tsou and Hong, 1991; Konovsky et al., 1994; Young et al., 2000). Factors which are believed to contribute to differences in vegetable soybean flavor are variety of soybean, fertilizer application, planting density, harvest procedures, processing conditions and duration of frozen storage (Konovsky et al., 1994). Post harvest handling is thought to be the main influence on vegetable soybean quality and flavor. The need for rapid cooling following harvest is essential, and blanching prior to freezing for vegetable soybeans is recommended to reduce occurrences of off flavor development (Robinson et al., 1995).

Attempts have been made at the AVRDC to develop an objective evaluation system, which could be used to grade the flavor quality of vegetable soybeans (Tsou and Hong, 1991). Tsou and Hong (1991) used gas chromatography to define aromatic compounds which could be related to vegetable soybean flavor. At vegetable soybean harvest the compounds that were the highest included: (Z)-3-hexenyl acetate, linalool, acetophenone, cis-jasmone, hexanal, 1-hexanol, (E)-2-hexenal, 1-octen-3-ol, and 2-pentylfuran. Beany flavor was speculated to be related to hexanal, and cis-jasmone was thought to contribute to highest overall flavor.

In 2000 Young et al. tested consumers to examine the acceptability of various vegetable soybean varieties. Flavor was rated by sweetness, nuttiness, beaniness, oiliness, aftertaste, and overall eating quality. Consumers rated all varieties to be non-oily, having a low beany flavor and having a pleasant aftertaste. Several varieties were higher in nutty flavor, and soybeans varied in total sweetness. The beans which scored the highest in overall acceptance were the most sweet and least beany.

U.S. consumers select food for nutrition, convenience, culture, economics and flavor. Among these selection criteria, flavor ranks the highest (Young et al., 2000). If vegetable soybeans are to be accepted by U.S. consumers, there is an apparent need for optimum flavor. The requirement for defining vegetable soybean flavor was achieved through the development of the frozen vegetable soybean lexicon. This lexicon facilitated an objective flavor comparison of frozen vegetable soybean un-blanched controls and blanched treatments, as well as any flavor changes in the soybeans which developed during frozen storage.

1.19 Processing vegetable soybeans

Freezing has long been established as an excellent method for preserving high quality in food products, including vegetables and fruits. Freezing decreases the rate of most deteriorative reactions, such as senescence, enzymatic decay, chemical decay, and microbial growth (Savas et al., 2005). Generally, freezing preserves the taste, texture, and nutritional value of foods better than any other preservation method; as a result, ever-increasing quantities of food are being frozen throughout the world. Frozen food markets have grown immensely between 1991 and 1996 (Pruthi, 1999).

U.S. consumers demand food products with a wholesome image, few additives, and optimal nutritional and sensory values. Extended shelf life is a processor and consumer concern (Giannakourou and Taoukis, 2003). If vegetables are stored in frozen conditions immediately following harvesting, there is a notable decline in quality. Enzymatic activity will continue in un-blanched vegetables at low temperatures. This enzymatic activity may result in changes in texture, flavor, color, and nutrient content (Halpin and Lee, 1987). The quality loss kinetics of stored, un-blanched green beans at various frozen temperatures has been examined (Martinis and Silva, 2003). Quality parameters that deteriorated included ascorbic acid, total vitamin C (ascorbic acid and dehydro-ascorbic acid), starch, reducing sugars, texture, chlorophylls, overall color, and flavor (Martinis and Silva, 2003).

Various groups of enzymes are related to quality deterioration of un-blanched frozen vegetables. LOX, lipases, and proteases have been associated with off flavor development; pectic enzymes and cellulases have been shown to cause textural changes; polyphenol oxidase, chlorophylase, and peroxidase may cause color changes; and ascorbic acid oxidase and thiaminase can lead to nutritional deterioration (Williams et al., 1986). In secondary reactions, LOX produces lipid hydroperoxides and hydroperoxy radicals that affect chlorophyll and carotenoids and cause a loss of color. Polyphenol oxidase produces benzoquinones and melanins. These compounds react with the alpha-amino lysine protein component and affect the nutritional quality and solubility of the proteins (Williams et al., 1986).

The majority of vegetables require a short heat treatment or blanching before freezing (Halpin and Lee, 1987). Blanching is a thermal process designed to inactivate the enzymes responsible for generating off flavors and odors (Savas et al., 2005). The blanching process can be achieved by immersing vegetables in boiling water. Blanching should provide uniform heat distribution to the individual units of product, uniform blanching time exposure to all units, overall high quality and product yield, and low consumption of energy and water (Poulsen, 1986). Conventionally, vegetables are blanched to the point of inactivation of specific enzymatic (e.g. LOX) activity (Halpin and Lee, 1987). Adequate blanching should provide inactivation of enzymes, improved microbial status, shortened cooking time for the finished product (Poulsen, 1986), and stabilization of texture, flavor and nutritional quality (Savas et al., 2005). Consumers demand that frozen vegetable products have a high resemblance to the raw counterpart, which requires minimal blanching induced degradation of nutritional and organoleptic properties (Ludikhuyze et al., 1998). A delicate balance between inactivating enzymes associated with degradation and minimizing losses in quality caused by prolonged blanching must be achieved in order to produce the highest quality frozen product.

Blanching of vegetables prior to freezing has both advantages and disadvantages. Given that blanching is a heat treatment, changes associated with mild thermal processing can be expected (Savas et al., 2005). Texture is one of the main attributes that define the quality of preserved fruits and vegetables, with lack of firmness being a limiting factor in marketing and consumer acceptability (Barrett and Theerakulkait, 1995). Heating produces micro-structural alterations in plant tissue that influence texture. The general result is softening, brought about by loss of turgor pressure and occluded air, thermal degradation of middle lamella-pectins and other cell wall polysaccharides and starch gelatinization (Llano et al., 2003).

The texture of vegetable soybeans has been previously studied in relation to consumer acceptance (Song et al., 2003; Young et al., 2000; Shanmugasundaram et al., 1991). Prior research has conflicted; Song, An, and Kim (2003) determined that consumers preferred vegetable soybeans which had a soft texture, whereas Young, Mebratu, and Johnson (2000) related vegetable soybean acceptability with a firm, and nut-like texture. Song et al. (2003) recommended blanching vegetable soybeans using the high temperature with short time (HTST) approach.

Sensory evaluation and instrumental determination are two objective ways to measure product texture (Hansen et al., 2004). Force/deformation methods are commonly used in instrumental analysis. These direct methods measure single or multiple mechanical properties of food, which are important in the sensory perception of texture by humans (Abbott and Abbott, 2004). Within the force/deformation analysis, a destructive approach to measuring texture is the compression method. Destructive methods are a preferred means of textural measurement for food because they highly correlate to sensory evaluation (Abbott, and Abbott, 2004). Compression can be used to measure solid foods and is considered to be qualified for prediction of sensory perception of consistency during mastication (Hansen et al., 2004).

A further effect of thermal processing is the degradation of chromophores such as chlorophyll, resulting in color change. Pigment degradation will continue to take place in frozen storage (Savas et al., 2005). The color of vegetable soybean pods is of paramount importance and genetically modified varieties in Asia have been created which have "stay green" pods. These varieties are highly popular with growers, due to extending harvest period closer to soybean maturity without experiencing the yellowing associated with maturity (Cui et al., 1999). Vegetable soybean color has also been directly correlated with ascorbic acid content. Masuda (1991) determined a direct relationship between the decline in ascorbic acid and browning of vegetable soybean pods, during refrigerated storage.

Blanching can also lead to thermally induced degradation of nutrients, such as ascorbic acid (Lee and Kader, 2000). Ascorbic acid losses increase with extended storage, improper frozen storage temperatures, low relative humidity, physical damage, and chilling injury (Lee and Kader, 2000). The retention of ascorbic acid in frozen products is dependant of the product temperature history (Halpin and Lee, 1987); including harvesting conditions, processing parameters, and temperatures during frozen storage.

The quality associated with frozen foods is dependant upon a variety of factors. The main factors affecting the final quality of frozen vegetables are: initial raw material, processing (including blanching and method of freezing), post processing distribution, storage and home handling (Giannakourou and Taoukis, 2003). In the frozen vegetable industry sometimes quality has been a second priority due to overcompensation in the area of food safety (Barrett and Theerakulkait, 1995). Physical changes observed in foods that result in a reduced shelf life are caused by mishandling of foods during harvesting, processing, and distribution (Singh, 1994). Temperature, humidity, oxygen and light are environmental factors that can lead to food degradation during storage and distribution. These reactions may alter food to the extent that it is either rejected, or becomes harmful to the consumer (Singh, 1994). The chemical changes associated with processed and stored foods are enzymatic, oxidative, and non-enzymatic reactions which can lead to altered flavor and change in appearance (Singh, 1994).

Shelf life for frozen products is estimated by using models of shelf life kinetics (Giannakourou and Taoukis, 2003), accelerated shelf life testing, consumer panels (Singh, 1994), and sensory panels (Martins and Silva, 2004). A prerequisite in planning a shelf life test for a frozen product is to select the most important, thermo-labile quality attribute (Singh, 1994). The loss of Vitamin C, as well as the degradation of chlorophyll in vegetables can be a measure of cold storage past shelf life or improper storage temperature. Various code dating procedures do not consider the nutritional attributes that in some instances may limit the shelf life (Martins and Silva, 2004). Objective nutrition tests, quality assurance, and sensory analysis should be used to determine shelf life (Singh, 1994).

Previous research has been utilized to determine optimum processing for many frozen vegetables such as; green beans (Martins et al., 2004), carrots (Lo et al., 2002), peas (Busto et al. 1999), and various vegetables (Giannakourou et al., 2003; Poulsen, 1986). An apparent need existed to optimize the processing of vegetable soybeans, specifically targeting blanching prior to freezing. The specific blanching time required to inactivate LOX and maintain the optimal quality during frozen storage for vegetable soybeans was examined in this research.

The majority of vegetable soybeans are currently produced in Asia; however as consumer demand for the product increases, U.S. industry will grow to meet the demand. There will be a need for standardization of quality control practices to ensure sensory quality and product consistency. A standardized lexicon would allow researchers to obtain results that are comparable beyond national borders, and could also be used to understand the factors that related to consumer acceptance (Barcenas et al., 1999). In order to determine the shelf life for frozen vegetable soybean products, this research included sensory, quality and nutritional measurements during 12 month storage. The results of this research will indicate the shortest acceptable blanching time for LOX inactivation while acceptable flavor, texture, green color, and ascorbic acid are successfully maintained in the frozen vegetable soybeans.

1.20 References

Barcenas, P., Perez-Elortondo, F.J., Salmeron, J., and Albisu, M. 1999. Development of a preliminary sensory lexicon and standard references of ewes milk cheeses aided by multivariate statistical procedures. *Journal of Sensory Studies*, 14, 161-179.

Barret, D.M., and Theerakulkait, C. 1995. Quality indicators in blanched, frozen, stored vegetables. *Food Technology*, 1(62), 64-65.

Berry, B.W., Maga, J.A., Calkins, C.R., Wells, L.H., Carpenter, A.L., and Cross, H.R. 1980. Flavor profile analysis of cooked beef lion steaks. *Journal of Food Science*, 45, 1113-1115.

Busto, M.D., Apenten Owusu, R.K., Robinson, D.S., Wu, Z., Casey, R., and Hughes, R.K. 1999. Kinetics of thermal inactivation of pea seed lipoxygenase and the effect of additives on their thermostability. *Food Chemistry,* 65(3), 323-329.

Carter, T.E., Jr. and Shanmuglasundaram, S. 1993. Edamame, the vegetable soybean. In: Underutilized Crops: Pulses and Vegetables (Edited by T.Howard). Pp. 219-239. London: Chapman and Hill.

Centers for Disease Control and Prevention (CDC). Preventing Heart Disease and Stroke: Addressing the Nation's Leading Killers. Chronic Disease Prevention. Centers for Disease Control and Prevention, Atlanta, Georgia. Available at http://www.cdc.gov/cvh (accessed September 25, 2004).

Chang Chi-Lin, CEO, Asia Foods. "Frozen Edamame: Global Market Conditions." Presentation at 2nd International Vegetable Soybean Conference, August 10-12, 2001. Tacoma Washington.

Chotiyarnwong, P. 1991. Varieties and varietals development of vegetable soybean. In: Vegetable Soybean Production. (Edited by S. Shanmugasundaram). Pp. 13-18. Proceedings of a workshop held in Chiang Mai, Taiwan, February 18-24, 1991. AVRDC, Publication No. 92-369.

Cui, Z., Carter, T.E., Jr., Gai, J., Qiu, J., & Nelson, R.L. 1999. Origin, Description, and Pedigree of Chinese Soybean Cultivars Released from 1923 to 1995. U.S. Department of Agriculture Technical Bulletin 1871. U.S. Government Printing Office, Washington, D.C.

Daillent-Spinner, B., Macfie, H.J.H, Beyts, P.K., Hedderly, D. 1996. Relationship between perceived sensory properties and major preferences directions of 12 varieties of apples from the southern hemisphere. *Journal of Food Quality Preferences,* 7, 113-126.

Davies, C.S., Coates, J.B., & Nielson, N.C. 1985. Inheritance and biochemical analysis of four electrophoretic variants of β-Conglycinin from soybean. *Theoretical and Applied Genetics*, 71, 351-358.

Drake, M.A., & Civille, G.V. 2003. Flavor lexicons. *Comprehensive Reviews in Food Science and Food Safety*, 1, 33-40.

Drake, M.A., McIngvale, S.C., Gerard, P.D., Cadwallader, K.R., & Civille, G.V. 2001. Development of a descriptive language for cheddar cheese. *Journal of Food Science*, 66(9), 1422-1427.

Eskin MNA, Grossman S, & Pinsky A. 1977. Biochemistry of lipoxygenase in relation to food quality. *Critical Reviews in Food Science and Nutrition*, 6(1), 1-40.

Federal Register. Food and Drug Administration. 21 CFR, Part 101. Food Labeling: Health Claims; Soy Protein and Coronary Heart Disease. Washington, DC. 64(206), 57699-733.

Fehr, W.E., Caviness, C.E., Burmood, P.T., and Pennington H. 1971. Stage of development description of soybean [Glycine max (L.) Merr.]. *Journal of Crop Science*, 11, 929-931.

Geater, C.W., and Fehr, W.R. 2000. Association of total sugar content with other seed traits of diverse soybean cultivars. *Journal of Crop Science*, 40, 1552-1555.

Giannakourou, M.C., and Taoukis, P.S. 2003. Application of a tti-based distribution management system for quality optimization of frozen vegetables at the consumer end. *Journal of Food Science*, 68(1), 201-209.

Giannakourou, M.C., and Taoukis, P.S. 2003. Kinetic modeling of vitamin C loss in frozen green vegetables under variable conditions. *Food Chemistry*, 83(1), 33-41.

Groff, J.L., and Gropper, S.S. 2000. Advanced Nutrition and Human Metabolism, 3rd Edition. United States: Wadsworth.

Halpin, B.E, and Lee, C.Y. 1987. Effect of blanching on enzyme activity and quality changes in green peas. *Journal of Food Science*, 52(4), 1002-1005.

Johnsen, P.B., Civille, G.V., Vercellotti, J., Sanders, T.H., and Dus, C.A. 1988. Development of a lexicon for the description of peanut flavor. *Journal of Sensory Studies,* 3, 9-18.

Johnson, D., Wang, S., and Suzuki, A. 1999. Edamame: A vegetable soybean for Colorado. In: Perspectives on New Crops and New Uses (Edited by J. Janick). Pp 385-387. ASHS Press: Alexandria, VA.

Kline, W.L. 1980. The Effect of Intra- and Inter-row Spacing on Yield Components of Vegetable Soybeans. Master's Thesis, Cornell University.

Kokobun, M. 1991. Cultural practices and cropping systems for vegetable soybean in Japan. In: Vegetable Soybean: Research Needs for Production and Quality Improvement (Edited by S. Shanmugasundaram). Pp. 53-60. Proceedings of a workshop held in Kenting, Taiwan, April 29– May 2, 1991. AVRDC, Publication No. 91-356.

Konovsky, J., Lumpkin, T.A., and McClary D. 1994. Edamame: The vegetable soybean. In: Understanding the Japanese Food and Agrimarket: A Multifaceted Opportunity. (Edited by A.D. O'Rourke). Pp. 173-181. Binghamton: Hayworth.

Kumar, V., Rani, A., Tindwani, C., and Jain, M. 2003. Lipoxygenase isozymes and trypsin inhibitor activities in soybean as influenced by growing location. *Food Chemistry,* 83, 79-83.

Lawless, H.T., and Heyman, H. 1999. Descriptive Analysis. In: Sensory Evaluation of Food. Pp. 341-378. Gaithersburg: Aspen.

Lee, S.K., and Kader, A.A. 2000. Preharvest and postharvest factors influencing vitamin C content of horticulture crops. *Postharvest Biology and Technology,* 20, 207-220.

Lin, C.C. 2001. Frozen edamame: Global market conditions. In: 2nd International Vegetable Soybean Conference (Edited by T.A. Lumpkin and S. Shanmugasundaram). Pp. 93-96. Washington State University: Pullman.

Liu, K. 1997. Soybeans: Chemistry, Technology and Utilization. New York: International Thomson Publishing.

Llano, K.M., Haedo, A.S., Gerschenson, L.N., and Rojas, A.M. 2003. Mechanical and biochemical response of kiwifruit tissue to steam blanching. *Food Research International*, 36, 767-775.

Lo, C.M., Grun, I.U., Taylor, T.A., Kramer, H., and Fernando, L.N. 2002. Blanching effects on the chemical composition and the cellular distribution of pectin in carrots. *Journal of Food Science*, 67(9), 3321-3328.

Ludikhuyze, L., Indrawati, Van den Broeck, I., Weemaes, C., and Hendrickx, M. 1998. Effects of combined pressure and temperature on soybean lipoxygenase. 1 Influence of extrinsic and intrinsic factors on isobaric- isothermal inactivation kinetics. *Journal of Agriculture and Food Chemistry*, 46, 4074-4080.

Lumpkin, T.A., Konovsky, J.C., Larson, K.J., and McClary, D.C. 1993. Potential new specialty crops from Asia: Azuki bean, edamame soybean, and astragalus. In: New Crops (Edited by J. Janick and J.E. Simon). Pp. 45-51. New York: Wiley.

Lyon, B.G. 1987. Development of chicken flavor descriptive attribute terms aided by multivariate statistical procedures. *Journal of Sensory Studies*, 2, 55-67.

Mahan, L.K., and Escott-Stump, S. Krause's Food, Nutrition, and Diet Therapy. 10th edition. W.B. Saunders Company. 2000.

Main, E.L., Pharr, D.M., Huber, S.C., and Moreland, D.E. 1983. Control of galactosyl-sugar metabolism in relation to rate of germination. *Plant Physiology*, 59, 387-392.

Singh, R.P. 1994. Scientific principles of shelf life evaluation. In: Shelf Life Evaluation of Foods. (Edited by C.M.D. Man and A.A. Jones). Pp. 3-26. London: Blackie Academic & Professional.

Martins, R.C., and Silva, C.L.M. 2004. Frozen green beans (Phaseolus vulgaris, L.) quality profile evaluation during home storage. *Journal of Food Engineering,* 64 (4), 481-488.

Markley, KS. 1950. Soybeans and Soybean Products. New York: Interscience Publishers, Inc.

Masuda, R. 1991. Quality requirement and improvement of vegetable soybean. In: Vegetable Soybean: Research Needs for Production and Quality Improvement (Edited by S. Shanmugasundaram). Pp. 92-107. Proceedings of a workshop held in Kenting, Taiwan, April 29-May 2, 1991. AVRDC, Publication No. 91-356.

Mbuvi, S.W. and Litchfield, J.B. 1995. Green soybeans as vegetable: Comparing green soybeans with green peas and lima beans, and maximized harvest time determinations using mathematical modeling. *Journal of Vegetable Crop Production*, 1, 99-121.

Mebrahtu, T.A., Mohamed A., and Mersie, W. 1991. Green pod and architectural traits of selected vegetable soybean genotypes. *Journal of Production in Agriculture*, 4(3), 395-399.

Mentreddy, S.R., Mohammed, A.I., Joshee, N., and Yadav, A.K. 2002. Edamame: A nutritious vegetable crop. In: Trends in New Crops and New Uses (Edited by J. Janick and A. Whipkey). Pp. 432-438. Alexandria, V.A.: ASHS Press.

Mohamed, A.I., and Rangappa, M. 1991. Nutrient composition and anti-nutritional factors in vegetable soybean: II. Oil, fatty acids, sterols, and lipoxygenase activity. *Food Chemistry*, 44, 277-282.

Munoz, A.M, and Civille, G.V. 1998. Universal, product and attribute specific scaling and the development of common lexicons in descriptive analysis. *Journal of Sensory Studies*, 13, 57-75.

Naito, S., Hirai, M.Y., Chino, M., and Komeda, Y. 1994. Expression of a soybean (Glycine max. (L.) Merr.) seed storage protein gene in transgenic arabidopsis thaliana and its response to nutritional stress and to ascorbic acid mutations. *Plant Physiology,* 104, 497-503.

Norman, A.G. 1963. The Soybean: Genetics, Breeding, Physiology, Nutrition, Management. New York: Academic Press.

Poulsen, K.P. 1986. Optimization of vegetable blanching. *Food Technology*, 21, 122-129.

Pruthi, J.S. 1999. Quick Freezing Preservation of Foods: Principles, Practices, R&D Needs. Volume 2. New Delhi: Allied Publishers Limited.

Qui, L., Chang, R., Sun, J., Li, X., Cui, Z., and Li, Z. 1999. The history and use of primitive varieties in Chinese soybean breeding. In: Proceedings of the World Soybean Research Conference VI. (Edited by AOCS Press). Pp. 165-172. Proceedings in Chicago, Illinois, August 4-7, 1999.

Rao, M.S.S., Mullinix, B.G., Rangappa, M., Cebert, E., Bhagsari, A.S., Sapra, V.T., Joshi, J.M., and Dadson, R.B. 2002. Genotype x environment interactions and yield stability of food-grade soybean genotypes. *Agronomy Journal*, 94, 72-80.

Robinson, D.S., Wu, Z., Domoney, C., and Casey, R. 1995. Lipoxygenase and the quality of foods. *Food Chemistry*, 54, 33-43.

Savas, B.K., Serpen A., Gokmen, V. and Acar, J. 2005. Study of lipoxyenase and peroxidase as indicator enzymes in green beans: change of enzyme activity, ascorbic acid and chlorophylls during frozen storage. *Journal of Food Engineering*, 66, 187-192.

Shanmugasundaram, S., Tsou, S.C.S. and M.R. Yan. 1992. Vegetable soybean for sustainable agriculture. In: The Impact of Biological Research on Agricultural Productivity. (Edited by S.C. Huang, S.C. Hsieh and D. J. Liu). Pp. 379-385. Taichung, Taiwan: DAIS.

Sheu, S.C., & Chen, A.O. 1991. Lipoxygenase as blanching index for frozen vegetable soybeans. *Journal of Food Science*, 56, 448-451.

Shurtleff, W., & Aoyagi, A. 1994. Green Vegetable Soybeans (Edamame) and Vegetable-Type Soybeans – Bibliography and Sourcebook, 3rd Century A.D. to 1994. Soyfoods Center Publishing: California.

Sitatani K. 1991. Cultivation practices for vegetable soybean. In: Vegetable soybean production: proceedings of a training course, Asian Vegetable Research and Development Center. Pp 19-23. Proceedings held in Chiang Mai, Thailand, 18-24 February, 1991.

Song, J.Y, An, G.H., and Kim, C.J. 2003. Color, texture, nutrient contents, and sensory values for vegetable soybeans (Glycine Max. (L.) Merrill) as affected by blanching. *Food Chemistry,* 83(1), 69-74.

Staswick, P.E., and Nielson, N.C. 1983. Characterization of a soybean cultivar lacking certain glycinin subunits. *Archives in Biochemistry and Biophysics*, 223, 1-8.

Takahashi, N. 1991. Vegetable soybean varietal improvement in Japan – past, present, and future. In: Vegetable soybean: research needs for production and quality improvement. (Edited by S. Shanmugasundaram) Pp. 26-29. Proceedings of a workshop held at Kenting, Taiwan April 29 – May 2, 1991. AVRDC, Publication No. 91-356.

Tsou, S.C.S. and Hong, T.L. 1991. Research on vegetable soybean quality in Taiwan. In: Vegetable soybean: research needs for production and quality improvement. (Edited by S. Shanmugasundaram) Pp. 103-107. Proceedings of a workshop held at Kenting, Taiwan April 29 – May 2, 1991. AVRDC, Publication No. 91-356.

United States Department of Agriculture, Agriculture Research Service. National Genetic Resources Program, Germplasm Resources Information Network (GRIN) [Online Database]. National Germplasm Resources Laboratory, Beltsville, Maryland. Available at http://www.ars.grin.gov (accessed September 25, 2004).

United States Department of Agriculture, Agriculture Research Service. Nutrient Data Laboratory [Online Database]. Nutrition Research Center, Beltsville, Maryland. Available at http://www.nal.usda.gov (accessed September 25, 2004).

Wang, H.J., and Murphy, P.A. 1994. Isoflavone content in commercial soybean foods. *Journal of Agriculture and Food Chemistry*, 42, 1666-1673.

Watanbe, S., Uesugi, S., and Kikuchi, Y. 2002. Isoflavones for prevention of cancer, cardiovascular diseases, gynecological problems and possible immune potentiation. *Biomedicine and Pharmacotherapy*, 56, 302-312.

Williams, D.C., Lim, M.H., Chen, A.O., Pangborn, R.M., and Whitaker, J.R. 1986. Blanching of vegetables for freezing; which indicator enzyme to choose. *Food Technology,* 40(6), 130-140.

Young, V.R. 1991. Soy protein in relation to human protein and amino acid nutrition. *Journal of the American Dietetic Association*, 95(1), 828-834.

Character	***Range***
Pod Appearance	
Pod color	Bright green, no blemishes
Pod length	> 5.0 cm
Pod width	> 1.4 cm
Frequency of 1 seeded pod	< 25 %
Plant Appearance	
Leaf	Large, lanceolate
Pubescence color	Gray
Branching	Minimal
Pod clearance	> 10 cm from soil
Number nodes on main stem at harvest	10 to 14
Flowering	> 40 days post planting
Seed appearance	
Seed color	Bright green, no blemishes
100 seed weight	> 30 g
Hilum color	Gray or light brown
Harvest	Pods easy to strip, long duration from R6 to R7
Resistance	Downy mildew, bacterial pustule, soybean rust, high temperature

Table 1. A partial list of ideal characteristics of edamame cultivars in Taiwan. (Carter and Shanmugasundaram, 1993)

Nutrients and Units	**FAO**	**USDA**	**Japan**
Energy (kcal)	437	452	429
Protein (g)	40.8	39.9	39.4
Lipid (g)	17.9	20.9	22.8
Carbohydrate (g)	35.8	34	32.2
Crude fiber (g)	6	6.3	6.6
Ash (g)	5.3	5.2	5.5
Calcium (mg)	245	606	242
Iron (mg)	11.9	10.9	5.9
Phosphorus (mg)	496	596	484
Potassium (mg)			484
Sodium (mg)			3
Ascorbic Acid (mg)	84.9	89.2	93.4
Thiamin (mg)	1.25	1.34	0.93
Riboflavin (mg)	0.53	0.54	0.48
Niacin (mg)		5.08	3.5
Vitamin A (IU)	1132	554	346

Table 2. Chemical composition of 100 g of vegetable soybeans.
(Konovsky et al, 1994)

Amino Acids	***Vegetable Soybeans*** **g/100 g protein**	***Adult human requirements*** **mg/kg BW/day**
Tryptophan	1.24	3.5
Threonine	4.09	7
Isoleucine	4.51	10
Leucine	7.33	14
Lysine	6.13	12
Methionine	1.24	13
Phenylalanine	4.64	14
Valine	4.56	10
Histidine	2.76	8 to 12
Non essential:		
Cystine	0.93	1
Tyrosine	3.67	6

Table 3. Amino acid composition of seed protein from edamame (vegetable soybean) seed (g/100 g protein) and estimated adult amino acid daily requirements. (Carter and Shanmugasundaram, 1993)

Chapter Two

The Development of a Lexicon for Frozen Vegetable Soybeans

2.1 Abstract

American vegetable soybean consumption is limited but potential for increased markets based on increased U.S. production is high. Interest in soy foods has risen, fueled by research proving health benefits correlated with soy consumption. The vegetable soybean (Glycine max. (L.) Merrill) is a specialty soybean harvested when the seeds are immature. Due to the narrow window of time available to harvest this crop, freezing is essential for year-round availability of vegetable soybeans. Investigation in vegetable soybean cultivation and processing in the U.S. is ongoing. A flavor lexicon, a set of terms which identify and define the associated aromatic, tastes and feeling factors of a product, for frozen vegetable soybeans was created. This lexicon will provide a standard flavor language for vegetable soybean producers and researchers. A representative sample of commercial frozen vegetable soybean samples was collected. The frozen vegetable soybean lexicon was developed by a 12 member panel of flavor and soybean specialists. Intensity ratings, based on the Sensory Spectrum® scaling method were given to all lexical terms. Food and chemical references, which exemplified the lexicon descriptors were generated and evaluated by the panel. Frozen vegetable soybean flavor was described by 8 aromatics, 3 feeling factors and the basic tastes. In the subsequent months a highly trained descriptive panel validated the lexical language and intensity scores.

2.2 Introduction

Vegetable soybeans are a well established legume of the human diet in Asia (Carter and Shanmugasundaram, 1993). Quality research in Asia on vegetable soybeans has focused on the processing industry. Taiwan is one of the largest producers of vegetable soybeans but does not have a full spectrum grading system for soybeans (Tsou and Hong, 1991). Evaluation of vegetable soybeans in Asia is based on a grading system for appearance, while flavor quality of vegetable soybeans has not been objectively defined (Tsou and Hong, 1991). Early methods to evaluate vegetable soybean flavor lacked descriptive detail (Carter and Shanmugasundaram, 1993) and the sensory characteristics were often vague. Indistinct statements such as, 'vegetable soybeans are characterized by a mild flavor' (Lumpkin et al., 1993) and 'superior eating quality compared to field soybeans' (Mbuvi and Litchfield, 1995) are insufficient to describe sensory characteristics.

Prior research has shown that the most desirable flavors in vegetable soybeans are sweetness, nuttiness (Carter and Shanmugasundaram, 1993), umami (Masuda, 1991) and low degree of beany flavor (Konovosky et al., 1994). Masuda has described bitter, astringent, and metallic flavors to be unacceptable flavors (Masuda, 1991). An opinion among older Japanese consumers is that the taste of vegetable soybeans has deteriorated as the product has become commercialized (Lumpkin et al., 1993); however, no characterization of the flavors causing this decline has been determined.

Descriptive analysis is useful in situations when a detailed characterization of the sensory attributes of a single product, or a comparison among products is desired. These techniques are ideal for shelf life testing, especially if the descriptive panel members are well trained and consistent over the experimental time (Lawless and Heymann, 1999).

Previous flavor lexicons have been used extensively in research and industry for comparing and monitoring products (Drake and Civille, 2002), as well as analyzing product consistency during storage. Researchers have used descriptive sensory analysis to compare the flavor and aroma in soy milk (Torres-Penaranda and Reitmeier, 2001). The peanut lexicon (Johnsen et. al, 1988) has been used to determine the effects of storage time, and processing parameters on peanut flavor and aroma perceptions. Prior to this research, Sensory Spectrum® based descriptive analysis had not been used to analyze the flavor in vegetable soybeans. The Spectrum approach employs a standard lexicon of terms for each product under analysis (Lawless and Heymann, 1999). The method is based on a universal scaling approach; attribute intensities are rated on an absolute and universal basis and the intensity boundaries are established on a 0 to 15 point scale (Meilgaard et al., 1997).

The positive health benefits of soy have greatly increased consumer awareness of soy products and created a market potential for soy foods (Ohr, 2000). Prior research has examined the consumer acceptability of vegetable soybeans, and has indicated a preference for the frozen product (Young et al., 2000). The objective of this study was to develop a lexicon and standard references of flavor descriptors for frozen vegetable soybeans. A standard sensory language will allow researchers to obtain descriptive sensory analysis results that are consistent over time, extend beyond national borders, and can be used to understand factors that generate consumer acceptance.

2.3 Materials and Methods

Twenty 16 oz. sample packages of frozen vegetable soybeans, manufactured in China, Taiwan and Japan, were obtained from traditional domestic and Asian grocery stores on the East and West coasts of the U.S. (Table 4). Samples included twelve brands marketed as both shelled and in-pod, and four additional brands only in-pod. Samples were purchased during a two month period prior to evaluation, and stored at -25° C +/- 2° C.

Preliminary Sample Screening

Because of prior experience with soy flavor (creating soy product lexicons) and vegetable soybean flavor the initial flavor screening was conducted by Sensory Spectrum®, Inc.. Samples were categorized into "on" note and "off" note groups by distinct flavor attributes of the samples. A preliminary list was developed that included flavor terms, feeling factors, and basic tastes (Table 5). Each vegetable soybean sample was scored for intensity of all terms. The owner of Delight Soy Foods, Inc. and an expert in soy flavor, Lila Chung, also participated in evaluation of soybean samples. Based on the soy flavor experience of Lila Chung, the samples were considered to be representative of the range of flavor characteristics present in vegetable soybeans.

Assessors

For lexicon development a twelve member panel of participants from academia, industry, and government was assembled. The panel consisted of 9 females and 3 males. Members were selected on the basis of their experience in descriptive sensory analysis and/or vegetable soybean flavor. The use of individuals with diverse backgrounds was effective in generating a comprehensive initial language for comparison with the preliminary Spectrum® list. Participants included Gail Civille (Sensory Spectrum, Inc., Chatham, N.J.), Timothy Sanders (USDA-ARS MQHR, Raleigh, N.C.), Lisa Dean (USDA-ARS MQHR, Raleigh, N.C.), Michele Keziah (North Carolina State University, Raleigh, N.C.), Stephanie Drake (North Carolina State University, Raleigh, N.C.), Mary

Anne Drake (North Carolina State University, Raleigh, N.C.), Keith Hendrix (USDA-ARS, MQHR, Raleigh, N.C.), Lila Chung (Delight Soy Foods, Inc., Morrisville, N.C.), Whitney Whooten (Delight Soy Foods, Inc., Morrisville, N.C.), Aju Lekwauwa (Processing Engineer Consultant, Winston-Salem, N.C.), Minoo Mehrotra (North Carolina State University, Raleigh, N.C.), and Beryl Krinsky (North Carolina State University, Raleigh, N.C.).

Sample Preparation

Vegetable soybean samples were prepared for sensory analysis by mixing distilled water with vegetable soybeans in a 2:1 ratio, respectively. According to directions on sample packages the samples were cooked by micro-wave on high heat. The in-shell vegetable soybeans were cooked for 12 minutes, and the shelled soybeans were cooked for 9 minutes. Following cooking the water was drained, and the soybeans were placed in 2 oz. coded cups with lids, and stored at 6°C overnight.

Vocabulary Development

The lexicon discussion was led by Gail Civille (Sensory Spectrum, Inc., Chatham, N.J.). Vegetable soybeans were divided into two groups based on their most distinct flavor characteristics. The panel initially evaluated the vegetable soybeans which represented the "on notes". This session generated terminology for characteristic vegetable soybean flavor. The panel then assessed the "off note" category and developed terms which described the off flavors present in the samples. Panel discussions identified common descriptors among word groups, and initial flavor definitions and references were composed.

To rate the intensity of vegetable soybean flavor the fifteen point Spectrum® numerical scale was utilized. The Spectrum® scale is standardized and anchored with multiple reference points. Potential references, food or chemical, that represented vegetable soybean flavor were evaluated by the panel.

Lexicon Validation

A previously trained descriptive sensory panel was employed to refine the developed language and confirm chosen references. Twelve individuals, 6 males and 6 females were selected from University staff and students based on descriptive analysis experience and a liking for vegetable soybeans. Eleven panelists had prior experience with the Spectrum® method of descriptive sensory analysis. The panel received weekly training sessions for two months using the Spectrum® method with the full range of references. During training panelists evaluated various vegetable soybean samples and references. Panelists were encouraged to discuss terms and intensity ratings during evaluation.

The final step in developing the frozen vegetable soybean lexicon was to validate the lexicon terminology. This was achieved by requiring the expert panel to evaluate "blind" samples using both the lexicon and the established intensity scale. The range of samples included references for both in-shell and shelled vegetable soybeans.

2.4 Results and Discussion

The descriptors initially agreed upon in the initial stage of lexicon development are shown in Table 6. These terms were used as a foundation for the descriptive analysis panel.

The refined language is shown in Table 7. All descriptors were clarified and included specific definitions and references. Appropriate chemical references were used whenever possible. References were chosen as characteristic of a lexicon term or similar specific flavor.

Various soy product lexicons, soymilk (Torres-Penaranda and Reitmeier, 2001) and soy protein concentrates/isolates (Russell, 2004) have been recently developed in the U.S. Some terms, definitions, and references were similar to those described and defined in this study, and others are unique. Differences may be explained by the variation in product category of the minimally processed vegetable soybeans versus more extensive processing of soymilk and soy protein.

During language identification and lexicon validation, 15 flavor terms were frequently observed in frozen vegetable soybeans. Six additional terms were found to be observed rarely in vegetable soybeans. The 6 terms that are not frequently observed are still important for the frozen vegetable soybean language. The basic language of 15 terms is sufficient for sample analysis or panel training, and the additional 6 terms should be referred to whenever necessary. It is crucial to develop a comprehensive lexicon while also maintaining clarity in the terms, to lessen the degree of panel confusion.

2.5 Conclusions

A defined and referenced sensory language for frozen vegetable soybean flavor was identified and validated. Fifteen terms could be used to describe and differentiate the majority of flavors found in frozen vegetable soybeans. The terminology can be used in correlation with instrumental data, product development, shelf-life analysis, quality control, and basic research.

2.6 References

Carter, T.E., Jr., Shanmugasundaram, S. 1993. Edamame, the vegetable soybean. In: Underutilized Crops: Pulses and Vegetables (Edited by T.Howard). Pp. 219-239. London: Chapman and Hill.

Drake, M.A., Civille, G.V. 2003. Flavor lexicons. *Comprehensive Reviews in Food Science and Food Safety*, 1, 33-40.

Drake, M.A., McIngvale, S.C., Gerard, P.D., Cadwallader, K.R., & Civille, G.V. 2001. Development of a descriptive language for cheddar cheese. *Journal of Food Science*, 66(9), 1422-1427.

Johnsen, P.B., Civille, G.V., Vercellotti, J., Sanders, T.H., Dus, C.A. 1988. Development of a lexicon for the description of peanut flavor. *Journal of Sensory Studies,* 3, 9-18.

Konovsky, J., Lumpkin, T.A., McClary D. 1994. Edamame: The vegetable soybean. In: Understanding the Japanese Food and Agrimarket: A Multifaceted Opportunity (Edited by A.D. O'Rourke). Pp. 173-181. Binghamton: Hayworth.

Lawless, H.T., Heyman, H. 1999. Descriptive Analysis. In: Sensory Evaluation of Food. Pp 341-378. Gaithersburg: Aspen.

Lumpkin, T.A., Konovsky, J.C., Larson, K.J., McClary, D.C. 1993. Potential new specialty crops from Asia: azuki bean, edamame soybean, and astragalus. In: New Crops (Edited by J. Janick and J.E. Simon). Pp. 45-51. New York: Wiley.

Masuda, R. 1991. Quality Requirement and Improvement of Vegetable Soybean. In: Vegetable Soybean: Research Needs for Production and Quality Improvement. (Edited by S. Shanmugasundaram) Pp. 92-107. Proceedings of a workshop held at Kenting, Taiwan April 29 – May 2, 1991. AVRDC, Publication No. 91- 356.

Mbuvi, S.W., Litchfield, J.B. 1995. Green soybeans as vegetable: Comparing green soybeans with green peas and lima beans, and maximized harvest time determinations using mathematical modeling. *Journal of Vegetable and Crop Production*, 1, 99-121.

Meilgaard, M., Civille, G.V., Carr, B.T. 1997. Sensory Evaluation Techniques. 3rd edition. Boca Raton, FL.: CRC Press, Inc. 387 p.

Ohr, L.M. 2000. A magic bean sprout. *Prepared Foods*, 69, 60-62.

Russell, T.A. 2004. Comparison of sensory properties of whey and soy protein concentrates and isolates. Master's Thesis. North Carolina State University.

Torres-Penaranda, A.V., Reitmeier, C.A. 2001. Sensory descriptive analysis of soymilk. *Journal of Food Science*, 66(2), 352-356.

Tsou, S.C.S., Hong, T.L. 1991. Research on vegetable soybean quality in Taiwan. In: Vegetable soybean: research needs for production and quality improvement. (Edited by S. Shanmugasundaram) Pp. 103-107. Proceedings of a workshop held at Kenting, Taiwan April 29 – May 2, 1991. AVRDC, Publication No. 91- 356.

Young, G.T., Mebrahtu, T., Johnson, J. 2000. Acceptability of green soybeans as a vegetable entity. *Plant Foods for Human Nutrition*, 55, 323-333.

Brand	In-Pod	Shelled
Asian Taste	+	+
HNSTY	+	+
Oriental Mascot	+	+
Whole Foods 365	+	+
Cascadian Farms	+	+
Seapoint Farms	+	+
Chef Bowl	+	+
Ye Yee	+	+
Nissui	+	-
Joy Food	+	-
Wel-Pac	+	-
Wei-Chaun	+	-

Table 4. Brands of frozen vegetable soybeans obtained for lexicon development.

Aromatics:

Fruity
- Stone
- Tropical/Raw coconut

Vegetable complex
- Legume/Beany/Raw
- Legume/Beany/Cooked

Potato/Earthy
Nutty
Hay/Straw
Moldy/Geosmin
Green complex
- Grassy
- Woody
- Stalk/Leafy/cooked
- Bell pepper

Painty
Cardboard
Degraded protein
Sulfur

Basic Tastes:

Salty
Sweet
Sour
Bitter

Feeling Factors:

Astringent
Metallic

Table 5. Sensory Spectrum® preliminary descriptor list.

Aromatics:	Basic Tastes:
Bean Complex	Salty
Raw Bean	Sweet
Cooked Bean	Bitter
Green Complex	Sour
Grassy	
Weedy	**Feeling Factors:**
Woody/Twigs	Astringent
Nutty, Raw Almond	Metallic
Fruity	Umami
Dried stone Fruit	
Coconut	
Brothy	
Sulfur	

Table 6. Flavor descriptors in the first stage of lexicon development

Term	Definition
Bean Complex	Aromatic characteristic of soybeans/legumes ***Reference:*** Raw/cooked peas/lima/green beans
Raw Bean	Aromatic characteristic of raw soybeans/legumes ***Reference:*** Raw peas/lima/green beans
Cooked Bean	Aromatic characteristic of cooked soybeans/legumes ***Reference:*** Frozen lima/green beans, canned peas cooked
Green Complex**	Aromatic characteristic of freshly cut twigs/grass ***Reference:*** Cis-3-hexanol
Grassy*	Green, sweet aromatic, similar to cut grass ***Reference:*** Fresh cut grass in distilled water
Weedy *	Sharp/pungent weed like aromatic ***Reference:*** 2-Isobutylthiazole
Woody/Twigs*	Aromatic associated with green/woody twigs ***Reference:*** Green twigs in distilled water
Nutty/Almond	Aromatic of raw almonds, legume like character ***Reference:*** Raw, sliced almonds, blanched
Fruity Complex**	Aromatic associated with a mixture apple/pear/tropical ***Reference:*** Brewed black tea, room temperature
Coconut*	Aromatic associated with coconut meat or milk ***Reference:*** Canned coconut milk
Stone fruit*	Aromatic associated with apples/pears ***Reference:*** Applesauce
Brothy	Aromatic/taste associated with boiled meat/soup/stock ***Reference:*** Kitchen Basic
Sulfur	Aromatic associated with hydrogen sulfide, rotten egg ***Reference:*** Frozen soybeans, left in ambient temperature (3 days)
Salty	Taste on tongue simulated by sodium salt (NaCl) ***Reference:*** 0.3% NaCl in distilled water
Sweet	Taste on tongue stimulated by sugar/high potency sweetener ***Reference:*** 5.0% Sucrose soln. in distilled water
Sour	Range from fermented vegetables to lactic or spoiled bacteria ***Reference:*** 0.08% citric acid soln. in distilled water
Bitter	Taste on tongue stimulated by caffeine/quinine/alkaloids ***Reference:*** 0.1% solution of caffeine
Astringent	Feeling factor on oral cavity; puckering/dry; tannins/alum ***Reference:*** 1% alum in distilled water
Umami	Feeling factor elicited from glutamate/aspartate/ribonucleotides ***Reference:*** 1% Monosodium glutamate in distilled water
Metallic*	Flat chemical feeling factor stimulated by coins on tongue

*Indicates term was not frequently encountered in frozen vegetable soybeans.
**Term is a combination of several terms.

Table 7. Frozen vegetable soybean lexicon following additional descriptive sensory analysis.

Chapter Three

Effect of Blanching Time on Sensory and Quality Parameters of Vegetable Soybeans during Frozen Storage

3.1 Abstract

Quality concerns related to vegetable soybeans require harvest to be carried out quickly, dictating that the product be frozen for year round availability. Enzyme inactivation by blanching is needed to maintain nutritional and sensory quality of the vegetable soybeans during storage. The research objective was to determine the optimal blanching time prior to frozen storage. Vegetable soybeans (Mojo Green var.) were harvested 119 days after planting. Soybean pods were water blanched (100 °C) for 30, 60, 90, 120 and 180 seconds in duplicate and cooled in ice water. One half of each treatment was shelled and the other half remained unshelled. Samples of both types were packed in plastic bags and stored at -24 ° C. Samples were evaluated after 0, 2, 4, 8, 12, 16, 30, 40 and 52 weeks. Analysis consisted of lipoxygenase activity, descriptive sensory analysis, Hunter L, a, b color, texture, and ascorbic acid quantification. Blanching times of 60 seconds or greater were sufficient to inactivate lipoxygenase. Descriptive sensory analysis confirmed that off-flavor production was enhanced at blanching times less than 60 seconds and that blanching time was directly related to the development of cooked bean and brothy flavor and umami feeling factor. Texture analysis revealed that blanching time was inversely related to bean firmness. Optimal color retention was achieved in 30 to 90 second blanched shelled soybeans and 30 to 120 second soybeans in pods. The highest ascorbic acid retention was found in shelled soybeans blanched for 60 to 120 seconds, and in-pod soybeans blanched for 60 to 90 seconds. The results indicated that the shortest acceptable blanching time (60 seconds) with respect to lipoxygenase inactivation also yielded acceptable soybean flavor, crisp texture, optimal green color and highest ascorbic acid retention during frozen storage.

3.2 Introduction

Vegetable soybeans are a popular food source in Asia. In Japan, the soybean is served as snack food, frozen, and used in vegetable mixes. Frozen soybeans in the pod are regularly imported from Asia to the U.S. to meet consumer's demand for Asian specialty food products (Mebratu et al., 1991). Individually owned farms in Asia produce vegetable soybeans for Asian and U.S. market distribution (Konovsky et al., 1994). The demand for soy products increased in the U.S. following the 1999 FDA soy health claim (Drake and Gerard, 2003). As the demand for vegetable soybeans increases in the U.S., the product establishes a new crop for farmers in the niche market arena (Carter and Shanmugasundaram, 1993). Due to the expanding U.S. interest, agricultural researchers and farmers in North Carolina, Kentucky, Virginia and Washington states have begun cultivating the vegetable soybean (Young et al., 2000).

In the beginning stages of mass production, there is a need for standardization of control practices in processing to ensure product quality and consistency. Blanching in hot water (70 – 100° C) or steam is a pre-freezing step used to reduce or eliminate product quality degradation during frozen storage in vegetable products. Blanching may be carried out by different methods, but water blanching is the most extensively used for vegetables (Savas et al., 2005). Excessive blanching will cause quality losses in vegetables, including texture (Bourne, 1982; Savas et al., 2005), color (Barret and Theerakulkait, 1995), and ascorbic acid (Bates and Matthews, 1975; Albrecht et al., 1990; Giannakourou and Taoukis, 2003). Process optimization involves measuring the indicator enzymes' rate of inactivation, ensuring that blanch time is sufficient to inactivate the enzyme, yet not too long to cause undesirable quality loss (Barret and Theerakulkait, 1995).

The lipoxygenase (LOX) present in vegetable soybeans (Kumar et al., 2003; Liu, 1997; Mohamed and Rangappa, 1991) has been associated with oxidative rancidity, leading to off flavor development (Baardseth, 1979), reduction of essential nutrients (Robinson et al., 1994) and fatty acids (Mohamed and Rangappa, 1991). Research has indicated that the LOX present in un-blanched vegetables may be responsible for bleaching of chlorophyll (Robinson et al., 1994). LOX activity can be suppressed by conventional heating, microwave heating, gamma irradiation, and soaking in lactic acid (Mohamed and Rangappa, 1991).

Research needs for vegetable soybeans have previously been outlined in Asia (Konovsky et al., 1994). The relationship between consumer preference for taste and chemical composition of the seeds needs exact characterization. Poor flavor in vegetable soybeans is the primary complaint of Japanese consumers. Negative flavors and the correlation of LOX activity in vegetable soybeans have not yet been fully explained. The action of soybean LOX forms compounds with objectionable flavors, responsible for lowered acceptability of soy milk and soy-nuts (Wang and Toledo, 1987). The question remains if the activity of the LOX found in vegetable soybeans is great enough to produce off flavors that negatively affect sweet and savory flavor characteristics (Konovsky et al., 1994). The objectives of this research will examine several of these issues.

The primary objective of this study was to determine the optimal blanching time for vegetable soybeans prior to frozen storage. The objective quality measurements performed on vegetable soybeans during 52 weeks of frozen storage included lipoxygenase activity, descriptive sensory analysis, texture, color, and ascorbic acid content.

3.3 Materials and Methods

Fresh vegetable soybeans (Mojo Green var.) were obtained from a North Carolina State University (N.C.S.U.) research farm (Goldsboro, N.C.) during the summer of 2003. The soybeans were planted on June 11 and began flowering approximately on July 20, 2003. Soybeans were harvested on August 27, 2003 and transferred to the N.C.S.U. Food Science Department fruit and vegetable processing pilot plant. Vegetable soybean pods were hand sorted to remove debris. Pods were tumbled and cleaned in a rotational spray drum until all visible debris was removed. Approximately 880 kg of soybean pods were subdivided into twelve sub-samples which were placed in a 32 gallon steam jacket kettle and water blanched (100° C), in pods, for either 30, 60, 90, 120 and 180 seconds. After blanching half of the samples were shelled and the other half were kept in-pods. Following blanching, the soybeans were rapidly cooled in ice water. The water was drained, and the soybeans were transported to a freezer where they were spread evenly on metal trays. Quick freezing was achieved by using 2 large fans which created an efficient air-blast pattern through the soybeans. After the vegetable soybeans cooled to an internal temperature of 10 to 20° C they were packaged in polyethylene bags for frozen storage at - 24° C. Samples were removed from frozen storage at 0, 2, 4, 8, 12, 16, 30, 40 and 52 weeks for determination of lipoxygenase activity, descriptive sensory analysis, texture, color, and ascorbic acid concentration.

Lipoxygenase Assay

LOX activity was assayed using the method described by Chen and Whitaker (1986). The 0.01M substrate stock mixture contained 157.2 ul linoleic acid, 157.2 ul Tween-20, and 10 ml of distilled water. The solution was clarified by adding 1.0 ml of 1.0 N NaOH and diluted with an additional 50 ml of distilled water. Prior to the assay, 0.2 M sodium phosphate buffer (pH 7.0) was added to the substrate, to yield a final concentration of 2.5 mM linoleic acid. The solution was flushed with pure oxygen for 2 minutes and placed in a water bath (37° C) for 10 minutes and allowed to equilibrate prior to use. All glassware used in the preparation of the substrate was wrapped in aluminum foil to exclude light. To prepare LOX assay sample's (25 g) of vegetable soybeans controls and from each blanching treatment were blended with 50 ml of Tris buffer (pH 8.0) in a Waring® commercial blender. Each blended sample was filtered by vacuum filtration through 4 layers of cheese cloth into Oakridge® centrifuge tubes and centrifuged at 17,000 rpm at 4° C for 1 hour in a Sorvall RC-5B super-speed refrigerated centrifuge®. A Pasteur pipette was used to remove 10 ml of supernatant, to ensure adequate amount for assay reading, and dispensed into a sterile plastic tube. For the LOX assay 10 ul of vegetable soybean extract was added to 3.0 ml of substrate in a 1 cm quartz cuvette, capped and shaken by hand for 10 seconds. The cuvette containing the solution was placed in a double beam UV-VIS scanning spectrophotometer, Gilford Model 2600. The initial rate of conjugated diene formation was measured from the linear change of absorbance at 234 nm. LOX activity was defined as the change in absorbance per minute divided by the quantity of vegetable soybean sample used.

Bicinchoninic acid Protein Assay

Protein was determined by the method of Smith et al. (1985). A standard curve was prepared by diluting bovine serum albumin (BSA) in Tris buffer to result in a concentration of 1 μg/ml. A series of dilutions (0, 1, 2.5, 5, 10, and 20 μg/test tube) were made in duplicates with a final volume of 100 μl. To prepare samples, 25 g of each vegetable soybean blanching treatment were blended with 50 ml of Tris buffer (pH 8.0) in a Waring® commercial blender. Each blended sample was filtered by vacuum filtration through 4 layers of cheese cloth into Oakridge® centrifuge tubes and centrifuged at 17,000 rpm at 4° C for 1 hour in a Sorvall RC-5B super-speed refrigerated centrifuge®. A Pasteur pipette was used to remove 10 ml of supernatant, to ensure adequate amount for assay reading, and dispensed into a sterile plastic tube. Vegetable soybean solutions were diluted such that they would fall within the BSA standard range (0-25 μg / 100 μl) and 100 μl were placed in glass test tubes. After standards and samples were diluted and transferred to test tubes, 2.0 ml of Bicinchonicinic acid (BCA) working reagent was added to each tube and mixed thoroughly in a vortex mixer. BCA working reagent was prepared by mixing 0.5 ml of 1% cupric sulfate with 0.5 ml of 2% sodium potassium tartrate, followed by the addition of 50 ml of 2% sodium carbonate in 0.1 N NaOH. The mixture was then allowed to incubate at room temperature for 10-15 minutes prior to the addition of 20 μl per well of 1.0 N Folin-Ciocalteu's reagent. All samples were incubated in a heated water bath (37 °C) for 30 minutes. The absorbance was measured at 562 nm in a double beam UV-VIS scanning spectrophotometer, Gilford Model 2600. Protein quantity was determined by relating the results of the standard BSA curve with the absorbance of each vegetable soybean sample.

Descriptive Sensory Analysis

Using the frozen vegetable soybean lexicon, 12 trained panelists evaluated the flavor attributes of soybean controls and from each blanching treatment. Vegetable soybean samples were prepared for sensory analysis by mixing distilled water with vegetable soybeans in a 2:1 ratio, respectively. Samples were cooked by micro-wave on high heat. The in-pod vegetable soybeans were cooked for 12 minutes and the shelled soybeans were cooked for 9 minutes. Following cooking the water was drained, and the soybeans were placed in 2 oz. coded cups with lids, and stored at 6°C overnight.

Texture Analysis

Texture of vegetable soybean samples was determined to evaluate changes due to blanching variation and storage time. The Instron Universal model testing machine is screw driven and can be used to measure hardness of fruits and vegetables. Data produced by the machine during testing was recorded by National Instruments Lab View® data acquisition software. The Kramer shear analysis was performed using the Instron Universal model testing machine (Model 1122, Canton, MA), and a 500 kg load cell. The Kramer shear cell consisted of 10 aluminum blades which were driven into corresponding slots of the extrusion cell to compress the vegetable soybeans until they were crushed and subsequently pushed through slots at the base of the cell. The force required for extrusion can be related to hardness of the sample (Bourne, 1982). All soybean samples used for texture analysis were cooked (refer to descriptive sensory analysis for cooking method) and shelled. Sample weights of 100 g were analyzed, using a crosshead speed of 100 mm/min.

Color Analysis

Objective color measurements were performed to determine differences between controls and blanching treatments and changes incurred during storage for shelled and in-shell soybeans. Color (L, a, and b values) was measured using a Hunter L, a, b colorimeter (Model DP-9000). Hunter L, a, b is a color scale based on the “opponent colors theory”, which assumes receptors in the human eye view color as opposites; light to dark, red to green, and yellow to blue. The L value for the scale indicates the level of light or dark, the a value indicates the degree of redness or greenness, and b shows yellowness or blues (Figure 1). The combination of L, a, and b are needed to fully describe the color of an object. The Hunter L, a, b scale is visually meaningful because the three values can be easily understood and translated into color (Hunter Lab, 2004).

Samples were cooked for color analysis (refer to descriptive sensory analysis for cooking method) and placed in 5-inch glass sample cups for measurement.

Ascorbic Acid Analysis

Ascorbic acid concentration in vegetable soybean samples was determined by AOAC method 967.21. Frozen vegetable soybean samples (5 g) were blended with 95 ml of metaphosphoric acid-acetic acid solution (15 g of hydrogen phosphorus and 40 ml of acetic acid in 500 ml of water). Each solution was filtered through four layers of cheese cloth by vacuum filtration into centrifuge tubes. Samples were centrifuged in a Damon/IEC division international centrifuge, model K, at 2,500 rpm for 20 minutes and diluted to obtain a final concentration of 10-100 mg of ascorbic acid/100 ml. Replicates were titrated by a 50 ml buret with indophenol solution until a pink color lasted for a minimum of 10 seconds.

Statistical Analysis

All statistical analyses were conducted using Statistical Analysis System, Version 8.2 (SAS Institute Inc., Cary, N.C., U.S.A., 2004). Significance was established at $p < 0.05$. Analyses were conducted on the means of replicates for each sample. Principal component analysis of the standardized responses (PROC PRINCOMP) was completed on the correlation matrix to determine how vegetable soybean blanching treatments were differentiated by flavor. LOX, color, texture and ascorbic acid data were analyzed using analysis of variance. Tukey’s Test was used to compare means of results from analyses performed on vegetable soybeans and Dunnett's Test was used to examine differences in vegetable soybeans which occurred during storage.

3.4 Results and Discussion

Processing

Soybeans blanched for 30 seconds reached an internal temperature of 80 ° C (Figure 2). Soybeans that were blanched for 60 to 180 seconds increased to an internal temperature of 95 – 100 ° C.

Vegetable soybeans blanched for 30 seconds produced the greatest yield in shelling efficiency (Figure 3). As blanching time increased, shelling efficiency decreased. The increased blanching time decreased the original firmness of the soybeans. As the vegetable soybeans softened, a higher percentage may have been crushed in the shelling machine.

Lipoxygenase

The use of LOX as an indicator enzyme has been proven effective for frozen vegetables (Barrett and Theerakulkait, 1995; William et al., 1986) and specifically vegetable soybeans (Sheu and Chen, 1991). In vegetable soybeans blanched for 30 seconds the LOX activity declined by 80%. All treatments that were blanched for $\geq$60 seconds had a minimal residual enzymatic activity of ca. 5 % (Table 8). Prior research (Sheu and Chen, 1991) has indicated that inactivating 90% of LOX is essential for maintaining favorable quality in vegetable soybeans during frozen storage

Over the course of the study there were no significant changes in the rate of LOX activity in the in-pod control, or any in-pod blanch treatment. After 30 weeks of storage the enzymatic rate of the shelled control declined significantly ($p < 0.05$), and remained significantly lower for the remainder of the study. There were no significant differences observed in any blanched and shelled vegetable soybean during the 52 weeks of storage. The mean enzymatic rate for shelled and in-pod control and blanched soybeans is displayed in Table 8.

Enzymatic activity rate may be influenced by the quantity of protein in vegetables (Kumar et al., 2003). Protein quantities for shelled and in-pod controls and blanched soybeans were not meaningfully different (Table 9).

Descriptive Sensory Analysis

Vegetable soybeans blanched for different times varied significantly in flavor. Un-blanched and minimally blanched (30 second) shelled and in-pod soybeans developed off-flavors of green complex, sulfur, sour and fruity. Shelled and in-pod vegetable soybeans blanched for more than 60 seconds did not develop off-flavors during 52 weeks of frozen storage.

At week 0, principal component analysis revealed that two components explained 57% of the variance (Figure 4). Principal component one showed an inverse relationship between bean complex, cooked bean with green complex, raw bean, and fruity. Vegetable soybeans which were highest in green complex, raw bean and fruity flavor were shelled and in-pod controls, 30 second shelled, and 180 second in-pod. Vegetable soybeans which had the highest level of bean complex were the 30 second blanched in-pod; vegetable soybeans which had been blanched for the longest times had the highest cooked bean flavor. Principal component two showed that raw bean, green complex were inversely related to umami, salty and bitter. Vegetable soybean controls and 30 second blanch treatments had more raw bean and green complex flavor. Treatments which had been blanched more extensively had higher levels of umami, salty, and bitter.

In week 2 (Figure 5), principal component one showed a clear difference between fruity, sulfur, sour, raw bean, green complex with bean complex, cooked bean. The shelled and in-pod controls and 30 second blanched soybeans were higher in fruity, sulfur, sour, raw bean, and green complex flavor; whereas shelled and in-pod vegetable soybeans which had been blanched for longer had higher cooked bean and bean complex flavor.

As storage time increased, the off-flavors green complex, sulfur, sour and fruity increased in the shelled and in-pod controls and 30 second blanched treatments. LOX activity during storage may have been responsible for the development of these off flavors. Sheu and Chen (1991) compared off flavor development in un-blanched and blanched vegetable soybeans, and found that un-blanched samples had significantly stronger rancid and grassy aromatics compared to blanched samples. During 52 weeks of frozen storage there were no significant off flavors found in shelled or in-pod vegetable soybeans which had been blanched for 90 or 120 seconds, or 180 second shelled vegetable soybeans. 180 second blanched in-pod soybeans were found to be more bitter and astringent; however did not develop green complex, sulfur, sour or fruity flavors during storage. Principal component space plots for week 4 through week 52 are displayed in Figures 6 through 12.

The percentage of variance explained by principal components one and two increased throughout the study to a maximum of 76%. Differences between vegetable soybean controls and blanched treatments became clear. The overall trends observed during the 52 week study are displayed in Figure 13. The flavors that generally comprised principal component one included; bean complex and sweet negatively correlated to sulfur and bitter. Flavors consisting of principal component two were;

umami, brothy, astringent and metallic, which were inversely correlated to green comlex and raw bean. Konovsky et al., 1994 considered sweet and savory flavors to be the most important in the flavor profile of vegetable soybeans. Konovsky believed that the beany flavor found in soybeans could be divided into acceptable beany and bitter beany. This observation was found in this research as well; with bean complex being inversely correlated to bitter, and raw bean being inversely correlated with umami and brothy.

Results from this research provide detailed flavor information for shelled and in-pod vegetable soybeans which had been blanched for various times and stored frozen for 52 weeks. For optimum flavor retention in shelled and in-pod vegetable soybeans, blanching in 100 °C water for 90 to 120 seconds is required.

Texture

The Kramer Shear compression device and the Instron Universal model testing machine were used for texture analysis. There were no initial significant differences found between the control and various blanching treatments of shelled or in-pod vegetable soybeans. Following two weeks of storage, the shelled and in-pod vegetable soybeans which were blanched for 180 seconds were significantly softer ($p< 0.0001$) than the un-blanched shelled and in-pod controls (Figure 14). This blanching treatment (shelled and in-pod) remained significantly softer than the control (shelled and in-pod) for 52 weeks of frozen storage. This decline in firmness may have been a combination of tissue turgor loss following heating and progressive tissue softening during storage. Previous research has shown a breakpoint in firmness loss following heating of produce, explained by membrane disruption and a loss of turgor (Greve et al., 1994), and a progressive decline in firmness following heating and extended storage (Llano et al., 2003; Savas et al., 2005).

There were not any additional significant textural differences observed. Additional blanching treatments were not significantly softer than the control, and with the exception of the 180 second blanched vegetable soybeans, all shelled and in-pod samples remained consistently firm over the course of storage (Table 10).

The results of this research indicate that vegetable soybeans frozen fresh, and blanched for 30 to 120 seconds do not significantly decline in texture during one year of frozen storage.

Color

During 52 weeks of frozen storage significant declines in L, a, and b values occurred in the majority of blanched and un-blanched vegetable soybeans (Tables 11 and 12). The color of vegetable soybean pods is of primary importance in total product quality and should be bright green (Masuda, 1991). The greenness value ($a = -3.89$) of the in-pod control declined at week 4, and soybean pods remained significantly ($p < 0.05$) less green from week 12 to week 52. The in-pod soybean control became significantly ($p < 0.05$) darker ($L = 27.38$) and less yellow ($b = 8.78$) at week 12, and color degradation in the pods continued throughout the study. Previous research has indicated that vegetable soybean pod color may change during frozen storage due to chlorophyll degradation (Iwata et al., 1982; Tsay and Sheu, 1991). A qualitative observation noted during the study was the development of a brown tinge on the control pods. Enzymes, such as polyphenol oxidase (PPO) cause browning in fruit if not inactivated (Baardseth, 1977).

The yellow value ($b = 16.86$) in the shelled control declined significantly ($p < 0.05$) at week 16, and soybeans remained less yellow for the duration of storage. After

52 weeks of storage the shelled control was significantly ($p < 0.05$) lighter ($L = 50.50$) and less green ($a = -8.86$).

Blanched shelled and in-pod soybeans also declined in L, a, and b values during storage. L values increased significantly ($p < 0.05$) in all blanched and shelled vegetable soybeans during the study. This lightening may have been caused by chlorophyll degradation during blanching and additional loss incurred during storage time.

L values decreased significantly ($p < 0.05$) in 30, 60 and 180 second blanched soybean pods. There was not a significant decline during storage in lightness values for soybean pods that were blanched for 90 or 120 seconds.

The majority of blanched shelled vegetable soybeans declined in a (greenness) and b (yellowness) values during storage. Shelled vegetable soybeans which had been blanched for 180 seconds had the highest retention of a value, and did not decline significantly in b value during storage.

All blanched vegetable soybean pods declined in a (greenness) value during storage. Pods with maximum b (yellowness) value retention were those blanched for 30, 60 and 90 seconds.

The variation in L, a, and b values for the controls compared to different blanching treatments for soybeans is depicted in Tables 13, 14 and 15. The L value became significantly ($p < 0.05$) different between the shelled soybeans from week 16 through week 40 due to the higher degree of lightening in the more extensively blanched (120 and 180 second) soybeans. At week 52 all shelled soybeans had become significantly lighter, and were not significantly different from each other. Greenness in the shelled control was significantly ($p < 0.05$) lower compared to all blanched soybeans for every measurement during the 52 weeks of storage. Yellowness remained constant for the initial 8 weeks of measurement, and then began to decline at week 12. The significant ($p < 0.05$) trend observed was a lower degree of yellow color in the shelled control compared to soybeans blanched. These results indicate that blanching is required for maximum retention of green and yellow hue. However, more extensive blanching causes higher degree of lightening during storage. The shelled 30, 60 and 90 second blanched soybeans maintained the most favorable color during 52 weeks of frozen storage.

Degree of lightness varied between different in-pod soybeans. The in-pod control became the darkest soybean pod during storage, and the in-pod 180 blanched soybean pod became the lightest. These results indicate that enzymes in pods could have caused this darkening (browning) of the in-pod control, and excessive blanching could have led to the loss of chlorophyll in the in-pod 180 second blanched soybean pods. Green color declined in all soybeans, but the greatest ($p < 0.05$) decline occurred in the in-pod control. Yellowness color also declined in the in-pod control, compared to blanched soybeans during storage. The most favorable pod color retention occurred in 30, 60, 90 and 120 second blanched vegetable soybean pods.

Blanching for 30 to 90 seconds maintains an optimal vegetable soybean seed color, and blanching for 30 to 120 seconds preserves a favorable pod color.

Ascorbic Acid

The initial quantity of ascorbic acid in un-blanched vegetable soybeans and in blanched vegetable soybeans, immediately following blanching and freezing, is displayed in Figure 15. Ascorbic acid content in fresh vegetable soybeans before freezing was 21.09 mg/100g (fresh weight). The initial quantity of ascorbic acid in the un-blanched controls compared to all soybeans blanched was not significantly different in shelled or in-pod vegetable soybeans. Following 8 weeks of frozen storage the shelled control declined significantly ($p < 0.05$) in ascorbic acid compared to shelled blanching treatments of 60 through 180 seconds (Figure 16). After 12 weeks of frozen storage the un-blanched in-pod control declined significantly ($p < 0.05$) in ascorbic acid compared to in-pod blanching times of 60 through 180 seconds (Figure 17).

All shelled and in-pod vegetable soybean blanching treatments declined significantly ($p < 0.001$) in ascorbic acid content after 52 weeks of storage. A comparison of initial ascorbic acid content and ascorbic acid content during 52 weeks of frozen storage is depicted in Table 16. There were no significant differences found between shelled and in-pod vegetable soybeans which were blanched for the same time.

Throughout the storage year both shelled and in-pod vegetable soybeans which had been blanched for 60 and 90 seconds were significantly ($p < 0.05$) higher in ascorbic acid compared to the un-blanched shelled and in-pod controls, as well as the shelled soybeans which had been blanched for 30 seconds. This trend is displayed visually in Figure 18.

Generally ascorbic acid content gradually decreases in fruits and vegetables as storage time increases (Lee and Kader, 2000). Prior research has shown that the ascorbic acid content of apples can decline to less than 50% of the original after 6 months of frozen storage (Zubeckis, 1962). Minimum loss of ascorbic acid during storage has been reported in cruciferous vegetables, whereas other vegetables have larger losses. Vegetables with high ascorbic acid retention were those which had high glutathione. Glutathione may be involved in the mechanism that reduces DHAA to AA (Albrecht et al., 1990). Vegetable soybeans do not contain glutathione (Liu, 1997), which may account for part of the loss of ascorbic acid.

Ascorbic acid is highly susceptible to oxidation during processing, cooking and storage of produce. Blanching may inhibit the action of ascorbic acid oxidase, however losses due to leaching of ascorbic acid may occur during water blanching of the product (Lee & Kader, 2000). For optimization of ascorbic acid retention in vegetable soybeans, a balance between ascorbic acid oxidase inactivation and short blanching time is required. Blanching between 60 and 90 seconds maintained the highest quantity of ascorbic acid in the shelled and in-pod vegetable soybeans during frozen storage.

3.5 Conclusions

Several processing recommendations can be made from this research. These include blanching for a minimum of 60 seconds for vegetable soybeans to achieve an internal temperature of 95 – 100 ° C; sorting vegetable soybeans by size to achieve uniform internal blanching temperatures; and blanching vegetable soybeans for shorter times to yield maximum shelled efficiency. A minimum blanch of 60 seconds in 100 ° C boiling water is required to inactivate LOX in vegetable soybeans.

For optimum flavor retention in vegetable soybeans, blanching is required for 90 to 120 seconds. For crisp texture retention, vegetable soybeans should be blanched between 30 and 120 seconds. A minimum of 180 second blanching is recommended to achieve a softer vegetable soybean product. Blanching for 30 to 90 seconds maintains an optimal vegetable soybean seed color, and blanching for 30 to 120 seconds preserves a favorable pod color. A 60 to 90 second blanching maintained the highest quantity of ascorbic acid in vegetable soybeans during frozen storage.

3.6 References:

Abbott, R.L., and Abbott, J.A. 2004. Force/deformation techniques for measuring texture (Edited by D. Kilcast). In: Texture in food, Voume 2: Solids Foods. Pp. 109-145. Cambridge, England: Woodhead Publishing, Ltd.

Albrecht, J.A., Schafer, H.W., Zottola, E.A. 1990. Relationship of total sulfur to initial and retained ascorbic acid in selected cruciferous and noncruciferous vegetables. *Journal of Food Science*, 55, 181-183.

Alzamora, S.M., Tapia, M.S., and Lopez-Malo, A. 2000. Minimally Processed Fruits and Vegetables: Fundamental Aspects and Applications. Pp. 117-131. Gaithersburg, M.D.: Aspen Publishers.

AOAC. 1995. Official methods of analysis of the Association of Analytic Chemists. Vitamin C (Ascorbic Acid). In: Vitamin preparation and juices, 2,6 Dichloroindophenol titrimetric methods. Pp. 16. VA: AOAC. 45.1.14.

Baardseth, P. 1979. Enzymatically induced quality changes in fresh and frozen carrot. *Acta Horticulture*. (ISHS) 93, 67-74. Available: http://www.actahort.org/books/93/93_8.htm. Accessed December 15, 2004.

Barret, D.M., & Theerakulkait, C. 1995. Quality indicators in blanched, frozen, stored vegetables. *Food Technology*, 1(62), 64-65.

Bates, R.P., & Matthews, R.F. 1975. Ascorbic acid and β-carotene in soybean as influenced by maturity, sprouting, processing and storage. *Proceedings of Florida State Horticulture Society*, 88, 266-277.

Bevilacqua, M., D'Amore, A., Polonara, F. 2004. A multi-criteria decision approach to choosing the optimal blanching-freezing system. *Journal of Food Engineering*, 63, 253-263.

Bourne, M.C. 1982. Food Texture and Viscosity: Concept and Measurement. Academic Press: New York.

Chen, A.O., and Whitaker, J. R. 1986. Purification and characterization of a lipoxygenase from immature English peas. *Journal of Agriculture and Food Chemistry*, 34, 203-211.

Cui, Z., Carter, T.E., Jr., Gai, J., Qiu, J., & Nelson, R.L. 1999. Origin, Description, and Pedigree of Chinese Soybean Cultivars Released from 1923 to 1995. U.S. Department of Agriculture Technical Bulletin 1871. U.S. Government Printing Office, Washington, D.C.

Drake, M.A., and Gerard, P.D. 2003. Consumer attitudes and acceptability of soy-fortified yogurts. *Journal of Food Science*, 68(3), 1-5.

Giannakourou, M.C., & Taoukis, P.S. 2003. Kinetic modeling of vitamin C loss in frozen green vegetables under variable conditions. *Food Chemistry*, 83(1), 33-41.

Goosens, A.E. 1974. Protein foods: flavors and off-flavors. *Journal of Food Engineering*, 46, 54-59.

Greve, L.C., Shakel, K.A., Ahmadi, H., McArdle, R.N., Gohlke, J.R., and Labavitch, J.M. 1994. Impact of heating on carrot firmness: contribution of cellular turgor. *Journal of Agriculture and Food Chemistry,* 42(12), 2896-2899.

Halpin, B.E, & Lee, C.Y. 1987. Effect of blanching on enzyme activity and quality changes in green peas. *Journal of Food Science*, 52(4), 1002-1005.

Hansen, S., Hansen, T., Aaslyng, M.D., and Byrne, D.V. 2004. Sensory and instrumental analysis of longitudinal and transverse variation in pork longissimus dorsi. *Meat Science*, 68, 611-629.

Haytowitz, D.B., & Matthews, R.H. 1984. Composition of Foods: Vegetables and Vegetable Products. U.S. Department of Agriculture. Handbook no. 8-11.

Huang, A.S., Hsieh, O.A.L., and Chang, S.S. 1982. Characterization of the nonvolatile minor constituents responsible for the objectionable taste of defatted soybean flour. *Journal of Food Science*, 47, 19-27.

Hunter Lab. 2004. Color Theory. Available: http://www.hunterlab.com/. December 12, 2004.

Hussein, A., Odumeru, J.A., Ayanbadejo, T., Faulkner, H., McNab, W.B., Hager, H. & Szijarto, L. 2000. Effects of processing and packaging on vitamin C and β-carotene content of ready-to-use (RTU) vegetables. *Food Research International,* 33, 131-136.

Konovsky, J., Lumpkin, T.A., and McClary D. 1994. Edamame: The vegetable soybean. In: Understanding the Japanese Food and Agrimarket: A Multifaceted Opportunity. (Edited by A.D. O'Rourke). Pp. 173-181. Binghamton: Hayworth.

Kumar, V., Rani, A., Tindwani, C., and Jain, M. 2003. Lipoxygenase isozymes and trypsin inhibitor activities in soybean as influenced by growing location. *Food Chemistry,* 83, 79-83.

Lee, S.K., & Kader, A.A. 2000. Preharvest and postharvest factors influencing vitamin C content of horticulture crops. *Postharvest Biology and Technology,* 20(3), 207-220.

Liu, K. 1997. Soybeans: Chemistry, Technology and Utilization. New York: International Thomson Publishing.

Llano, K.M., Haedo, A.S., Gerschenson, L.N., Rojas, A.M. 2003. Mechanical and biochemical response to kiwifruit tissue to steam blanching. *Food Research International,* 36, 767-775.

Mahan, L.K., & Escott-Stump, S. Krause's Food, Nutrition, and Diet Therapy. 10th edition. W.B. Saunders Company. 2000.

Masuda, R. 1991. Quality requirement and improvement of vegetable soybean. In: Vegetable Soybean: Research Needs for Production and Quality Improvement (Edited by S. Shanmugasundaram). Pp. 92-102. Proceedings of a workshop held in Kenting, Taiwan, April 29-May 2, 1991. AVRDC, Publication No. 91-356.

Mohamed, A.I., and Rangappa, M. 1991. Nutrient composition and anti-nutritional factors in vegetable soybean: II. Oil, fatty acids, sterols, and lipoxygenase activity. *Food Chemistry*, 44, 277-282.

Robinson, D.S., Wu, Z., Domoney, C., and Casey, R. 1995. Lipoxygenase and the quality of foods. *Food Chemistry*, 54, 33-43.

Savas, B.K., Serpen A., Gokmen, V. and Acar, J. 2005. Study of lipoxyenase and peroxidase as indicator enzymes in green beans: change of enzyme activity, ascorbic acid and chlorophylls during frozen storage. *Journal of Food Engineering*, 66, 187-192.

Sheu, S.C., & Chen, A.O. 1991. Lipoxygenase as blanching index for frozen vegetable soybeans. *Journal of Food Science*, 56, 448-451.

Smith, P.K., et al. 1985. Measurement of Protein Using Bicinchoninic Acid. *Analytical Biochemistry*, 150, 76-85.

Song, J.Y., An, G.H., Kim, C.J. 2003. Color, texture, nutrient contents, and sensory values of vegetable soybeans [Glycine max (L.) Merrill] as affected by blanching. *Food Chemistry,* 83(1), 69-74.

Tijskens, L.M.M., Luyten, H. 2004. Modelling food texture (Edited by D. Kilcast). In: Texture in food, Voume 2: Solids Foods. Pp. 205-238. Cambridge, England: Woodhead Publishing, Ltd.

Tsay, L.M., and Sheu, S.C. 1991. Studies on the effects of cold storage and precooling on the quality of vegetable soybeans. In: Vegetable Soybean: Research Needs for Production and Quality Improvement (Edited by S. Shanmugasundaram). Pp 113-119. Proceedings of a workshop held in Kenting, Taiwan, April 29- May 2, 1991. AVRDC, Publication No. 91-356.

Tsou, S.C.S. and Hong, T.L. 1991. Research on vegetable soybean quality in Taiwan. In: Vegetable soybean: research needs for production and quality improvement. (Edited by S. Shanmugasundaram) Pp. 103-107. Proceedings of a workshop held at Kenting, Taiwan April 29 – May 2, 1991. AVRDC, Publication No. 91-356.

Valle, J.M., Aranguiz, V., and Leon, H. 1998. Effects of blanching and calcium infiltration on PPO activity, texture, microstructure and kinetics of osmotic dehydration of apple tissue. *Food Research International,* 31(8), 557-569.

Wang, S.H., and Toledo, M.C.F. 1987. Inactivation of soybean lipoxygenase by microwave heating: effect of moisture content and exposure time. *Journal of Food Science*, 52(5), 1344-1347.

Williams, D.C., Lim, M.H., Chen, A.O., Pangborn, R.M., and Whitaker, J.R. 1986. Blanching of vegetables for freezing; which indicator enzyme to choose. *Food Technology,* 40(6), 130-140.

Wilkens, W.F., and Lin, F.M. 1970. Gas chromatographic and mass spectral analyses of soybean milk volatiles. *Journal of Agriculture and Food Chemistry*, 18, 333-338.

Young, G., Mebrahtu, T., and Johnson, J. 2000. Acceptability of green soybeans as a vegetable entity. *Plant Foods for Human Nutrition*, 55, 323-333.

Zubeckis, E., 1962. Ascorbic acid content of fruit grown at Vineland, Ontario. In: 1962 Report of the Horticultural Experiment Station and Products Laboratory. Pp 90-96. Ontario, Canada: Vineland.

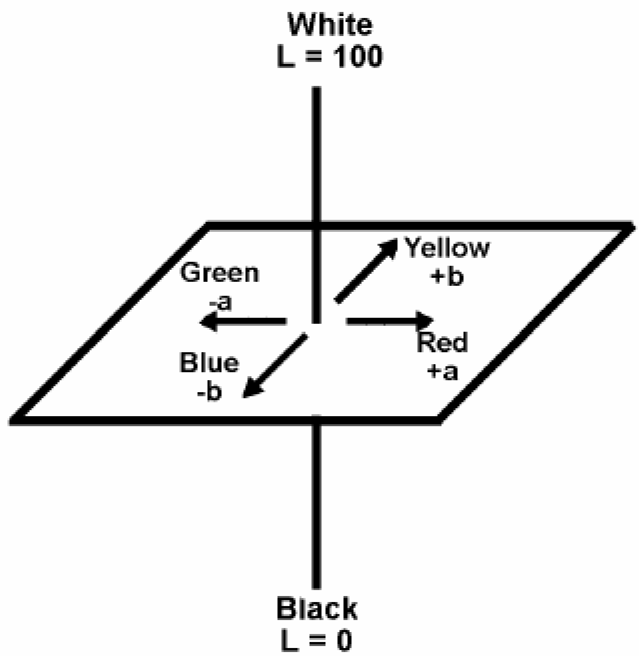

Figure 1. Hunter L, a, b color system.

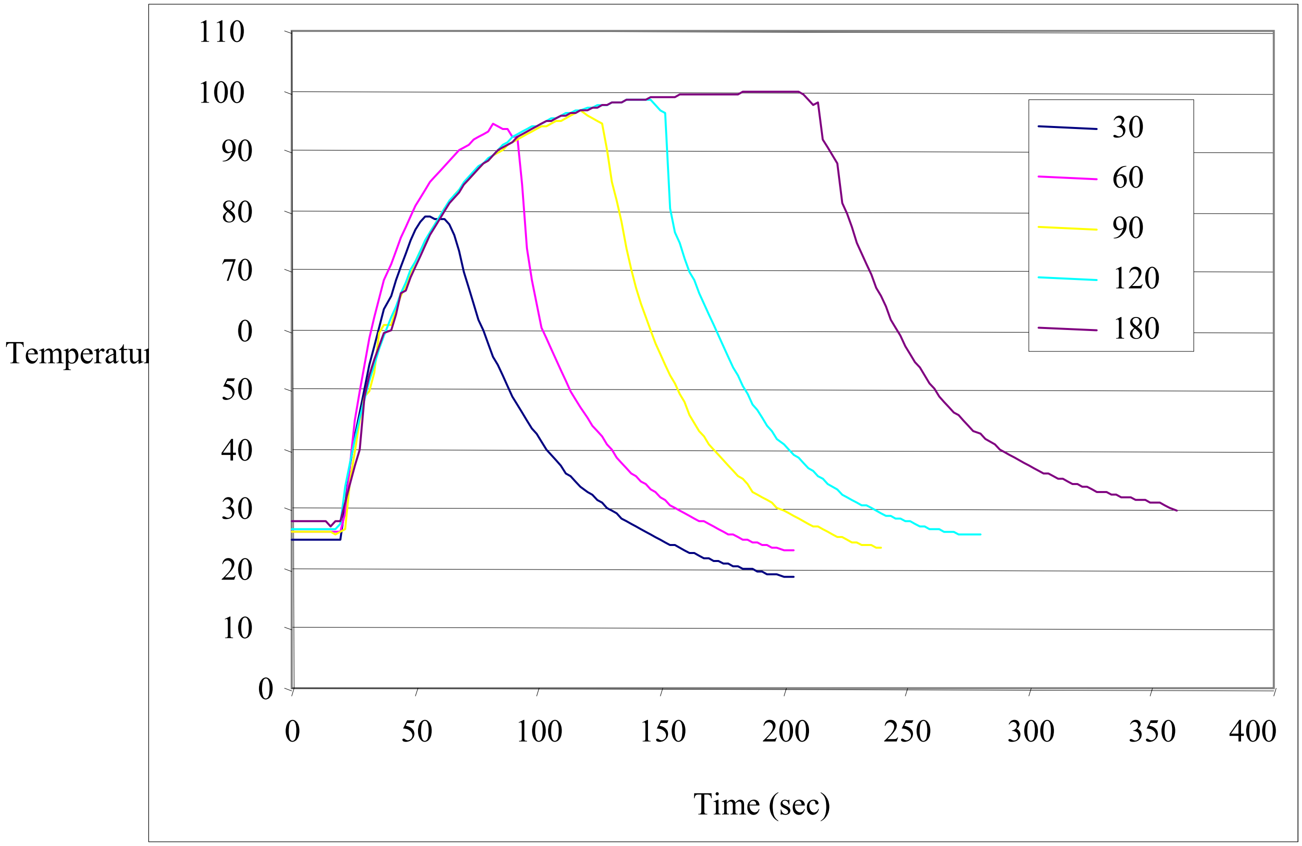

Figure 2. Mean internal temperatures of vegetable soybeans subjected to various water blanching time treatments.

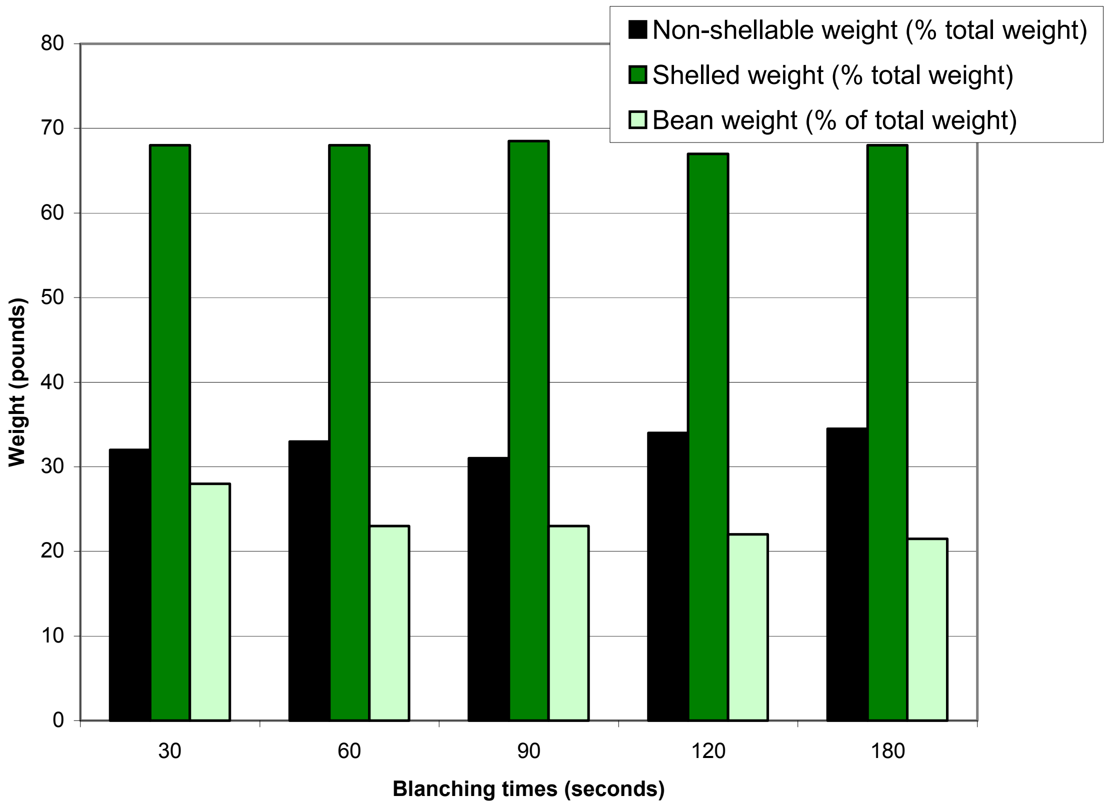

Figure 3. Mechanical vegetable shelling machine efficiency for vegetable soybeans blanched for different times.

Shelled	**Week 0**	**Week 2**	**Week 4**	**Week 8**	**Week 12**
0s blanch	0.3938	0.3572	0.3538	0.3583	0.4122
30s blanch	0.0539	0.0614	0.0772	0.0626	0.0624
60s blanch	0.0366	0.0063	0.0102	0.0172	0.0126
90s blanch	0.0106	0.0090	0.0154	0.0210	0.0119
120s blanch	0.0050	0.0086	0.0118	0.0118	0.0123
180s blanch	0.0052	0.0098	0.0130	0.0169	0.0119
In-Pod					
0s blanch	0.3636	0.2340	0.3479	0.2970	0.3336
30s blanch	0.0537	0.0569	0.0584	0.0552	0.0597
60s blanch	0.0084	0.0085	0.0053	0.0227	0.0081
90s blanch	0.0060	0.0055	0.0062	0.0186	0.0078
120s blanch	0.0061	0.0110	0.0110	0.0185	0.0101
180s blanch	0.0061	0.0122	0.0115	0.0064	0.0109

Shelled	**Week 16**	**Week 30**	**Week 40**	**Week 52**	**Year Mean**
0s blanch	0.3712	***0.3118****	***0.3104****	***0.2697****	**0.3487**
30s blanch	0.0633	0.1037	0.0862	0.0957	**0.0740**
60s blanch	0.0188	0.009	0.0263	0.0223	**0.0177**
90s blanch	0.0211	0.0104	0.0226	0.0238	**0.0162**
120s blanch	0.0104	0.0203	0.0156	0.0107	**0.0118**
180s blanch	0.0096	0.0241	0.0192	0.0124	**0.0136**
In-Pod					
0s blanch	0.3633	0.3509	0.3082	0.3403	**0.3265**
30s blanch	0.0586	0.0670	0.0581	0.0581	**0.0584**
60s blanch	0.0195	0.0127	0.0084	0.0083	**0.0113**
90s blanch	0.0182	0.0114	0.0288	0.0167	**0.0132**
120s blanch	0.0163	0.0095	0.0300	0.0188	**0.0146**
180s blanch	0.0153	0.0215	0.0166	0.0220	**0.0136**

Table 8. Rate comparison of LOX (ΔA/min per mg vegetable soybean) in controls and blanched shelled and in-pod vegetable soybeans from week 0 through week 52. Significantly different (*) from week 0 if $p < 0.05$.

Shelled	Week 2	Week 4	Week 8	Week 12	Week 16
0s blanch	9.7	9.5	9.9	8.7	13.0
30s blanch	7.0	7.6	7.7	9.6	7.6
60s blanch	7.3	6.9	7.6	9.0	8.9
90s blanch	5.3	7.2	6.0	8.6	6.4
120s blanch	7.8	5.3	4.2	7.5	7.6
180s blanch	7.2	8.3	6.6	7.5	5.9
In-Pod					
0s blanch	14.6	10.9	12.1	9.6	8.9
30s blanch	11.4	8.2	8.6	11.4	12.4
60s blanch	8.5	6.0	9.5	8.1	8.3
90s blanch	9.2	5.2	5.6	7.0	9.3
120s blanch	7.3	5.8	6.6	7.8	7.0
180s blanch	10.9	5.0	5.0	7.5	8.8

Shelled	Week 30	Week 40	Week 52	Year Mean
0s blanch	8.3	9.6	8.5	9.5
30s blanch	9.0	6.5	5.7	8
60s blanch	7.7	5.8	4.9	7.7
90s blanch	7.3	4.3	3.8	6.8
120s blanch	8.8	4.3	3.7	6.2
180s blanch	8.6	5.9	3.7	7.3
In-Pod				
0s blanch	9.1	8.3	8.6	11.8
30s blanch	12.0	5.9	8.0	9.9
60s blanch	10.0	6.0	7.7	8
90s blanch	7.9	5.4	7.6	6.7
120s blanch	9.8	8.1	7.2	6.8
180s blanch	8.5	5.5	5.8	7.1

Table 9. Protein quantity (mg/g) of control and blanched shelled and in-pod vegetable soybeans for week 2 through week 52.

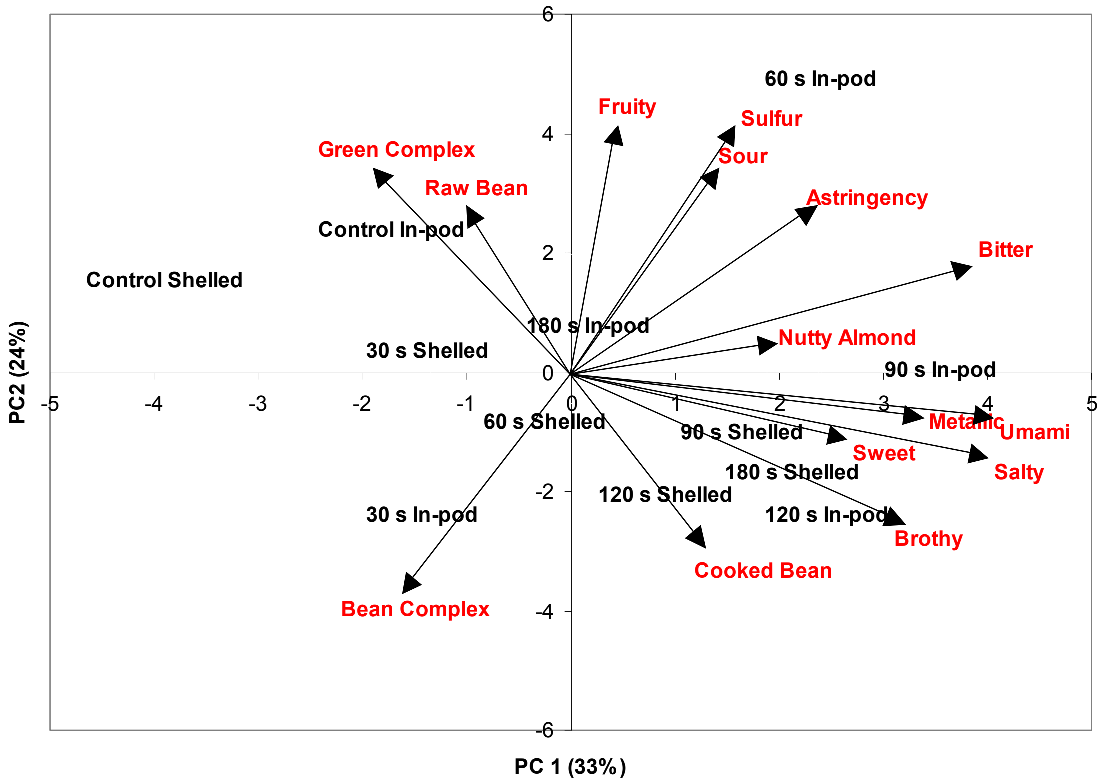

Figure 4. Week 0 principal component space plot for vegetable soybeans and flavor descriptors.

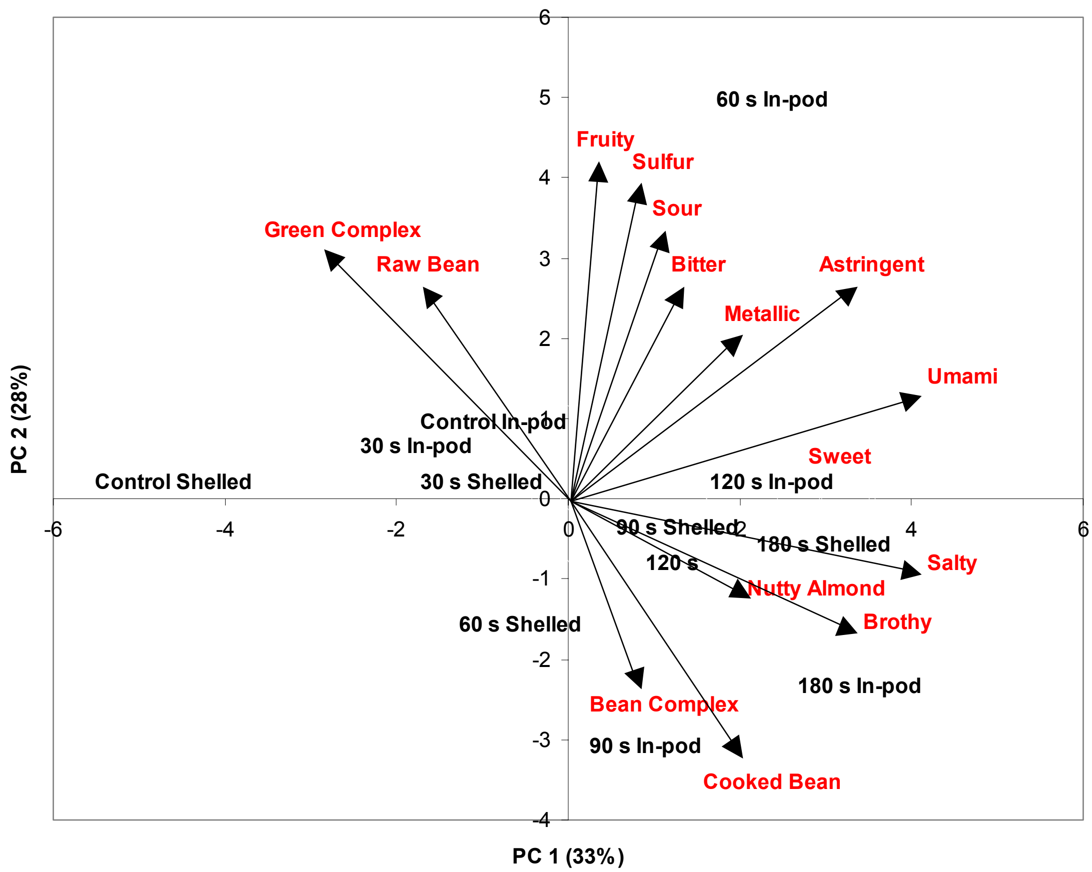

Figure 5. Week 2 principal component space plot for vegetable soybeans and flavor descriptors.

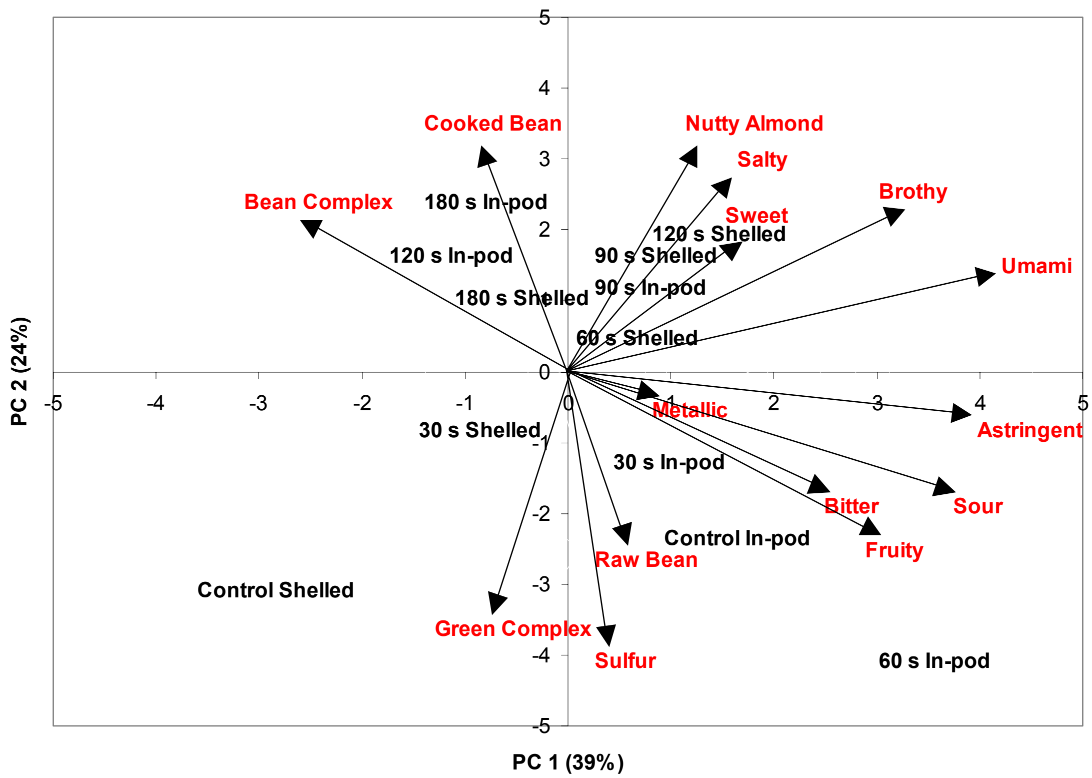

Figure 6. Week 4 principal component space plot for vegetable soybeans and flavor descriptors.

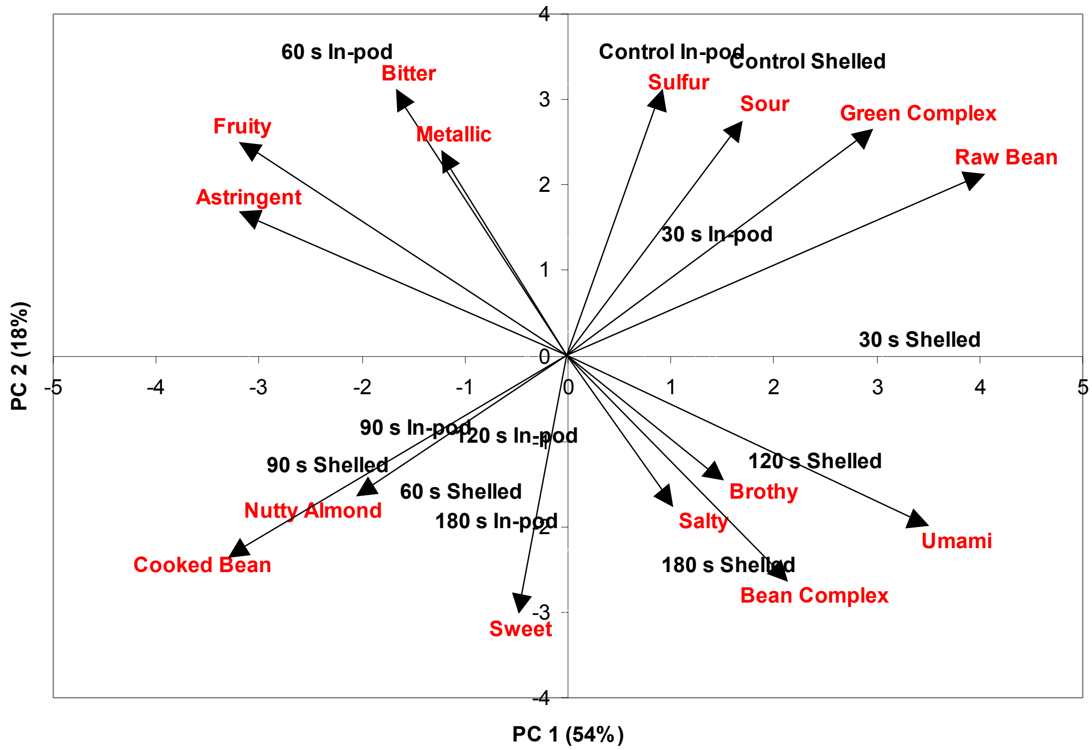

Figure 7. Week 8 principal component space plot for vegetable soybeans and flavor descriptors.

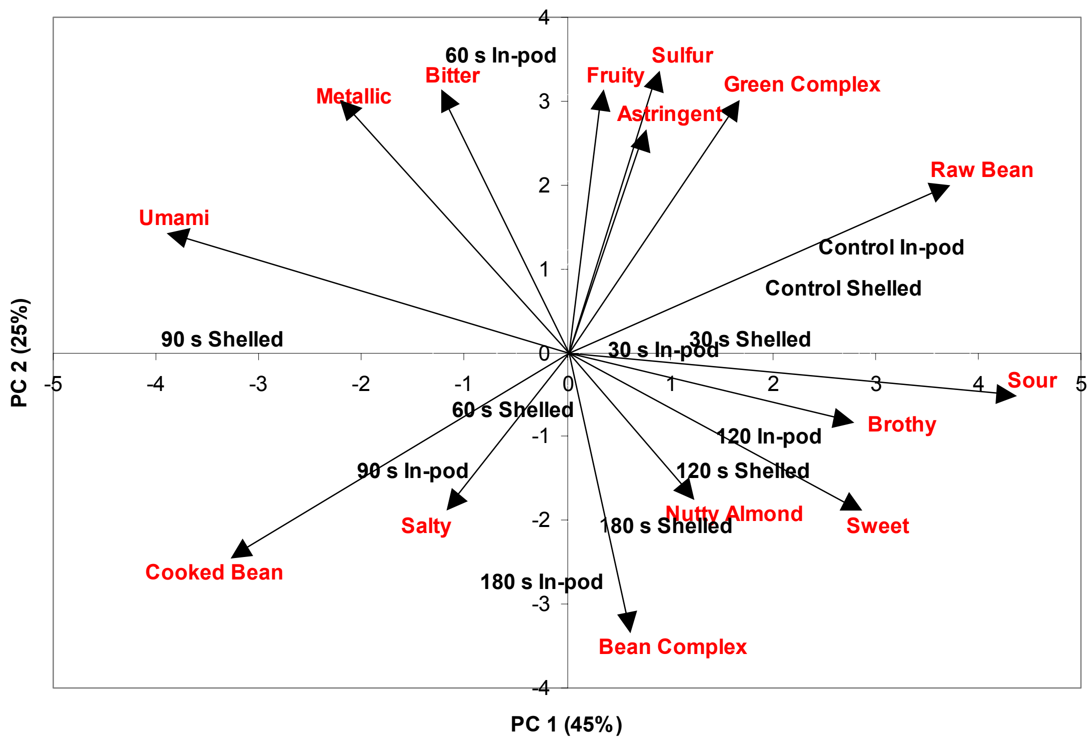

Figure 8. Week 12 principal component space plot for vegetable soybeans and flavor descriptors.

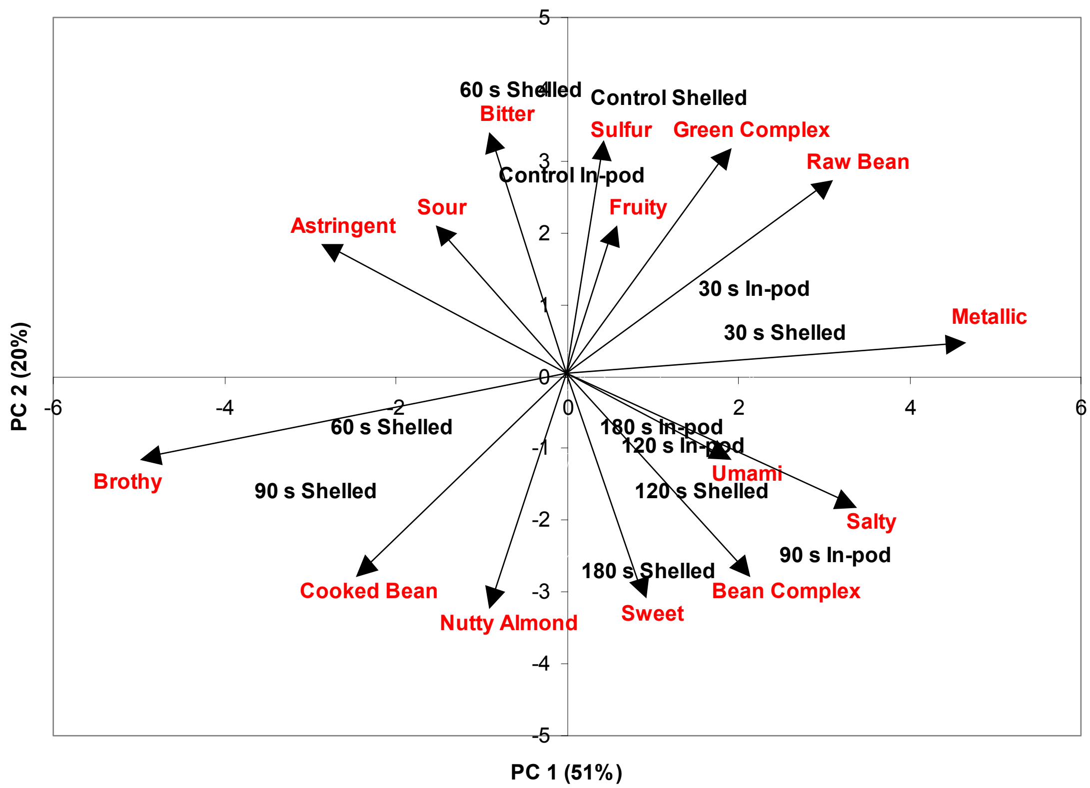

Figure 9. Week 16 principal component space plot for vegetable soybeans and flavor descriptors.

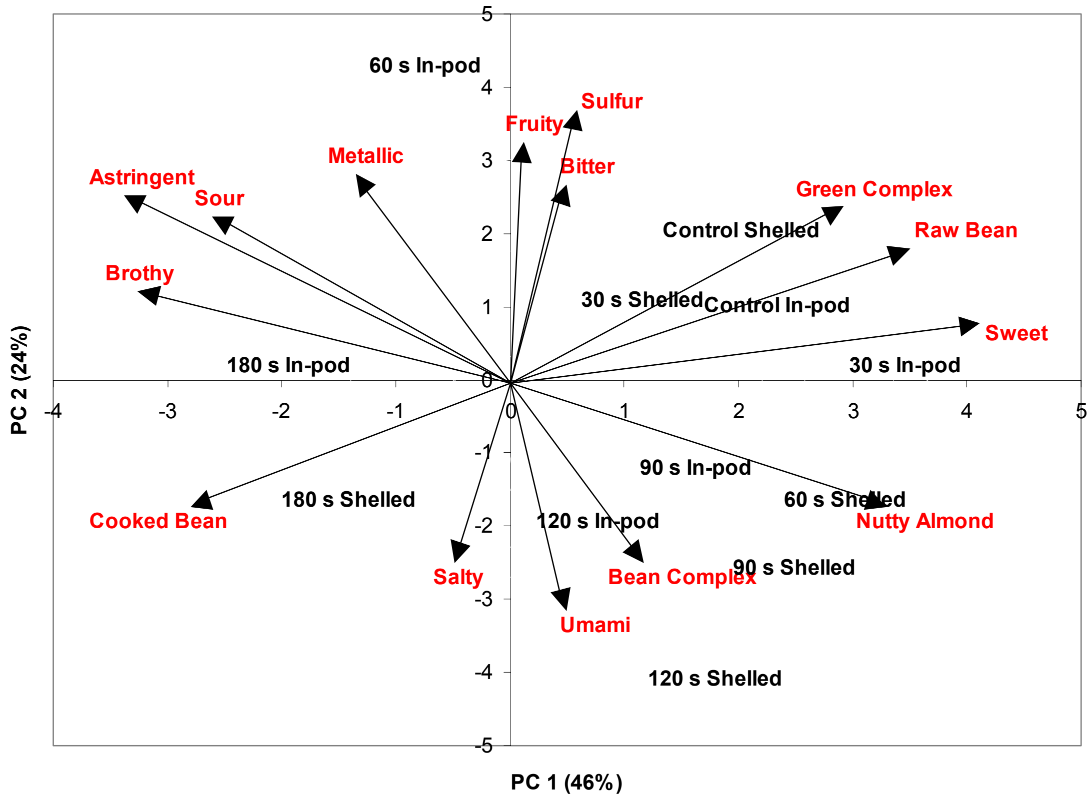

Figure 10. Week 30 principal component space plot for vegetable soybeans and flavor descriptors.

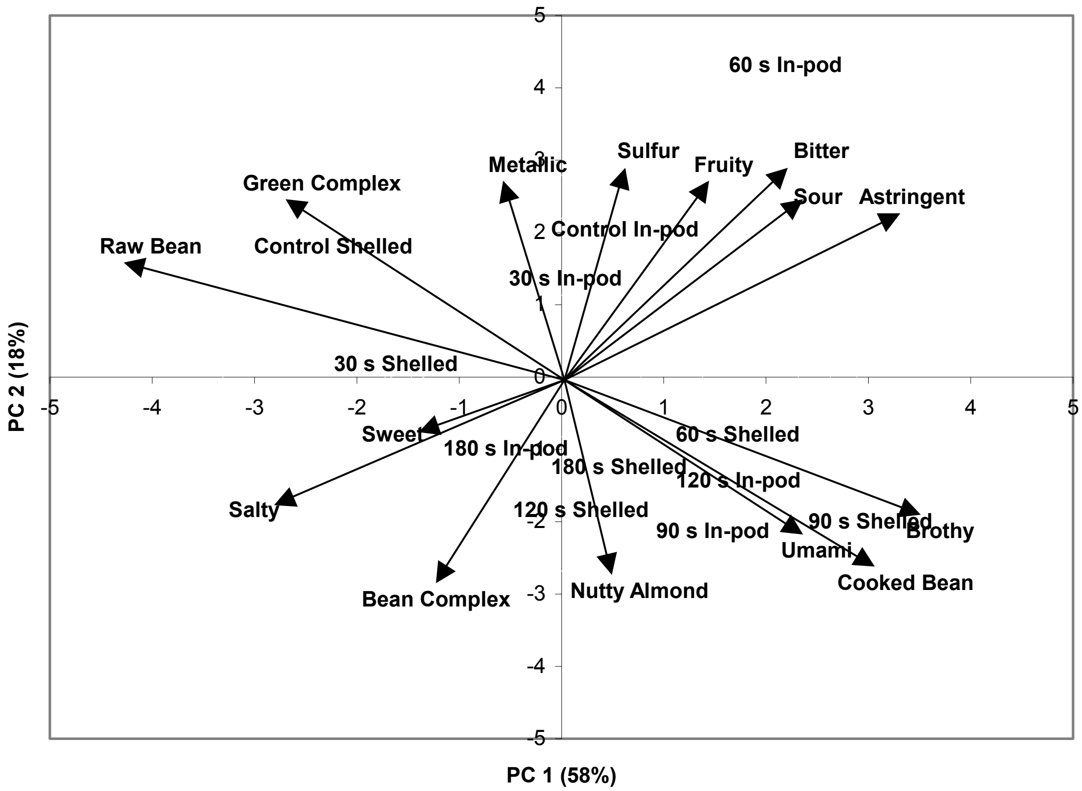

Figure 11. Week 40 principal component space plot for vegetable soybeans and flavor descriptors.

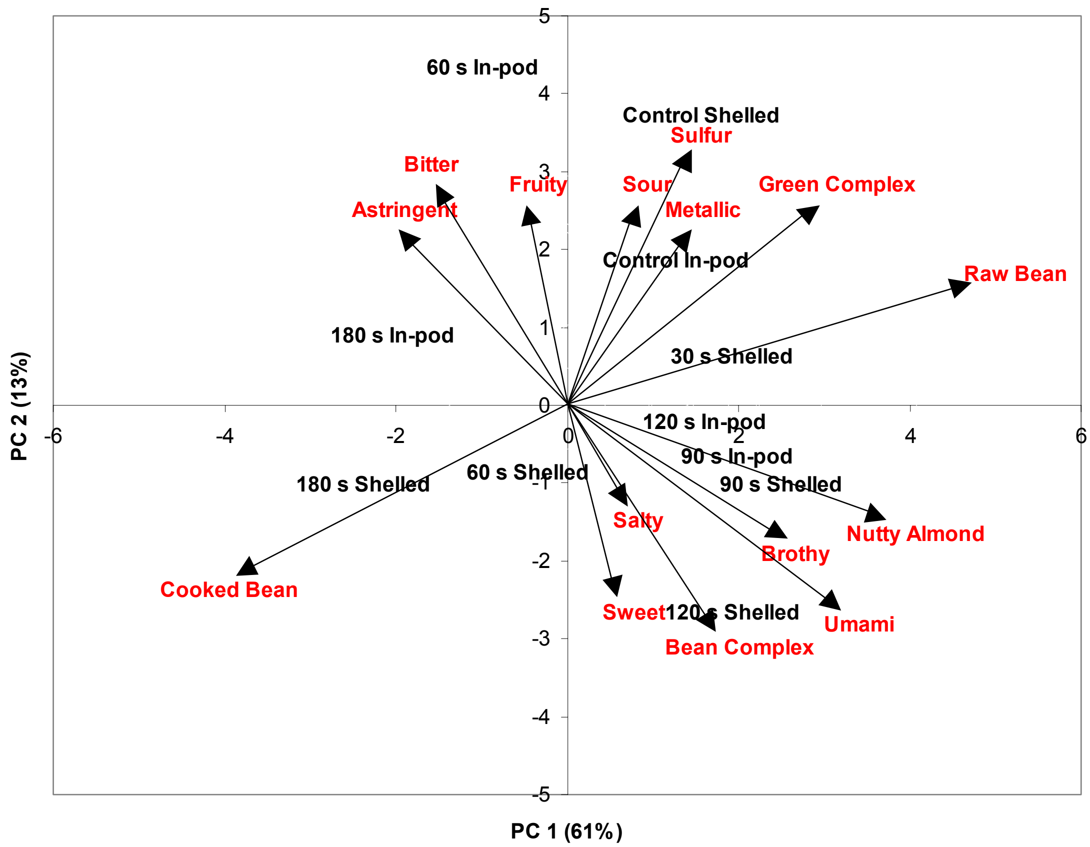

Figure 12. Week 52 principal component space plot for vegetable soybeans and flavor descriptors.

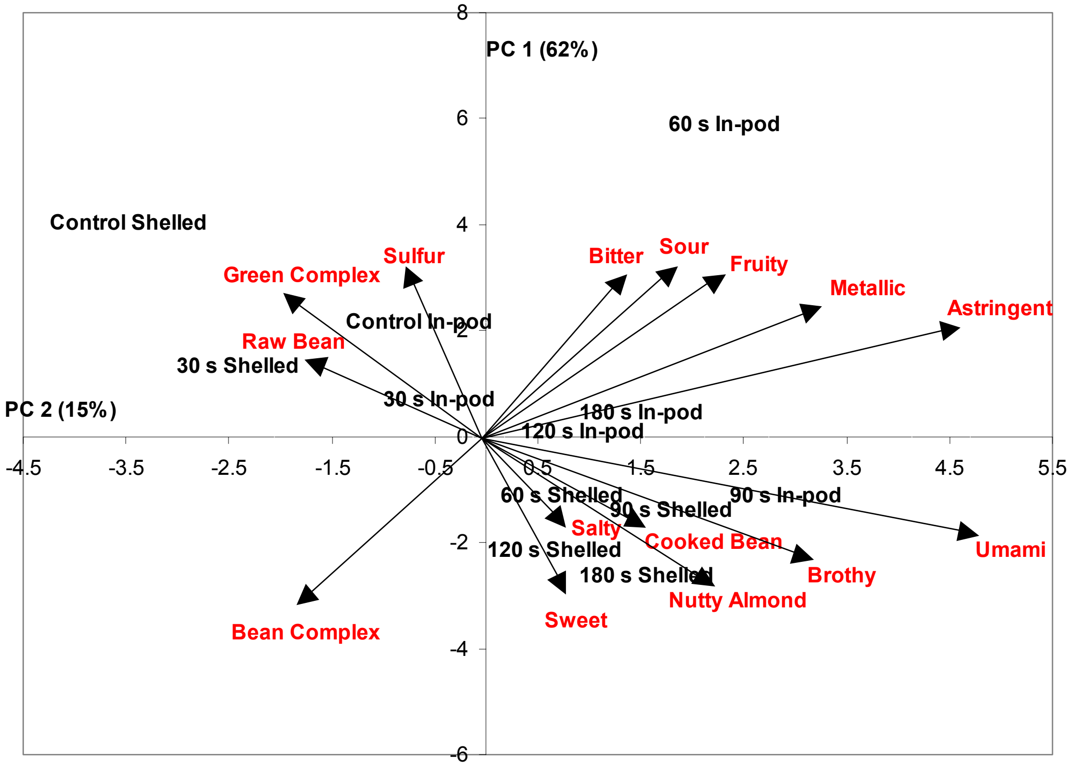

Figure 13. 52 week trend displayed as a principal component space plot for vegetable soybeans and flavor descriptors.

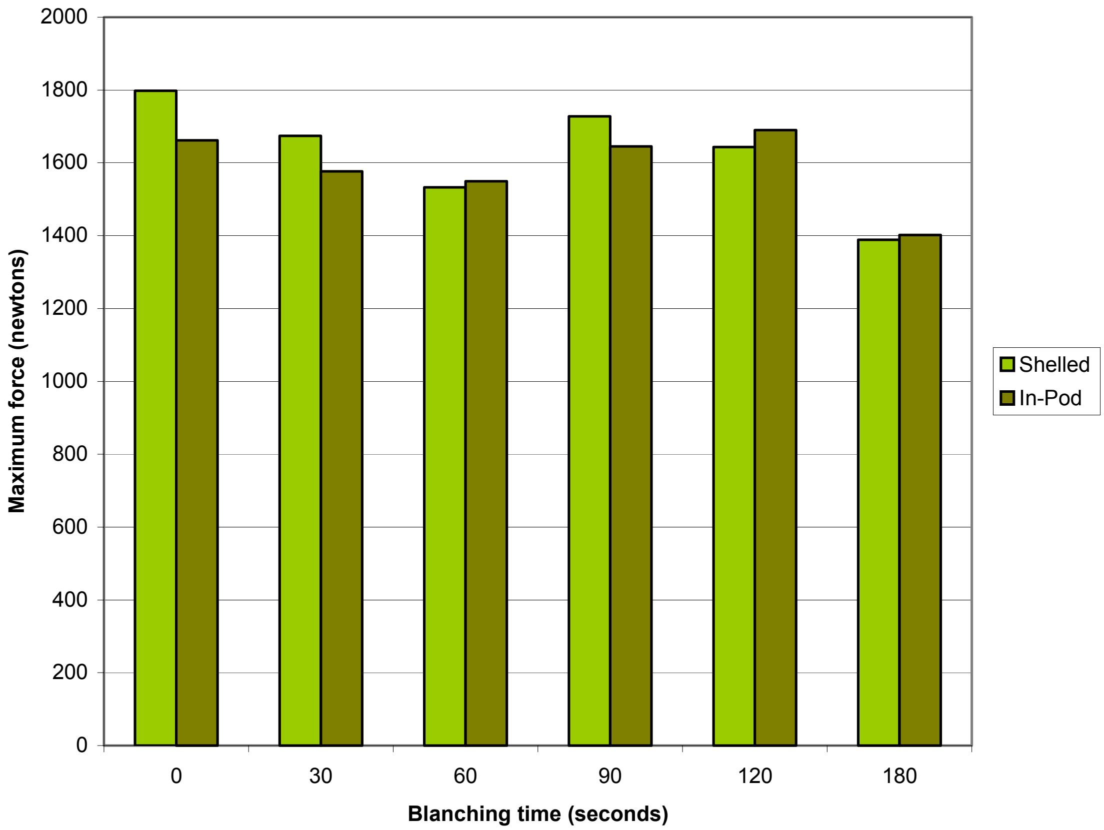

Figure 14. Week 2: Maximum force required to crush shelled and in-pod controls and blanched vegetable soybeans.

Shelled	**Week 0**	**Week 2**	**Week 4**	**Week 8**	**Week 12**
0s blanch	1654.65	1797.65	1698.20	1678.95	1611.90
30s blanch	1485.10	1674.50	1508.55	1592.35	1548.70
60s blanch	1506.40	1533.15	1572.80	1521.00	1595.95
90s blanch	1565.10	1727.65	1645.55	1527.85	1545.35
120s blanch	1582.10	1643.15	1694.95	1518.05	1548.85
180s blanch	1521.0	***1388.60****	***1391.60****	***1363.45****	***1300.60****
In-Pod					
0s blanch	1654.65	1661.90	1638.25	1602.95	1592.00
30s blanch	1470.80	1576.50	1631.50	1583.80	1537.60
60s blanch	1588.80	1549.40	1605.85	1585.95	1573.35
90s blanch	1568.05	1644.90	1573.50	1600.25	1649.50
120s blanch	1499.60	1689.60	1657.70	1520.30	1530.85
180s blanch	1565.60	***1402.00****	***1475.55****	***1356.70****	***1422.75****

Shelled	**Week 16**	**Week 30**	**Week 40**	**Week 52**
0s blanch	1654.20	1666.95	1676.80	1626.80
30s blanch	1614.00	1580.65	1624.85	1626.00
60s blanch	1613.75	1620.60	1715.80	1666.40
90s blanch	1505.40	1631.85	1575.55	1621.10
120s blanch	1557.85	1579.20	1597.10	1607.95
180s blanch	***1477.45****	***1392.45****	***1467.65****	***1463.70****
In-Pod				
0s blanch	1658.45	1686.75	1635.30	1585.20
30s blanch	1519.70	1629.25	1723.70	1641.00
60s blanch	1610.85	1628.55	1567.50	1516.60
90s blanch	1596.60	1603.05	1589.35	1502.20
120s blanch	1587.90	1597.05	1482.45	1471.45
180s blanch	***1296.90****	***1468.00****	***1400.50****	***1394.00****

Table 10. Maximum force required to crush vegetable soybean blanching treatments for 0 to 52 weeks of analysis.
Significantly different (*) from week 0 if $p < 0.05$.

Treatment	Week	L	a	b	Treatment	Week	L	a	b
Control Shelled	**0**	**42.85**	**-10.71**	**19.90**	Control In-pod	**0**	**31.03**	**-6.39**	**12.75**
Control Shelled	**2**	41.70	-9.84	19.57	Control In-pod	**2**	31.6	-5.81	10.63
Control Shelled	**4**	41.39	-9.65	17.64	Control In-pod	**4**	29.36	*-3.89**	11.04
Control Shelled	**8**	42.55	-9.89	17.63	Control In-pod	**8**	29.33	-4.18	11.37
Control Shelled	**12**	41.59	-9.68	18.81	Control In-pod	**12**	*27.38**	*-1.82**	*8.78**
Control Shelled	**16**	41.50	-9.89	*16.86**	Control In-pod	**16**	29.42	*-3.23**	10.83
Control Shelled	**30**	40.95	-9.22	*16.26**	Control In-pod	**30**	*28.23**	*-3.63**	*9.31**
Control Shelled	**40**	46.25	-9.24	*16.86**	Control In-pod	**40**	*28.59**	*-4.00**	*7.53**
Control Shelled	**52**	*50.50**	*-8.86**	*16.25**	Control In-pod	**52**	*28.10**	*-0.87**	*6.77**
30 s Shelled	**0**	**42.95**	**-16.11**	**22.35**	30 s In-pod	**0**	**34.39**	**-12.35**	**12.45**
30 s Shelled	**2**	41.25	-15.29	21.42	30 s In-pod	**2**	33.16	-7.56	13.11
30 s Shelled	**4**	40.57	-13.72	*19.50**	30 s In-pod	**4**	33.92	-8.35	12.4
30 s Shelled	**8**	41.77	*-13.54**	*20.07**	30 s In-pod	**8**	31.77	*-7.32**	12.26
30 s Shelled	**12**	41.74	*-13.29**	*19.88**	30 s In-pod	**12**	32.39	-6.51	12.09
30 s Shelled	**16**	40.79	*-13.39**	*19.62**	30 s In-pod	**16**	33.19	-8.07	12.67
30 s Shelled	**30**	42.39	*-12.73**	*19.37**	30 s In-pod	**30**	31.18	*-7.62**	12.18
30 s Shelled	**40**	43.65	*-12.16**	*18.63**	30 s In-pod	**40**	30.29	*-6.43**	10.52
30 s Shelled	**52**	*49.55**	*-11.90**	*18.27**	30 s In-pod	**52**	29.54*	*-2.45**	9.94
60 s Shelled	**0**	**43.4**	**-15.91**	**21.65**	60 s In-pod	**0**	**34.05**	**-7.94**	**12.86**
60 s Shelled	**2**	40.54	-15.36	21.73	60 s In-pod	**2**	32.84	-5.92	12.12
60 s Shelled	**4**	39.97	-14.86	19.29*	60 s In-pod	**4**	30.82	-5.73	11.18
60 s Shelled	**8**	39.77	*-13.87**	20.01	60 s In-pod	**8**	31.06	-6.81	11.29
60 s Shelled	**12**	42.44	*-13.36**	19.73*	60 s In-pod	**12**	31.05	-7.09	11.72
60 s Shelled	**16**	39.96	*-13.04**	18.89*	60 s In-pod	**16**	30.52	-6.79	11.26
60 s Shelled	**30**	42.25	*-12.76**	19.17*	60 s In-pod	**30**	*30.21**	-5.54	11.01
60 s Shelled	**40**	44.43	*-12.69**	18.87*	60 s In-pod	**40**	*30.44**	-4.89	10.25
60 s Shelled	**52**	50.65*	*-12.56**	18.99*	60 s In-pod	**52**	*30.41**	*-2.95**	9.85

Table 11. Comparison of L, a, b changes within shelled and in-pod Control, 30 second blanch and 60 second blanch during 52 weeks of storage.
Significantly different (*) from week 0 if $p < 0.05$.

Treatment	Week	L	a	b	Treatment	Week	L	a	b
90 s Shelled	**0**	**37.26**	**-15.78**	**21.44**	90 s In-pod	**0**	**32.12**	**-7.97**	**12.51**
90 s Shelled	**2**	38.96	-15.85	21.82	90 s In-pod	**2**	32.02	*-4.82**	12.79
90 s Shelled	**4**	40.33	*-13.47**	21.11	90 s In-pod	**4**	30.45	-5.83	11.32
90 s Shelled	**8**	40.87	-14.05	21.48	90 s In-pod	**8**	29.32	-5.17	10.97
90 s Shelled	**12**	*42.55**	*-13.85**	20.48	90 s In-pod	**12**	30.59	-7.81	10.62
90 s Shelled	**16**	*42.26**	*-13.88**	20.70	90 s In-pod	**16**	29.47	-6.46	10.85
90 s Shelled	**30**	*42.99**	*-13.13**	*19.42**	90 s In-pod	**30**	29.98	-5.13	10.67
90 s Shelled	**40**	*43.63**	*-13.16**	*19.41**	90 s In-pod	**40**	30.10	*-4.55**	10.53
90 s Shelled	**52**	*49.57**	*-11.75**	*19.22**	90 s In-pod	**52**	30.12	*-4.12**	10.36
120 s Shelled	**0**	**37.49**	**-15.31**	**21.62**	120 s In-pod	**0**	**28.03**	**-8.18**	**12.87**
120 s Shelled	**2**	38.86	-14.92	21.25	120 s In-pod	**2**	31.55	*-4.58**	*10.17**
120 s Shelled	**4**	39.97	*-13.19**	18.82*	120 s In-pod	**4**	30.41	*-6.11**	*9.93**
120 s Shelled	**8**	40.95	*-13.22**	19.53	120 s In-pod	**8**	29.76	*-5.93**	11.48
120 s Shelled	**12**	*41.53**	*-12.64**	*18.25**	120 s In-pod	**12**	32.59	*-5.40**	11.43
120 s Shelled	**16**	*42.49**	*-12.16**	*17.51**	120 s In-pod	**16**	29.96	-6.35	*10.34**
120 s Shelled	**30**	*41.51**	*-12.76**	*18.69**	120 s In-pod	**30**	30.68	*-5.77**	10.97
120 s Shelled	**40**	*42.23**	*-11.00**	19.06	120 s In-pod	**40**	29.45	*-5.88**	*9.97**
120 s Shelled	**52**	*47.35**	*-11.05**	*18.25**	120 s In-pod	**52**	29.37	*-2.46**	*9.38**
180 s Shelled	**0**	**39.01**	**-14.97**	**22.75**	180 s In-pod	**0**	**28.21**	**-7.21**	**12.81**
180 s Shelled	**2**	40.77	-13.18	21.63	180 s In-pod	**2**	30.63	-6.60	11.73
180 s Shelled	**4**	40.27	-13.38	19.81	180 s In-pod	**4**	30.27	-5.92	10.89
180 s Shelled	**8**	40.29	-13.83	19.45	180 s In-pod	**8**	29.64	*-4.93**	10.78
180 s Shelled	**12**	*43.32**	-15.95	20.25	180 s In-pod	**12**	31.38	-5.85	11.18
180 s Shelled	**16**	*43.17**	-13.01	19.71	180 s In-pod	**16**	31.08	*-4.83**	*10.54**
180 s Shelled	**30**	*44.38**	*-12.32**	19.90	180 s In-pod	**30**	*32.97**	-5.83	*10.73**
180 s Shelled	**40**	*45.09**	*-12.63**	19.77	180 s In-pod	**40**	*32.37**	*-4.31**	*10.41**
180 s Shelled	**52**	*49.82**	*-10.76**	19.09	180 s In-pod	**52**	*39.65**	*-3.88**	*10.47**

Table 12. Comparison of L, a, b changes within shelled and in-pod 90 second blanch, 120 second blanch and 180 second blanch during 52 weeks of storage. Significantly different (*) from week 0 if $p < 0.05$.

Week	Treatment	L	a	b
0	Control Shelled	**42.85^{a}**	**-10.71^{a}**	**19.90^{a}**
	30 s Shelled	42.95^{a}	-16.11^{b}	22.35^{a}
	60 s Shelled	43.40^{a}	-15.91^{b}	21.65^{a}
	90 s Shelled	37.26^{a}	-15.78^{b}	21.44^{a}
	120 s Shelled	37.49^{a}	-15.31^{b}	21.62^{a}
	180 s Shelled	39.01^{a}	-14.97^{b}	22.75^{a}
	Control In-pod	**31.03^{a}**	**-6.39^{a}**	**12.75^{a}**
	30 s In-pod	34.39^{a}	-12.35^{a}	12.45^{a}
	60 s Inpod	34.05^{a}	-7.94^{a}	12.86^{a}
	90 s In-pod	32.12^{a}	-7.97^{a}	12.51^{a}
	120 s In-pod	28.03^{a}	-8.18^{a}	12.87^{a}
	180 s In-pod	28.21^{a}	-7.21^{a}	12.81^{a}
2	Control Shelled	**41.70^{a}**	**-9.84^{a}**	**19.57^{a}**
	30 s Shelled	41.25^{a}	-15.29^{b}	21.42^{a}
	60 s Shelled	40.54^{a}	-15.36^{b}	21.73^{a}
	90 s Shelled	38.96^{a}	-15.85^{b}	21.82^{a}
	120 s Shelled	38.86^{a}	-14.92^{b}	21.25^{a}
	180 s Shelled	40.77^{a}	-13.18^{b}	21.63^{a}
	Control In-pod	**31.60^{a}**	**-5.81^{a}**	**10.63^{a}**
	30 s In-pod	33.16^{a}	-7.56^{a}	13.11^{a}
	60 s Inpod	32.84^{a}	-5.92^{a}	12.12^{a}
	90 s In-pod	32.02^{a}	-4.82^{a}	12.79^{a}
	120 s In-pod	31.55^{a}	-4.58^{a}	10.17^{a}
	180 s In-pod	30.63^{a}	-6.60^{a}	11.73^{a}
4	Control Shelled	**41.39^{a}**	**-9.65^{a}**	**17.64^{a}**
	30 s Shelled	40.57^{a}	-13.72^{b}	19.50^{a}
	60 s Shelled	39.97^{a}	-14.86$^{a\,b}$	19.29^{a}
	90 s Shelled	40.33^{a}	-13.47^{b}	21.11^{a}
	120 s Shelled	39.97^{a}	-13.19$^{a\,b}$	18.82^{a}
	180 s Shelled	40.27^{a}	-13.38^{b}	19.81^{a}
	Control In-pod	**29.36^{a}**	**-3.89^{a}**	**11.04^{a}**
	30 s In-pod	33.92^{a}	-8.35^{b}	12.40^{a}
	60 s Inpod	30.82^{a}	-5.73^{ab}	11.18^{a}
	90 s In-pod	30.45^{a}	-5.83^{ab}	11.32^{a}
	120 s In-pod	30.41^{a}	-6.11^{ab}	9.93^{a}
	180 s In-pod	30.27^{a}	-5.92^{ab}	10.89^{a}

Table 13. Comparison of weeks 0, 2, and 4 of L, a, and b values for vegetable soybean controls and blanching treatments.
Different letters in columns represents significant difference ($p<0.05$) between controls and blanched soybeans.

Week	Treatment	L	a	b
8	Control Shelled	**42.55^{a}**	**-9.89^{a}**	**17.63^{a}**
	30 s Shelled	41.77^{a}	-13.54^{b}	20.07^{a}
	60 s Shelled	39.77^{a}	-13.87^{b}	20.01^{a}
	90 s Shelled	40.87^{a}	-14.05^{b}	21.48^{a}
	120 s Shelled	41.51^{a}	-13.22^{b}	19.53^{a}
	180 s Shelled	40.29^{a}	-13.83^{b}	19.45^{a}
	Control In-pod	**29.33^{a}**	**-4.18^{a}**	**11.37^{a}**
	30 s In-pod	31.77^{a}	-7.32^{a}	12.26^{a}
	60 s Inpod	31.06^{a}	-6.81^{a}	11.29^{a}
	90 s In-pod	29.32^{a}	-5.17^{a}	10.97^{a}
	120 s In-pod	29.76^{a}	-5.93^{a}	11.48^{a}
	180 s In-pod	29.64^{a}	-4.93^{a}	10.78^{a}
12	Control Shelled	**41.59^{a}**	**-9.68^{a}**	**18.81^{b}**
	30 s Shelled	41.74^{a}	-13.29^{b}	19.88^{a}
	60 s Shelled	42.44^{a}	-13.36^{b}	19.73^{a}
	90 s Shelled	42.55^{a}	-13.85^{b}	20.48^{a}
	120 s Shelled	41.53^{a}	-12.64^{b}	18.25^{b}
	180 s Shelled	43.32^{a}	-15.95^{b}	20.25^{a}
	Control In-pod	**27.38^{a}**	**-1.82^{a}**	**8.78^{a}**
	30 s In-pod	32.39^{b}	-6.51^{b}	12.09^{b}
	60 s Inpod	31.05^{b}	-7.09^{b}	11.72^{b}
	90 s In-pod	30.59^{b}	-7.81^{b}	10.62^{b}
	120 s In-pod	32.59^{b}	-5.40^{b}	11.43^{b}
	180 s In-pod	31.38^{b}	-5.85^{b}	11.18^{b}
16	Control Shelled	**41.50^{a}**	**-9.89^{a}**	**16.86^{a}**
	30 s Shelled	40.79^{a}	-13.39^{b}	19.62^{b}
	60 s Shelled	39.96^{a}	-13.04^{b}	18.89^{b}
	90 s Shelled	42.26^{b}	-13.88^{b}	20.70^{b}
	120 s Shelled	42.49^{b}	-12.16^{b}	17.51^{a}
	180 s Shelled	43.17^{b}	-13.01^{b}	19.71^{b}
	Control In-pod	**29.42^{a}**	**-3.23^{a}**	**10.83^{a}**
	30 s In-pod	33.19^{a}	-8.07^{b}	12.67^{a}
	60 s Inpod	30.52^{a}	-6.79^{b}	11.26^{a}
	90 s In-pod	29.47^{a}	-6.46^{b}	10.85^{a}
	120 s In-pod	29.96^{a}	-6.35^{b}	10.34^{a}
	180 s In-pod	31.08^{a}	-4.83^{b}	10.54^{a}

Table 14. Comparison of weeks 8, 12, and 16 of L, a, and b values for vegetable soybean controls and blanching treatments.
Different letters in columns represents significant difference ($p<0.05$) between controls and blanched soybeans.

Week	Treatment	L	a	b
30	Control Shelled	**40.95[a]**	**-9.22[a]**	**16.26[a]**
	30 s Shelled	42.39[b]	-12.73[b]	19.37[b]
	60 s Shelled	42.25[b]	-12.76[b]	19.17[b]
	90 s Shelled	42.99[a]	-13.13[b]	19.42[b]
	120 s Shelled	40.95[a]	-12.76[b]	18.69[b]
	180 s Shelled	44.38[b]	-12.32[b]	19.90[b]
	Control In-pod	**28.23[a]**	**-3.63[a]**	**9.31[a]**
	30 s In-pod	31.18[ab]	-7.62[b]	12.18[b]
	60 s Inpod	30.21[ab]	-5.54[ab]	11.01[b]
	90 s In-pod	29.98[a]	-5.13[ab]	10.67[b]
	120 s In-pod	30.68[ab]	-5.77[ab]	10.97[b]
	180 s In-pod	32.97[b]	-5.83[ab]	10.73[b]
40	Control Shelled	**46.25[a]**	**-9.24[a]**	**16.86[a]**
	30 s Shelled	43.65[b]	-12.16[b]	18.63[b]
	60 s Shelled	44.43[b]	-12.69[b]	18.87[b]
	90 s Shelled	43.63[b]	-13.16[b]	19.41[b]
	120 s Shelled	42.23[b]	-11.00[b]	19.06[b]
	180 s Shelled	45.09[a]	-12.63[b]	19.77[b]
	Control In-pod	**28.59[a]**	**-4.00[a]**	**7.53[a]**
	30 s In-pod	30.29[a]	-6.43[b]	10.52[b]
	60 s Inpod	30.44[a]	-4.89[a]	10.25[b]
	90 s In-pod	30.10[a]	-4.55[a]	10.53[b]
	120 s In-pod	29.45[a]	-5.88[a]	9.97[b]
	180 s In-pod	32.37 [b]	-4.31[a]	10.41[b]
52	Control Shelled	**50.50[a]**	**-8.86[a]**	**16.25[a]**
	30 s Shelled	49.55[a]	-11.90[b]	18.27[b]
	60 s Shelled	50.65[a]	-12.56[b]	18.99[b]
	90 s Shelled	49.57[a]	-11.75[b]	19.22[b]
	120 s Shelled	47.35[a]	-11.05[b]	18.25[b]
	180 s Shelled	49.82[a]	-10.76[b]	19.09[b]
	Control In-pod	**28.10[a]**	**-0.87[a]**	**6.77[a]**
	30 s In-pod	29.54[a]	-2.45[b]	9.94[b]
	60 s Inpod	30.41[a]	-2.95[b]	9.85[b]
	90 s In-pod	30.12[a]	-4.12[b]	10.36[b]
	120 s In-pod	29.37[a]	-2.46[b]	9.38[b]
	180 s In-pod	39.65[b]	-3.88[b]	10.47[b]

Table 15. Comparison of weeks 30, 40, and 52 of L, a, and b values for vegetable soybean controls and blanched treatments.
Different letters in columns represents significant difference ($p<0.05$) between controls and blanched soybeans.

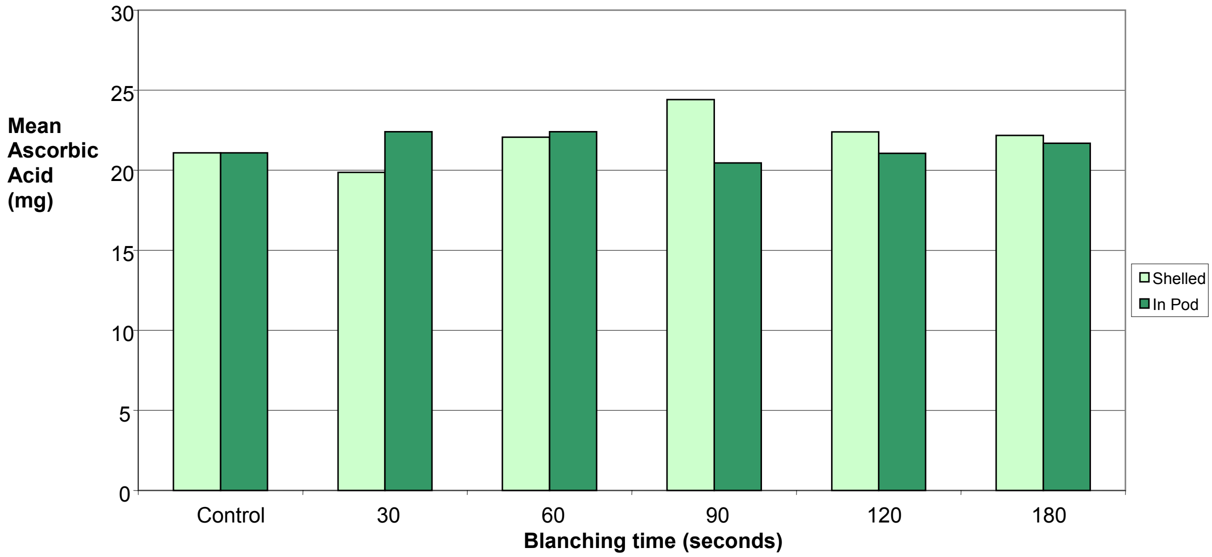

Figure 15. Initial quantity of ascorbic acid in shelled and in-pod controls and blanched vegetable soybeans treatments immediately following blanching and freezing.

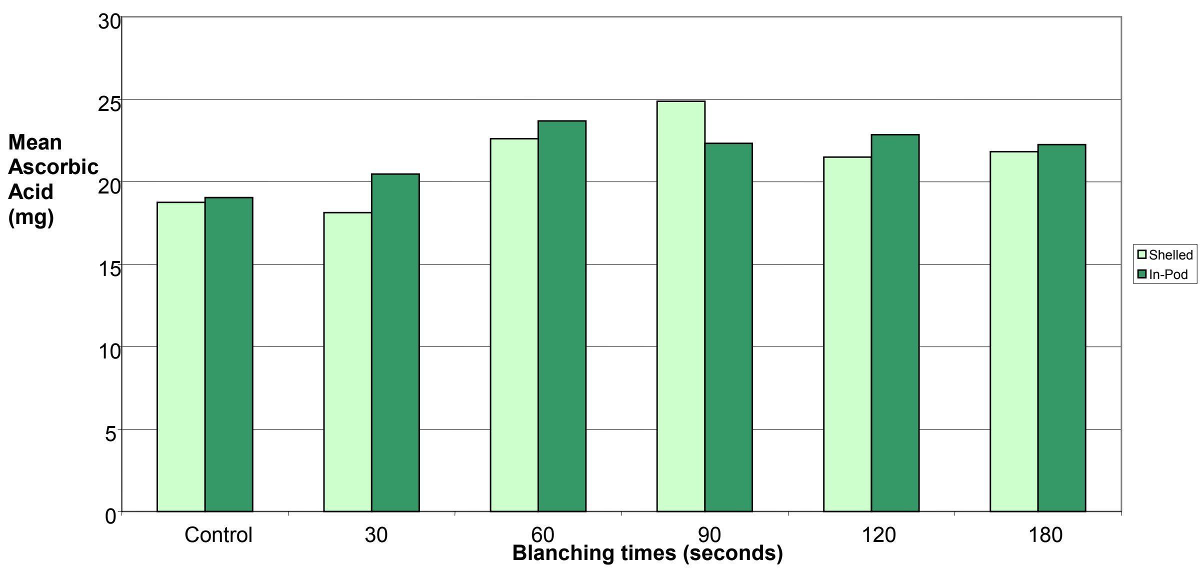

Figure 16. Week 8 quantity of ascorbic acid in shelled and in-pod controls and blanched vegetable soybean treatments.

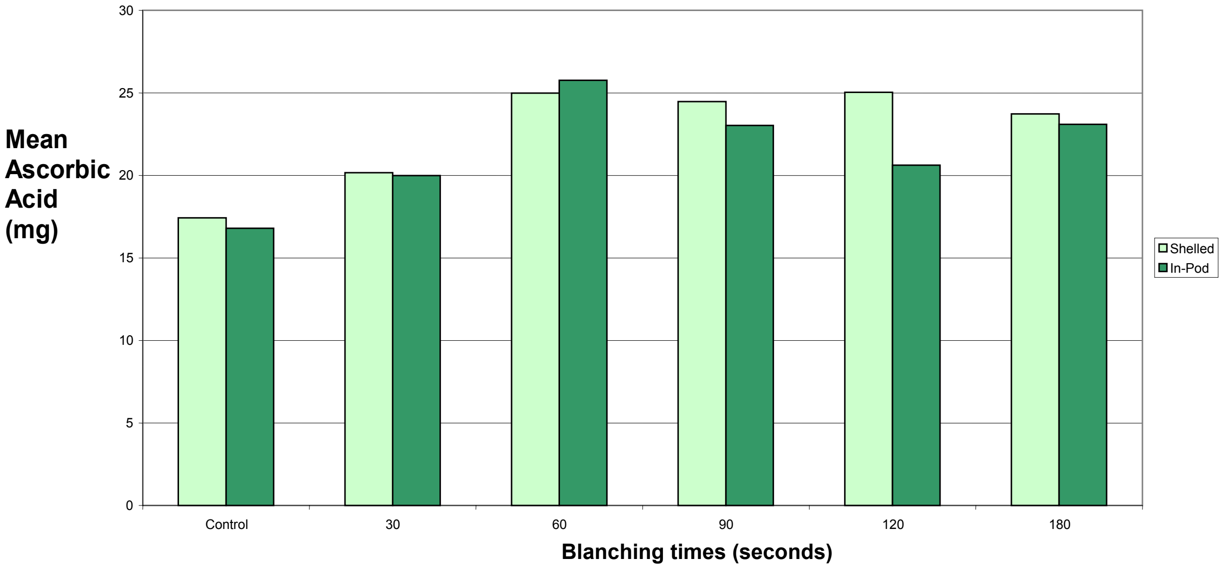

Figure 17. Week 12 quantity of ascorbic acid in shelled and in-pod controls and blanched vegetable soybean treatments.

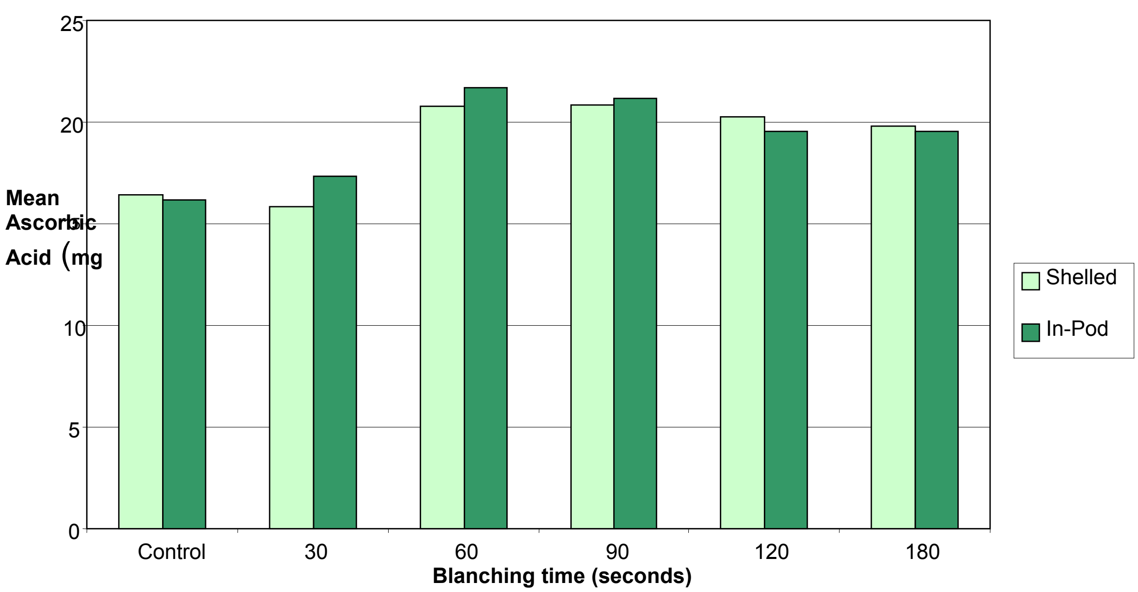

Figure 18. Mean ascorbic acid quantity during 52 weeks of storage for shelled and in-pod controls and blanched vegetable soybean treatments.

Shelled	**Week 0**	**Week 2**	**Week 4**	**Week 8**	**Week 12**
0s blanch	21.09	20.50	20.06	***18.74****	***17.43****
30s blanch	19.86	19.10	20.50	***18.12****	20.16
60s blanch	22.06	21.87	24.75	22.61	24.97
90s blanch	24.4	22.63	22.38	24.88	24.47
120s blanch	22.39	21.01	23.33	21.49	25.03
180s blanch	22.16	22.50	22.54	21.83	23.71
In-Pod					
0s blanch	21.09	19.95	18.64	19.04	***16.80****
30s blanch	22.40	19.15	19.86	20.47	19.99
60s blanch	22.4	24.55	24.39	23.68	25.76
90s blanch	20.45	25.00	22.03	22.33	23.02
120s blanch	21.05	24.45	23.78	22.86	20.61
180s blanch	21.68	19.39	22.18	22.25	23.09

Shelled	**Week 16**	**Week 30**	**Week 40**	**Week 52**
0s blanch	***17.22****	***14.70****	***13.78****	***4.01******
30s blanch	***16.16****	***12.90****	***12.00****	***3.99******
60s blanch	22.87	20.99	***18.03****	***8.80******
90s blanch	23.97	19.48	***16.91****	***8.76******
120s blanch	21.81	19.01	***17.92****	***9.31******
180s blanch	21.73	***18.46****	***17.92****	***7.30******
In-Pod				
0s blanch	***14.40****	***16.73****	***12.96****	***1.71******
30s blanch	22.31	19.60	***12.38****	***5.21******
60s blanch	23.86	19.60	***17.56****	***13.47******
90s blanch	26.07	20.03	***16.90****	***14.57******
120s blanch	23.83	***18.14****	***16.10****	***10.87******
180s blanch	21.44	***18.38****	***16.58****	***8.82******

Table 16. Comparison of ascorbic acid quantity in vegetable soybeans from week 0 to week 52.
Significantly different (*) from week 0 if $p < 0.05$.
Significantly different (***) from week 0 if $p < 0.001$.